
Proceedings of the 10th

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# FOREWORD

The workshop program at the UbiComp conference provides a valuable opportunity for researchers and practitioners from a variety of disciplines to get together to explore specific areas of interest. The UbiComp 2008 Workshop Program includes seven workshops that cover a range of timely and emerging topics including the evaluation of ubiquitous systems, sustainability, ambient information systems, devices that alter our perceptions, technologies that augment our daily journeys, smart workplaces, and smart objects.

**Ambient Information Systems** builds on last year's workshop at the Pervasive 2007 conference to bring together researchers who are working in the areas of ambient displays, peripheral displays, slow technology, glanceable displays, and calm technology to explore new design approaches for creating ambient information systems.

**Automated Journeys** focuses on the common journeys that we experience everyday that increasingly include technologies such as mobile phones, music players, vending machines, contact-less payment systems, and RFID-enabled turnstiles. The workshop examines the public, semi-public, and private nature of these "augmented journeys" and speculates on future innovations.

**Design and Integration Principles for Smart Objects (DIPSO 2008)** builds on last year's workshop at UbiComp 2007 to focus on current practices and align on key issues to continue progress on the development of smart objects, such as the everyday objects and instrumented environments that are tagged with sensors and actuators.

**Devices that Alter Perception (DAP 2008)** explores the sensors, actuators, implantables, wearable computers, and neural interfaces that alter and manipulate our perceptions. The workshop aims to better understand the process of perception, aid developers of such devices by sharing design ideas, and debate the ethical and social issues that arise when considering devices that operate below or upon awareness.

**Ubiquitous Sustainability: Citizen Science & Activism** examines new approaches that are encouraging sustainability by exploring technologies that enable individuals to have a powerful voice in society, act as "citizen scientists," and collectively learn and lobby for worldwide change.

**Ubiquitous Systems Evaluation (USE 2008)** builds on last year's workshop at Ubicomp 2007 to bring together researchers and practitioners to discuss the best practices and challenges in the evaluation of ubiquitous systems.

**UbiWORK: Design and Evaluation of Smart Environments in the Workplace** builds on a series of prior UbiComp workshops on smart environment technologies and applications for the workplace. This year's workshop focuses on design processes and evaluation metrics for these smart environments.

These workshops will bring about interesting discussions and generate new visions for future research.

We would like to thank: the workshop organizers, those who submitted workshop position papers, and the workshop attendees for their interest and contributions; and the local organizers, student volunteers, Webmaster, Program Co-Chairs, Publication Co-Chairs, Poster Co-Chairs, Student Volunteer Co-Chairs, and General Co-Chairs for their work in support of the UbiComp 2008 Workshop Program.

We would also like to extend a special thank you to our sponsors—Nokia, Microsoft Research, the Korea Electronics Technology Institute, Samsung SDS, Korea Research Foundation, ED Corporation and SungKyunKwan University—whose financial support made the workshop program at UbiComp 2008 possible.

We are excited to present these proceedings of the UbiComp 2008 Workshop Program and hope that the proceedings inspire you.

Sunny Consolvo
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*Workshop Co-Chairs*

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# Devices that Alter Perception (DAP 2008)

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Devices that Alter Perception is a new workshop that aims to instigate development and critique of systems that focus on the human percepts. Sensors, actuators, implants, wearable computers, and neural interfaces can do more than simply observe our bodies; these devices can alter and manipulate our perceptions. The goals of the workshop are to: (1) better understand the process of perception (2) aid those developing devices by sharing designs (3) debate of ethical and social issues that are unique to devices that operate below or upon awareness.

Accepted position papers are presented in 10-minute oral presentations or demonstrations followed by 5-minute question and answers sessions. Additionally, the position papers are uploaded to a special discussion site (http://dap.reddit.com) for commentary as well as voting. The paper receiving the highest score–as determined by open, public voting–will be awarded a best paper prize.

**ACKNOWLEDGEMENTS**
We would like to thank the Sunny Consolvo, Hyung Kyu Song, Jongwon Kim, Timothy Sohn and the UbiComp organizers for the tremendous amount of help provided. We would also like the thank Masatoshi Ishikawa for providing a supportive environment for the development of this research theme.

**ON LINE MATERIALS**
The call for papers, information for attendees, and accepted submissions are hosted at:

http://www.k2.t.u-tokyo.ac.jp/perception/dap2008/

**SPONSORS**
This workshop is jointly sponsored by the University of Tokyo's Meta-Perception Research Group and the Royal College of Art's Design Interactions Department.

# Feel the Force: Using Tactile Technologies to Investigate the Extended Mind

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**ABSTRACT**
We describe the motivations behind the E-Sense project which will investigate augmented perception by building a range of novel tactile interfaces. As well as exploring the practical utility of these systems for real world tasks, we are particularly interested in the following question: how can we design tactile interfaces to mediate novel sensory information so that the user experiences the technology as an extension of themselves?

**Author Keywords**
E-Sense, extended mind, transparent technologies, tactile interface

**ACM Classification Keywords**
B.4.2 Input/Output Devices, H5.m. Information interfaces and presentation, K.4.1.c Ethics

## INTRODUCTION

Recent work in philosophy and cognitive science has introduced the idea of the extended mind (for example, [5]), a view of the human cognitive system as a plastic hybrid of biological and non-biological components, including external representations and technologies. This perspective has profound implications for our notion of what it means to be human, pointing to the potential to change thought and action by integrating new technologies and information sources.

Research into augmented perception[1] has established that a variety of sensory information can be mediated through tactile interfaces in a way that is understandable to users and can guide their actions. For example, in the pioneering work of Bach-y-Rita and co-workers on sensory substitution [1], blind participants have visual information from a camera represented to them in the form of the activation of an array of tactile actuators placed on their back, thighs or tongues. With practice, participants are able to use this tactile information to make perceptual judgements and co-ordinate action, for example batting a ball that is rolling off a table. Interestingly, as participants learn to use the tactile stimulation their perception of it changes: sensing the percept in space rather than on their skin. The interface becomes transparent in use, or 'ready-at-hand' to use Heidegger's phrase [6] - that is, the user experiences the technology as though it were an extension of themselves.

Neuroscience experiments have established that tool use can cause structural changes in the brain: the receptive fields of some neurons expand and incorporate the tool into the 'body schema' [12]. Significantly, the neuronal changes only occur when the tactile information is used to guide action, a finding that provides support for O'Regan and Noë's [13] characterisation of perception as primarily involving the mapping of sensorimotor contingencies: systematic relationships between action and sensory input. These perceptual mappings can be surprisingly plastic. Early work by Stratton [19] and Kohler [10] established that humans can adapt to radical disruptions of the relationship between sensors and actuators, for example, inverting glasses turning the visual field upside down. Of particular relevance to our project, Ramachandran and Blakeslee describe how the perceptual system can be tricked into producing the experience of having a two foot nose or experiencing tactile sensation in a table [15].

However, despite extensive citations in the literature, there is still substantial uncertainty concerning the nature of these augmenting sensory experiences. Given the remarkable capacity of people to adapt to changes in existing sensorimotor mappings and to incorporate novel sensory modalities, under what conditions does a mediating technology *not* become transparent? Does sensory extension support a 'sensorimotor contingencies' model of perceptual experience? If it does, what can we learn about the form of sensorimotor contingency mappings that remain 'opaque' and do not become

[1] 'Augmented perception' encompasses both 'sensory extension' and 'sensory substitution', and is where technology provides access to environmental energy not available to a person's biological perceptual system (for example, IR or ultrasound). In the substitution case this is because of perceptual impairment, for example, an individual is blind or deaf.

incorporated into the body; if it does not, which models better explain the perceptual experience of sensory extension? Are the mappings between action and augmenting sensory input as plastic as those coordinating biological senses and motor systems? In the interdisciplinary E-Sense project we believe that by creating a wide array of tactile interfaces and monitoring both their use and the user experiences on an ongoing, day to day level, we will gain important insights into these questions.

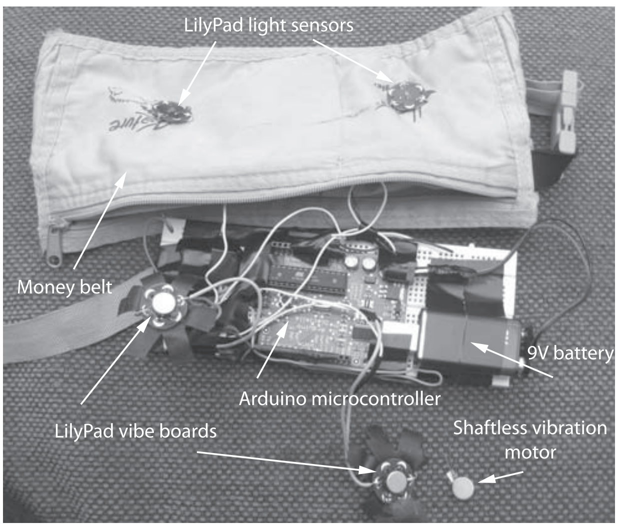


**Figure 1. A rapid prototype built to test the suitability of Arduino LilyPad vibe boards for tactile sensory extension interfaces. If light levels go above a hard-wired threshold value, then each of the sensors switches on one of the vibe boards. The diameter of the shaftless vibration motor is 20mm. The LilyPad vibe boards consist of one of these motors mounted on a printed circuit board that enables users to connect them to a microcontroller using conductive thread and incorporate them into clothing.**

## METHODOLOGY

In our interdisciplinary approach conceptual philosophical analysis feeds into the design of the sensory augmentation systems and user studies will reciprocally feed back into philosophy. One concrete goal is to build useful sensory extension tools; another, more nebulous, goal is to generate novel insights into the extended mind. Our project is extremely open-ended as relatively little is known about the design issues related to tactile systems or about the conditions under which such technologies become transparent in use. Consequently, we believe a productive approach is to combine concepts and approaches from very different disciplines - psychology, philosophy and computer science. We are very aware of the potential pitfalls, as well as the benefits, that can result from interdisciplinary collaboration [18].

### Rapid Prototyping Approach

We believe that a good way to develop and refine our conceptual thinking about the extended mind and sensory augmentation is to embody our ideas in physical artefacts and test them in the real world. This approach has been successful in the past, particularly in open-ended exploratory projects [3,4]. We want to complete as many iterations of the build-test-reflect cycle as possible during the project and so we are adopting a rapid prototyping approach to constructing sensory extension interfaces. We are using open source technologies such as the Arduino electronics prototyping platform [2] and the Processing programming language and environment [14] because with these tools we can quickly connect cheap, off-the-shelf components and build working prototypes. See Figure 1 for a prototype that was built in a few hours to test whether Arduino LilyPad vibe boards [11] were suitable actuators for a wearable tactile system. Constructing this prototype confirmed that these cheap shaftless motors do provide a clearly perceptible signal through clothing and also highlighted the advantage of building a system where the mapping between sensors and vibration motors is easily configurable.

The building blocks of our tactile interfaces will be reconfigurable modules, each of which will consist of up to 16 shaftless coin-type vibration motors (See Figure 1) - this is the maximum number that can be driven using Pulse Width Modulation (PWM) by a Texas Instruments TLC5940 chip. Modules can be daisy chained and driven by a single Arduino microcontroller. The motors will attach to garments using velcro so that their spatial arrangement can be changed quickly. The modules can mediate between behaviour and different environment energies simply by changing the sensors that are connected to the microcontroller. The mapping between the sensors and the vibration motors can be configured in software, as can interactions between the sensors (for example, we could implement lateral inhibition). This flexibility will allow us to rapidly configure different mappings between sensorimotor contingencies and explore the conditions under which the interface becomes transparent or remains opaque.

### Evaluation

We plan to carry out the evaluations using a qualitative case study approach with a small number of participants. On going interviews and informal tests of performance will be conducted to investigate participants' phenomenal experience of using the technologies and to explore whether performance benefits might result. Findings from the empirical studies will be used to inform theoretical models as well as develop predictions about particular sensory extension systems.

## EMPIRICAL STUDIES

We plan to build and test the three sensory extension systems summarised in Table 1 which details:

- where the tactile interface will be placed on a user's body
- the number of tactile modules and vibration motors
- the type of sensors connected to the system
- the motor actions that are mediated by the tactile interface - what is the system for?
- the initial mapping between the sensors and each tactile module

| Prototype | Location of tactile interface | No. of tactile sensor modules and sensors | Sensor contingency | Motor contingency | Initial mapping |
|---|---|---|---|---|---|
| Tactile Car Seat | Back | 1 (6) | Ultrasound | Sense close targets | topographic |
| Feel the Force | Waist | 1 (8) | Virtual | Localize target | topographic |
| Exploring Harmony Space | Back | 3 (48) | Pitch | Harmonic improvisation | topographic |

**Table 1. A comparison of the three prototype devices that we are planning on building with our configurable tactile interface**

### Tactile Car Seat

We propose to design a car seat that will provide the driver with a direct perceptual representation of objects in close proximity to the vehicle. We will use an array of 6 vibration motors driven by the activation of 6 ultrasonic sensors positioned on each side of the car at the front, middle and rear. The intensity of vibration will correspond to the proximity of objects to the associated sensor. We predict that with practice this information might improve drivers' situational awareness and increase vehicle safety. This is an important goal: approximately 50000 reports on road accident injuries or fatalities in the UK in 2005 listed failure to look properly as a contributing factor to the accident and approximately 1500 listed failure to see due to the vehicle blind spot [16].

The idea of using tactile representations of information in a car is not a new one. Ho, Tan and Spence [7], for example, describe how vibrotactile warning signals can be used to alert drivers to dangers on the road. However, these systems are designed to be attention grabbing and present information only at critical moments. We predict that presenting tactile information continuously through the car seat might increase the driver's feeling of connection to the car. In certain situations this could be advantageous, for example, enhancing a driver's ability to judge whether the car might fit into a tight parking space.

We will test the prototype interface using two 'quick and dirty' evaluation methods, neither of which will require a person to drive a real car. This is to avoid the heavy development overheads associated with designing for a real vehicle or complex high-end driving simulator. Firstly we will use the tactile interface to play 'blind man's buff' games where a blindfolded user seated in the lab has to detect the approach of people; and secondly, we will employ a Wizard-of-Oz approach linking movement in an off-the-shelf PC driving simulator with activation of the vibration motor module. While obviously very different from driving a real sensor augmented vehicle, these evaluation methods will enable us to rapidly gauge the potential of this interface to guide action and under what conditions it becomes transparent.

### Feel the Force

This playful empirical study is inspired by the scene in Star Wars Episode IV: A New Hope where Luke Skywalker is getting his first training in the Force on the Millennium Falcon. He is wearing a helmet with an opaque visor that prevents him from seeing a flying robot that moves around him and occasionally zaps him with an electric shock. He has to 'feel the Force' in order to sense the position of the robot and block its zap with his light sabre.

Each user will wear a cummerbund containing 8 equally spaced vibration motors (45 degree separation). The user's 'light sabre' will consist of a Wii nunchuk connected to an Arduino microcontroller. Users will start in a 'registration' position and then the system will track their movements using the 3 axis accelerometer in the nunchuk. The aim of the game is to move the nunchuk so that it blocks zaps from a virtual robot. Its movement will be indicated by changes in activation across the array of vibration motors. A zap occurs when the robot gets closer, indicated by an increase in vibration intensity. If a user responds to this increase by moving the nunchuk to the correct position then they will get force feedback from a vibration motor attached to the nunchuk, indicating that they have blocked the zap; if they move to the wrong position then a number of vibration motors in the cummerbund will vibrate indicating they have been 'hit'.

We will measure how long it takes users to become proficient in blocking zaps. If combined with interviews, then one might be able to determine whether transparency, if achieved, is signalled by performance level. We can map any of the locations in virtual zap space to the vibration motors and explore how different mappings affect users' performance. We predict that the topographic representation, where adjacent vibration motors map to adjacent locations in space, will facilitate the best performance.

### Exploring Harmony Space

We plan to develop a system that uses Holland's Harmony Space system [8, 9] to provide a tactile spatial representation of harmonic structure to musicians learning to improvise. Beginning improvisers typically get stuck on 'noodling' around individual chords from moment to moment and are unable to interact meaningfully with the strategic, longer term harmonic elements, for example, chord progressions and modulations, which are typically essential to higher-level structure in western tonal music, including jazz and much popular music.

Harmony Space draws on cognitive theories of harmonic perception, providing consistent uniform spatial metaphors for virtually all harmonic phenomena, which can be translated into spatial phenomena such as trajectories, whose length, direction and target all encode important information. Thus, Harmony Space enables numerous harmonic relationships to be re-represented in a way that may be more cognitively tractable.

We will use the Harmony Space representation to provide musicians with a tactile representation of the harmonic relationships of music they are currently playing. This will be achieved by having the musicians wear a vest with a 6x8 array of tactile actuators where each actuator will represent a note that the musician is playing. The notes will be identified directly in the case of electronic instruments, or sensed using microphones and pitch trackers in the case of acoustic (monophonic) instruments. We predict that representing pitch movement in this way will facilitate the development of a spatial understanding of musical relationships, which will transfer to improved performance in a wide variety of musical tasks, including improvisation. We will investigate whether performance is linked to the interface becoming transparent.

## CONCLUSION

The E-Sense project is taking an interdisciplinary approach to investigating the extended mind, in particular the nature of sensory augmentation. We will use a rapid prototyping approach to build 3 novel tactile interfaces that mediate different sensory modalities (ultrasound, pitch and 'virtual' location). As well as testing the practical utility of these systems, we hope to gain more insight into the conditions under which technologies become transparent as well as gather more evidence for the theoretical viability of the sensorimotor contingency model.

## ACKNOWLEDGEMENTS

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# SocialSense: A System For Social Environment Awareness

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**ABSTRACT**
SocialSense is a system designed to provide additional social information about nearby people. SocialSense detects Bluetooth devices and uses them to infer the presence of particular people, pulling their profiles and status from online social networking sites. SocialSense differs from existing mobile social awareness systems by integrating live feeds from multiple sources. Information is shown to the user via a head-mounted display, and the user controls the system using buttons mounted on a ring input device or "Magic Ring". The aim is a system that can be used unobtrusively, allowing users to go about face-to-face interactions in a normal manner.

**Author Keywords**
social networking, wearable computer, presence sharing.

**ACM Classification Keywords**
H.5.3 [Information Interfaces And Presentation (e.g., HCI)]: Group and Organization Interfaces — Collaborative computing

**INTRODUCTION**
As people go about their lives, they pass through spaces filled with other people. They will interact with some of these people, but most will be passed by without interaction. One barrier to interaction is unfamiliarity: people are less likely to talk to a stranger they don't know anything about. There is also forgetfulness, such as remembering someone's face but forgetting their name, organizational affiliation, and interests.

This paper describes a system called SocialSense that allows users to be more aware of the social background of people in the environments they inhabit. SocialSense allows the user to explore the profiles and status information of nearby people who have agreed to participate in the system. Profiles are retrieved from an online community site, while status comes from the Twitter microblogging service [14]. Twitter status information consists of a message of up to 140 characters, similar to mobile SMS messages, and provides a potentially dynamic snapshot of a person's current thoughts or activities. The current prototype scans for nearby Bluetooth devices as a proxy for the people in the user's vicinity. The profiles are shown to the user via a head-mounted display (HMD), and the user controls the system using buttons mounted on a ring input device or "Magic Ring". We see the combination of technologies in SocialSense as particularly important. The HMD allows us to display profile icons in the user's peripheral vision to be attended to or ignored based on the user's wishes, as in the eye-q system [3]. The Magic Ring is a deliberately simple input device, designed to allow users to navigate the user interface as easily as possible. While the current SocialSense prototype is quite bulky, we aim to develop a system that can be used unobtrusively, which is important for a system designed to aid social interactions.

For example, a SocialSense user could be walking through a University courtyard filled with people on their way to lunch. As the user is walking, a thumbnail picture of a colleague appears at the edge of their field of view, indicating that the person is nearby. Without this notification, the user might not have noticed the presence of the colleague. Picking them out of the crowd, the user approaches the colleague and asks if they are free for lunch. As they walk to lunch, the user can see their colleague's most recent Twitter status update regarding a paper submission to an upcoming conference. The user is also going to that conference, potentially providing a fertile topic for lunchtime conversation.

**RELATED WORK**
SocialSense brings together research on location-based social networking systems and alternative input devices.


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### Location-based Social Networking Systems

Social network services such as MySpace and Facebook allow users to create profiles for themselves, such as uploading a picture and specifying friendship links with other users. Commercial systems for mobile and location based social networking services make use of self-reported location (e.g., SocialLight), GPS (e.g., Loopt), and Bluetooth (e.g., MobiLuck) in order to leverage location and context specific social information. All Bluetooth devices are capable of 'device-discovery', which allows them to collect information on other Bluetooth devices within 5-10 meters [5]. This information includes a unique Bluetooth MAC address (BTID), device name, and type. The BlueAware system [5] runs in the background on MIDP2-enabled phones allowing them to record and timestamp BTIDs in a proximity log and making them available to other applications. Researchers have been using the BTID patterns to analyze and predict relationships between users and organizational rhythms [5, 13]. Bluscreen is a public advertising system [16] that detects users via their Bluetooth devices and has advertising agents bidding for screen time. Commercial social networking systems such as MobiLuck allow mobile phones to detect all nearby Bluetooth devices, ringing or vibrating when found, supporting message and photo exchange. WirelessRope also uses Bluetooth and supports contact between groups of colleagues at a conference [11]. The Jabberwocky system [12] investigates the "familiar stranger" concept of people who have seen each other in public places on multiple occasions but have never met. The Jabberwocky devices log Bluetooth IDs and no central server is involved, unlike SocialSense.

These systems give us a feel for the possibilities of consumer devices in the mobile social networking field. In addition, there have been many custom social networking applications developed in the wearable computing field including the infamous lovegety [8], GroupWear [2], Smart-Its Friends [7], nTag, and SpotMe. Particularly interesting is the development of systems that incorporate gestural language. For example, iBand [9] is a social networking device that creates connections between two users when they shake hands.

### Input Devices

Effective interaction technology is also important when using a head-mounted display and there have been a number of gesture-based interfaces developed including Ubi-finger [17], GestureWrist [15], FingeRing [6], and Twiddler (http://www.handykey.com/). There have been several input devices developed in a ring form factor. FingerSleeve [18] has a six-degree-of-freedom tracker, with which you have ability to sense all movement, and translation and orientation changes. However, it is unsuited for our application because of its size and wire connection, and because SocialSense does not require that level of tracking functionality.

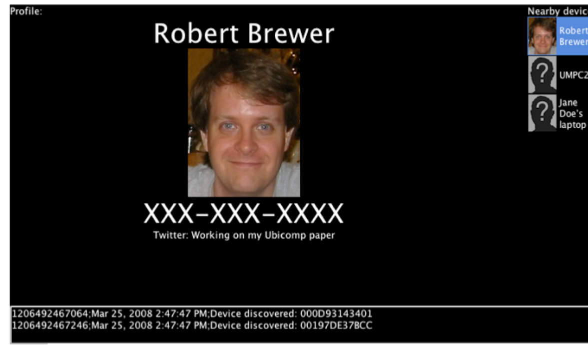


**Figure 1: SocialSense user interface, showing an abbreviated profile (redacted for privacy)**

## PROTOTYPE DEVELOPMENT

SocialSense consists of a computer with a Bluetooth adapter that continuously scans for nearby Bluetooth devices. For each Bluetooth device discovered, it contacts a server to see if there is a profile associated with the BTID of the discovered device. If a profile is found, the information is downloaded and added to a list of nearby devices. In addition, if there is a Twitter account associated with the profile, the latest status message is retrieved. Devices that are not associated with a profile are also displayed, but the only information that can be displayed is the name that the device provides (which can sometimes be helpful, such as "Adam Smith's iPhone") [10].

### Software Implementation

The SocialSense client is written in Java. This decision was made early on because Java allows for cross platform development and deployment. Of particular note is the availability of a cross-platform specification for using Bluetooth with Java, known as JSR 82 (http://jcp.org/en/jsr/detail?id=82).

The user interface is simple by design. It displays the detected users by name and thumbnail image on the right hand side, and the currently selected profile in the center. Log messages are displayed at the bottom of the window showing the status of Bluetooth scans and any errors encountered. Figure 1 shows the user interface.

The interface uses white text on a black background because on some optical see-through HMDs black is transparent thus avoiding unnecessary occlusion of the real world.

To select a device, the user shifts the selection up and down in the list. Moving the selection off the top or bottom of the list causes the profile area to be cleared, allowing the user to focus on his or her physical environment instead of the interface. When a person is selected, that person's abbreviated profile is displayed, showing their name, picture, phone number and Twitter status. The user can then toggle between an extended profile that displays the person's full bio and the abbreviated profile.

Currently the server side of SocialSense is implemented in Ruby on Rails as part of the larger disCourse online collaboration system. The ability to associate BTIDs with an individual was added to the existing disCourse profile system. The SocialSense client makes a HTTP request (via WiFi) containing each BTID discovered to the server. If there is a profile associated with a BTID, the server replies with a XML document containing the profile contents, which is then parsed by the client. If the profile has an associated Twitter account, the latest 'tweet' is retrieved from Twitter.

#### Hardware

The SocialSense prototype runs on a Samsung Q1 UMPC (Ultra Mobile PC). UMPCs are like miniaturized laptops, but they run full versions of Windows. The Samsung model has built-in Bluetooth, WiFi, 2 USB ports, and a VGA port for connecting to the HMD.

We initially used the LitEye LE-750, which is an optical see-through device, for the HMD, but found it too bulky and unsuited for social computing applications. We settled on the Creative Display Systems i-Port as a less obtrusive display. The i-Port consists of a modified pair of Oakley sunglasses with the display mounted onto the right hand side. Unlike the LitEye display, the i-Port is not an optical see-through HMD so it does partially occlude the right eye, but it does not occupy the user's full field of view so it allows some situational awareness.

For input to SocialSense, we developed a "Magic Ring" device to match the simplicity of the user interface. The Magic Ring consists of three small buttons attached to a metal ring, which is attached by wires to a wrist-mounted controller and battery. The wrist-mounted device communicates wirelessly to the receiver module, which attaches to the UMPC via a USB cable. The receiver module appears as a keyboard to the UMPC, and the three buttons send the keystrokes for up arrow, Enter, and down arrow respectively. We are working on an evaluation of the Magic Ring compared to other input devices for common navigation tasks. Figure 2 shows a picture of the device.

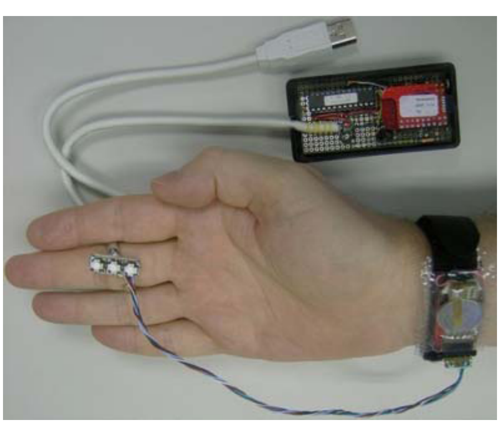

**Figure 2: Magic Ring input device**

**Figure 3: SocialSense hardware being worn**

### FUTURE WORK

The SocialSense system is still in an early prototype phase, and although we have a working prototype, there are many ways in which it could be improved.

#### Unobtrusiveness

Significant work is still required before the system can be considered unobtrusive. The head-mounted display is probably the most difficult hurdle towards unobtrusiveness. Current displays are simply too bulky and obvious. While there are many companies working on technologies that they claim will be tiny and practically invisible, only time will tell if these displays live up to the manufacturers' claims.

It may be some time before we can develop a system that can be truly unobtrusive. An alternative approach would be to develop a version of SocialSense for a mobile device like the Apple iPhone. Such a device would be relatively unobtrusive, but it would require a way to make the user aware of nearby people. Given the near ubiquity of Bluetooth headsets, one option would be to have the mobile device "whisper" in the user's ear when someone entered their social space, at which point the user could browse profiles on their mobile device if they wished to.

#### Beyond Profiles

While profiles from social networking sites can be useful snapshots of a person's identity and interests, they can grow stale if the user does not update them. Updating one's profile does not provide any direct benefit to the user updating the profile; it only helps others. However, there are other sources of data that we can display such blog posts, or FaceBook updates. These information sources, like Twitter, could provide a more up to date indication of what is relevant to the person in question.

The system could even display email messages from the detected individuals that had been sent to the SocialSense user. Such a feature could be very helpful in making sure conversations with colleagues didn't require repetitive explanation of unread emails.

### Privacy

With any social networking application, privacy issues are crucial and this is especially true in a mobile wireless environment. The SmokeScreen system [4] allows users to engage in presence-sharing using Bluetooth IDs or WiFi MAC addresses, but provides privacy management using cryptography. SmokeScreen provides a method for presence sharing between strangers using a centralized broker service. Privacy controls can also be on the server side where the user profiles are stored; allowing users to display only limited profile information to users not on their 'buddy list'. The server could also record who retrieved a profile, providing awareness to those being looked up. Critical for privacy is making sure that SocialSense is "opt-in", i.e. you decide if you want to share your profile and who you want to share it with.

### Augmented Reality

Azuma and colleagues [1] define an augmented reality (AR) system as one that combines real and computer-generated information in a real environment, interactively and in real time, and registers virtual objects with physical ones. A future AR-enabled version of SocialSense could make the retrieved profiles appear to float above peoples' heads from the perspective of the user wearing the HMD. This would make it obvious who the profiles referred to, but such a feature would require significant advances in AR technology to be practical.

## CONCLUSION

We have presented SocialSense, our application for providing context to social situations by sensing Bluetooth devices and displaying nearby user profile and status information. We have developed a prototype using a HMD and the custom Magic Ring input device. The prototype works, but is too cumbersome for routine use. We believe that in time it may be possible to develop an unobtrusive version that displays helpful information about nearby people and we have mapped out several areas for future research.

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# Boxed Ego

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## ABSTRACT

Boxed Ego is a double trap for the Self. A peep-show box waiting in a corner of the exhibition space first captures the curiosity of the observer - and then the observer himself. Although of an artistic flavor, from the research perspective this work is a preliminary experiment on the cognitive (and possible practical) aspects of artificial autoscopy (AS). In order to understand how artificial autoscopy can generate an out-of-body experience (OBE), we embrace the enactive approach to perception [1] and we further hypothesize that the *sense of self*, may be itself a second-order perceptual experience: that resulting not from the exploration of the world based on skillful mastery of the visual, tactile, proprioceptive or auditive sensorimotor contingencies (SMCs), but on exploring/acting on the world with skillful mastery of these SMC *as well as the rules governing the relations (extended in time) between these SMCs*. A first corollary of this hypothesis is that there may be different senses of self: at one extreme, those inextricably linked to each primal sense (and thus experientially ineffable), and at the other extreme, a more abstract sense of self that result from the knowledge of cross-modal contingencies. In between, there may be experiences rendering a more or less unified sense of self, which is precisely why this model seems to us ideal to explain OBEs. A second corollary of this view, is that attentional blindness may also pertain to the sense of self, a testable hypothesis.

### Author Keywords

telexistence, out-of-body, autoscopy, self-awareness

### ACM Classification Keywords

H.5.1 Multimedia Information Systems — Artificial, augmented, and virtual realities,
H.5.2 User Interfaces — User/Machine Systems

## INTRODUCTION

That language and consciousness are inextricably interrelated is not a coincidence since language is a more or less natural formalization of conceptual reasoning, playing a crucial role in the process of self-representation and subjective consciousness [2]. But language alone is not sufficient and surely not even indispensable in order to provide organism self-awareness. How can someone/something incapable of describing knowledge of his/its internal states (even to oneself/itself) be capable of self-awareness? The paradox disappears if one consider that 'description' (internal or external) does not need to be propositional, but can be *enactive* [3].



With this remark in mind, we will leave aside the problem of language-based self-reference, and concentrate instead on enactive forms of self-awareness (as a passing remark, let's note that the ineffable character of enactive knowledge may be responsible for the ineffable part of the sense of self). For one, vision plays a fundamental role in the generation of an egocentric perspective on the world; visual artists have been experimenting in this arena well before science created the right tools or even the proper language capable to describe such phenomena. Self-referential pictures have been around from ten of thousands of years, and artificial mirrors are thousands of years old; however, it's the invention of magnetic recording and closed loop video that opened really new exploratory possibilities. 'Present Continuous Past(s)' by Dan Graham (1974) is perhaps one of the first interactive video-art installations challenging the special vantage point of the audience, and transforming the spectator into its own object of observation. Time delay is purposely used to trick the spectator into the belief that he is seeing a pre-recorded scene unrelated to himself, but then he would slowly gain understanding of his central role in the piece. This calculated spatio-temporal disembodiment brings confusion: as with the Necker cube, the perceptual content is of flipping nature: that of the filmed person being someone else or being oneself. Only very recently these experiments were reproduced in a controlled environment [4]. In this workshop, I would like to foster an informal discussion about the scientific, practical (and of course artistic) potential of this kind of experimentation by describing a media-art installation called 'Boxed Ego' [5].

## BOXED EGO INSTALLATION

A pair of cameras are aimed towards a small platform on a corner of the exhibition space over which sits a cubic peep-show box. The holes of the peep-box are in fact the eye-pieces of a live-stereoscope. The separation of the video cameras in real space is set to about ten times the real inter-ocular distance, so that the viewer will see a ten times scaled-down version of himself inside an equally miniaturized exhibition space (hyperstereo effect). The box appears empty; however, if the observer talks or breathes, the box readily detects this human prey and traps it in its interior, effectively transforming the observer into its own object of observation. Indeed, a dwarfed, truly three-dimensional version of the observer (peering inside an even smaller box) will slowly materialize (figure 1). Perhaps the main difference between Boxed Ego and other works featuring artificial autoscopy (either in the Media Arts or in the field of experimental psychology [4]) is that (1) the object/subject is perceived truly in 3d, although miniaturized (thus combining autoscopy with micropsia, which are both phenomena that correlate somehow in the medical literature ; (2) the spectator is filmed from behind, and without a time delay it becomes impossible for him to see his own face (this makes the experience very different from that of a mirror or a camera on top of a screen, reminding us of Magritte's famous painting 'La reproduction Interdite'); (3) there is a limited form of correlated tactile feedback (the spectator can grasp the box and see himself grasping it, while at the same time feel the real box his hands); (3) lastly, although not sufficiently compelling in this experiment, the suggested infinite recurrence of observer-observers could potentially generate a sense of multiple body relocation (see below).

The idea behind this installation was to explore, in an artistic way, the links between *curiosity and voyeurism*. While peering inside the box, one can see oneself in every detail, and to a certain extent play with one's own avatar (in particular thanks to some time delay in the video loop). At the same time, one cannot see the other people in the exhibition space (see video in [5]). The installation was exhibited for a week at SonarMatica Media Art festival in Barcelona (2008) with much success. A commentator later reasoned that this could be because 'the theme of self-voyeurism is unsurprisingly very popular with the festival goers.' We agree with this remark (after all, even a simple mirror always retains some magic), but the question remains open: why are we so attracted by these devices? Of course there is a practical aspect to the experience (e.g. tighting your necktie); however, we hypothesize that there is more to this: this sort of setup brings us close to an out-of-body experience which is interesting per se: it give our minds the opportunity to better itself in the mastery of the sensorimotor contingencies in an unusual territory.

**Figure 1. Stereo pair as displayed inside the box (without optics)**

## THE OUT-OF-BODY EXPERIENCE

Out-of-body experiences (OBEs) are a culturally invariant neuropsychological phenomena that can take a variety of different forms, ranging from seeing one's own body from an elevated visuospatial perspective (the placement of the stereo cameras in the Boxed Ego installation tries to capture this) to the less known 'heautoscopic' hallucination, consisting on perceiving a duplicate of ones body in extrapersonal space [6]. Although the etiology of the OBEs varies widely (organic dysfunctions such as epilepsy, sleep-paralysis, psychological disorders or traumatic experiences but also episodes without a know trigger), direct electrical stimulation of the cortex in pre-operatory brain surgery for intractable epilepsy as well as less invasive experiments (trans-cranial electrical or magnetic stimulation [7]) and fMRI performed during paroxystical hallucinations, all point to the involvement of a very specific area in the brain, namely the *temporo-parietal area* [6].

### Complete distal attribution and OBE

It is interesting to note that although classical OBE imply whole visuospatial relocation in space, it is also possible to have relocated *parts* of the body. This partial relocation is a relatively common occurrence described in the medical literature [9], but also easily reproducible on healthy subjects [10]. It may be argued that 'relocation' of sensation is a normal way of functioning of the sensory-motor apparatus: for any practical purpose, it *must* feel like the sensation is precisely located at the site of stimulation (e.g. on the tip of our finger), instead of, say, inside the head. We always feel *located sensations*, and in particular located in a part of the world that we perceive as 'ours'. *Distal attribution* is the technical term for a very common phenomena, that of situating the stimulus where the action responsible for it is taking place - even if this part is extracorporeal. That's why we feel the texture of paper at the end of the pen, not on your fingers where the force is actually sensed. Distal attribution is exploited in robotic telexistence systems (the user can operate the robot on the same room, or be in another continent for that matter). However, there seems to be a threshold of sensory immersion and sensory-motor correlation that when reached, transforms the fairly common experience described as distal attribution into something qualitatively different: *it elicits a sense of presence in extracorporeal space*. It is therefore tempting to see OBEs as the consequence of a full body relocation in which the experiencer can still see his original body (an experience with an entirely different phenomenology).

## SENSE OF PRESENCE: A SENSORIMOTOR ACCOUNT

### An ineffable sense of self

As noted in [1], a subset of the 'apparatus-based' sensorimotor contingencies (SMCs) relevant to the sense of vision may derive from sensorimotor laws relative to an 'observer oriented coordinate system'. Learning these laws would provide the system with a rudimentary (enactive) notion of self. For instance, objects (or other people) generate stimuli that can be removed and put back into the visual scene, while sensation about one's own body is always potentially available. Furthermore, some parts of the perceived environment can be controlled at will (i.e. in a manner independent to the motion of the sensory apparatus) while others not (e.g. we don't need to look away in order to hide our own hand). We can generalize this claim as follows: things that are *not ourselves* generate stimuli that can be removed or put back into the *visual, auditive or tactile scenes*, while our own body generates stimuli (including this time proprioceptive information) that cannot be so easily removed. Therefore a sense of self-location is brought by active exploration of the world with (implicit, practical) knowledge of the structure of *egocentric* sensorimotor contingencies. (If the observer was not physically located in a particular place in space, these sensorimotor contingencies would be of a very different nature; perhaps one day a robot with pervasive sensors and actuators - like HALL9000 supercomputer from '2001: Space Odyssey'- will tell us what it's like to have an ubiquitous sense of self).

### Sensorial awareness and sense of self

SMCs determined by the character of the 'sensory apparatus' would roughly correspond to the crude character of 'sensation', while those related to the character of the explored objects would form the basis of 'perceived content' [1]. In other words, *awareness* of the character of the experience (is it visual, auditive or something else?) as well as understanding of its content (for the purpose of thought, planning and speech behavior) may be worked out by a concurrent neural mechanism responsible of recognizing and analyzing each particular pattern of SMC. In fact, there may be different levels of 'understanding' (each more or less accessible to consciousness). At the top of the hierarchy, we may have abstract knowledge relative to the occurrence of *some form* of sensory experience, as long as the SMC has some recognizable, familiar structure (perhaps learned late in life). In other words, we may be aware of *being experiencing something* without paying attention to the actual content of the experience. This could contribute to (or even form) a sense of self: if while actively exploring the world, familiar patterns of SMCs appear, then you may not only experience something, but you may experience being a Self experiencing that; if, on the other hand, you fail to recognize any patterns, then you may not just be sense-blind: you may not even experience *being* someone at all.

## IDEAS FOR EXPERIMENTS AND PRACTICAL USES

Altering in a controlled way the SMC pattern for a particular sensorial modality may be more or less easy to achieve (the inverted-glass experiment [11] is a classic example). However, altering in a controlled way all the sensorimotor contingencies as well as their inter-relations (including time correlations) may be more difficult to do. To start with, the altering device should be multi-modal. An immersive virtual reality environment could be an ideal setup, but the technology for haptic and proprioceptive actuators is not nearly as developed as auditory or visual displays. For example, while it is easy to set an inverted vision experiment, it is not so easy to conceive –left alone design– a setup for 'inverted haptics': it would mean for instance than when touching something with my right hand, I would feel the object on my left hand.

### Attentional self-ness for human computer interfaces

Another interesting consequence of this view is that it should be possible to apply the same principles behind attentional blindness (i.e. *experiential* blindness while retaining sensation) and induce *attentional self-ness*. It turns out that this may be a normal occurrence in everyday life: we do perform repetitive tasks automatically, sometimes without even registering in memory the fact that we did them. (In a sense, we are all *philosophical zombies* from time to time.) However, it would be interesting to be able to control this, perhaps in order to reduce cognitive load from tasks that can be done by a machine and don't need attention from part of the user.

### Medical Applications

The temporo-parietal junction seems to be the common lesion site in patients suffering from disturbances of the egocentric spatial-relationship with extrapersonal space (a conditional called *visuospatial neglect*). This is not surprising if we believe the results reported in [8]: this region is in fact very involved in the real-time integration of proprioceptive, tactile, visual and vestibular sensory input, generating a three-dimensional, dynamic representation of the body in space. Therefore, one can wonder if artificially manipulating these inputs may lead to some degree of control over the way the body is represented in space, for therapeutic or at least for palliative care. An example related to this may be the 'revival' of phantom-limbs for the purpose of treating associated pain [9]. Another interesting possibility may be the treatment of higher cognitive dysfunctions, such as dissociative identity disorders; indeed, it has been found that OBEs correlate in people with these disorders [8]. In short, we hypothesize that the availability of a machine through which one is capable of artificially creating and manipulating autoscopic imagery may render a sense of control over otherwise contradictory or poorly organized sensorimotor feedback.

### Super mirrors?

Perfectly reflecting surfaces capable of creating an image indistinguishable from reality is a relatively recent human invention that can be traced back to the first century AD [12]. Yet it was a luxury object; Modern ubiquitous mirrors are a much more recent invention Therefore one should be surprised more than not about how comfortably we seem to get along with these artifacts. It is well known that most animals do not pass the 'mirror test', and fall pray once and again to the illusion of reflexions, so one has the right to wonder if our getting used to these ubiquitous reflexions is not because of an intensive exposure in our daily lives (fun house mirrors do make us uncomfortable!). However, since a mirror breaks the natural egocentric visuospatial perspective, one can suspect that their intrusion in the visual field may still disrupt the normal integration of visuospatial information. In fact, researchers have shown that the temporo-parietal region is activated when one tries to mentally superimpose one's body on a front-facing schematic human figures, while the same region is not activated when one observes back-facing characters [8]. It is like the mere idea of seeing oneself from an outside perspective had a special experiential content – everyday mirrors may not be so innocent after all! Perhaps a device that could give finer control of this disruption would be more efficient or safer. This remark is particularly important if one is to consider the use of mirrors on vehicles. A (wearable?) 'autoscopic super mirror' could display a 3d model of the observed/observer as seen from any arbitrary position in extrapersonal space, and this position could be naturally controlled by the user after learning a properly designed artificial SMC scheme that *would not disrupt the sense of self in a way that is counterproductive or dangerous for the task at hand*. In the future this may be achieved by mounting several cameras and reconstructing the scene from an arbitrary point of view. Uses of this could range from 'enhanced mirrors' for dancers that could see their own body from any location during rehearsal, to their use on cars, as an enhancement or substitute of the front and rear mirrors (this can be achieved by collecting images from street cameras or from cameras mounted on other cars, or more simply by using a unique fish-eye camera could be mounted high on the car). Research on telexistence systems is solving part of the problem [13]; indeed, these 'super mirrors' are *autoscopic telexistence* systems.

## CONCLUSION AND FURTHER WORK

The system described in this paper tampers with two of the sensory stimuli that seems directly involved in the construction of body self-awareness, namely visuospatial input as well as a limited form of tactile feedback. This experiment does seem to generate a mild form of OBE (or at least the feeling of being in a 'twilight zone' and that without care one can be induced an OBE - and be absorbed by the box). A more objective study is needed in order to asses the efficacy of the illusion, but this was not the goal at this stage of the experiment. In this paper we have deliberately concentrated on a rudimentary notion of the self, one that could account at least for some form of body self-perception. Borrowing the terminology of the sensorimotor contingency model, we may say that being-in-the-body is a way of acting on objects in the world. OBEs would result from the *alteration of normal sensorimotor dependencies as well as cross-modal dependencies*. (This view suggests that synesthesia and out-of-body experiences may be co-morbid phenomena, a view for which there seems to be some medical evidence [14]). If this alteration is consistent in time (something that could be done with the help of 'device that alters perception' more complex than a movable mirror for instance), then one can expect that a functional sense of self could be regained once one comes to grips with the new set of artificial SMCs. This may indeed happens in everyday circumstances. For instance, we usually don't experience any severe disturbance of the sense of self when looking at a mirror, nor is our self disintegrated when playing a first-person shooter game. There may be fundamental reasons for that immunity (such that too few sensorial modalities are involved in these experiments), but it may also be that we have learned enough about these abnormal situations so as to 'flip' the whole set of sensorimotor contingencies, and tune to the one that makes more sense (a bistable form of adaptation similar to the one observed in the limited-time inverted glasses experiment [11]). In any case, it would be interesting to design a device capable of a deeper alteration (although controlled and consistent) of the whole scheme of sensory motor contingencies. A first concrete step would be to include some form of synchronized visuo-tactile stimulation in our own experiment; however, instead of passive stimulation as in [4], it would be interesting if the participant could be himself at the origin of the stimulation. For example, the box could have an opening for a hand, through which the participant would reach the head of his avatar; at the same time, some actuator would touch the real head. Another idea would be to set the whole installation on a moving platform that would tilt as the user tilts the box in his hands, thus instantiating a form of vestibular feedback.

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# Fear tuners – Prostheses for instincts

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**ABSTRACT**
This paper concerns "Fear Tuners", a critical design project that was initiated at the Royal College of Art in 2008. In this paper, I argue that our bodies are equipped with a sensory system that only allows us to detect immediate dangers, for example it helps us to decide where to tread and what to eat. This system though is not suitable to sense the abstract and global dangers that occur in our highly complicated world.

Fear Tuners brings forward the arguments that people are in need of tools to help them sense global and abstract dangers. As a response to the problem, this project explores the potential use of wearable devices as prostheses for those missing instincts. The paper suggests using the skin as an interface to stimulate a physical sensation resulting into a mental state of increased awareness, whenever a deferred danger occurs.

**Author Keywords**
Augmented cognition, prosthetic design, haptics, wearables, critical design, device art.

**ACM Classification Keywords**
B.4.2. Input/Output Devices, H.5.m. Information Interfaces and presentation, K.4.1.c Ethics

## INTRODUCTION

This paper concerns "Fear Tuners", a critical design project that began life in the Design Interactions Department at the Royal College of Art in 2008. It is a project of *design research*, practiced from the perspective of artist-designers. Fear Tuners stands in the tradition of critical design. This approach aims to open new spaces for designers and means to provide an alternative method to design, in contrast to focusing on the factors of 'usability' or commercial viability of a product, service or system. Embodying different values into the designs triggers a debate on the impact of specific technologies that comes with these. The designs can be seen as a manifestation of people's hopes and fears in relation to those technologies [6].
The Fear Tuners objects are wearable, functional devices, which also stand in the tradition of *device art.* This classification defines artworks that consist of a hardware, which is specifically designed to realize a particular concept. The functional and visual design aspects of these objects make an essential part of the artwork [8].


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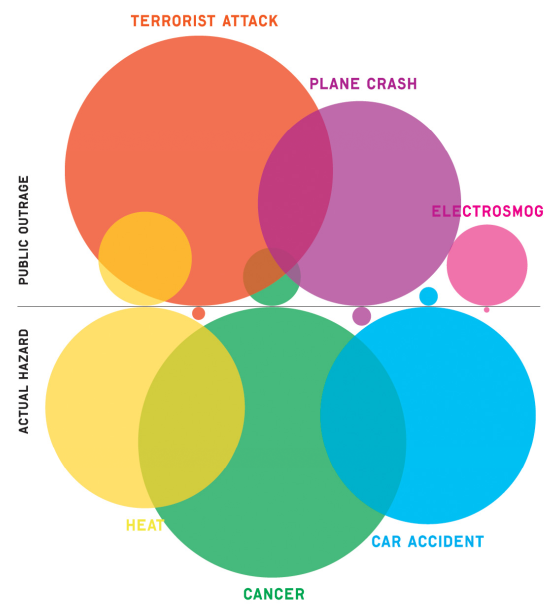


**Figure 1. Risk perception and actual hazards**

## BACKGROUND

The project arose from the insight of being unable to assess the threats, dangers and risks that we are faced with in today's complicated world. Technologies have greatly reduced some of the biggest risks of humankind, yet our modern life seems to spawn a whole new array of abstract threats and fears [1]. Creating a common feeling of "being at risk" has become a popular political method as well it is widely exploited in mainstream journalism [5]. The consent to a common fear in a community can result into a more cohesive society and the choice to be aware of a danger is often meant to conform a specific way of life [3]. Generally, it can be observed that people seem to be unable to differentiate between mere panic mongering and the real threats that surround them. For example, we can register a massive media outrage on minor or non-existing threats (e.g. bird flu, MMR vaccine), and a neglect of many serious risks, such as old age poverty related to non-functional pension schemes (Figure 1).

## HUMAN SENSES AND ABSTRACT DANGERS

Our hard-wired sense apparatus is not suitable to sense the modern dangers in an array of fear stories. We are only hardwired to deal with sudden or physical dangers, such as approaching cars, burning fires or rotten food. But we do not have the instincts to sense the abstract and deferred dangers that have a huge effect on our daily lives, like stock market crashes and the rising oil price.

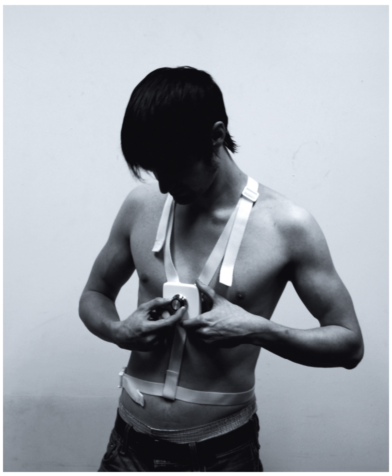

**Figure 2. Fear Tuners – Form prototype**

I propose to face this inability with the implementation of wearable devices (Figure 2) as prostheses for these instincts to be able to sense the deferred and abstract dangers of today.

## SKIN AS INTERFACE

When we sense a physical danger, a set of bodily reactions comes into action. We can feel cold shivers that run down our spines, get goose bumps, sweaty hands, our neck hair raises and we start to tremble. The most extreme of these reflexes is the so-called 'fight or flight response' that jumps into action, whenever we are faced with a sudden attack [2]. In this state, our pupils have narrowed and we have lost peripheral vision, we have an accelerated heart and lung activity, and nutrient has been released to our muscles, among many others, to get us ready for action [7]. None of these physical manifestations is voluntarily chosen or the outcome of an intellectually driven thought process. Instead, they are the immediate reflexes to an instinct sensing danger.

These processes are hard-wired into our bodies as a result of evolution, even though we rarely encounter emergencies that require physical effort.

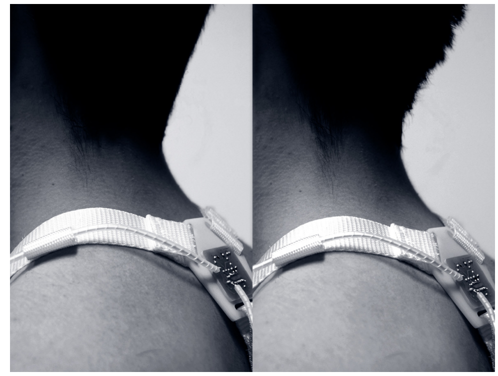

**Figure 3. Raised neck hair and increased alertness through physical stimulation**

Fear Tuners as prostheses for instincts proposes to use the skin as an interface to stimulate similar physical sensations (Figure 3), as described in the preceding paragraph. Fear Tuners create an equally immediate and intense experience.

Referring on the concept of body-to-emotion-feedback, by Paul Ekman, who describes how voluntary facial actions are capable to generate changes in both autonomic and central nervous system, I propose that wearing Fear Tuners will similarly result into changed mental state. By inducing a set of physical reactions normally related to fear, such as raising a person's neck hair or generating cold shivers and goose bumps, a state of increased awareness will be generated [4].

**Figure 4. Visualization – Stimulation of cold shivers related to the current inflation rate**

## AUGMENTATION OF HUMAN INSTINCTS TO PERCEIVE GLOBAL DATA

Fear Tuners are wearable devices, which act directly on the skin. Wireless technology links them to a piece of software that harvests the internet for related data streams, e.g. stock market data, oil price etc. Whenever a severe change in data occurs, the device passes on a sensation to the wearer.

Presenting the information in form of physical stimuli, rather than intellectual (textual and image based information), allows the Fear Tuners wearer to focus the center of his or her attention on other things. The wearer can completely process Fear Tuners' signals in the background of awareness. This form of ambient information presentation engages the senses and thus results into a subtle, yet intense experience that does not disrupt the wearers daily routine [10].
In the process of exploring suitable sensations, I was investigating different actuators, such as solenoids and vibration motors, peltier pumps and electrical deep tissue stimulation aiming to create cold shivers (Figure 4), goose bumps, raised neck hair and hot stings. I also looked into possibilities of exploiting the phenomenon of somatosensory illusions [9].

I identified five key scenarios, Disasters, Financial, Health, Personal and Technology, in which Fear Tuners would act as an 'artificial sixth sense' in the form of a device.

## CONCLUSIONS

At present, Fear Tuners exist as a series of technical experiments, form prototypes, a video scenario and booklet. They were presented as part of my thesis at the Royal College of Art graduation show. I am hoping to bring the project to a next level, in which the preceding research and experimentation in form and function would be combined to create to a fully functional prototype. For this next step, I am looking for collaboration partners from a different background other than design.


## ACKNOWLEDGMENTS

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# Gesture recognition as ubiquitous input for mobile phones

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**ABSTRACT**

A ubiquitous input mechanism utilizing gesture recognition techniques on a mobile phone is presented. Possible applications using readily available hardware are suggested and the effects of a mobile gaming system on perception is discussed.

**Author Keywords**

ubiquitous computing, accelerometers, gesture recognition, optimization, human-computer interfaces

**ACM Classification Keywords**

B.4.2 Input/Output Devices, H5.m. Information interfaces and presentation

## INTRODUCTION

Mobile phones are the most pervasive wearable computers currently available and have the capabilities to alter and manipulate our perceptions. They contain various sensors, such as accelerometers and microphones, as well as actuators in the form of vibro-tactile feedback. Visual feedback may be provided through mobile screens or video eye wear.

Dynamic input systems in the form of gesture recognition are proving popular with users, with Nintendo's Wii being the most prominent example of this new form of interaction, that allows users to become more engaged in video games [1]. The video game experience is now affected not only by timing and pressing buttons, but also by body movement.

To ensure a fast adoption rate of gesture recognition as an ubiquitous input mechanism, technologies already available in mobile phones should be utilized. Features like accelerometer sensing and vibro-tactile feedback are readily available in high-end mobile phones, and this should filter through to most mobile phones in the future.

Hand gestures are a powerful human-to-human communication modality [2], and the expressiveness of hand gestures also allows for the altering of perceptions in human-computer interaction. Gesture recognition allows users to perceive their bodies as an input mechanism, without having to rely on the limited input capabilities of current mobile devices. Possible applications of gesture recognition as ubiquitous input on a mobile phone include interacting with large public displays or TVs (without requiring a separate workstation) as well as personal gaming with LCD video glasses.

The ability to recognize gestures on a mobile device allows for new ways of remote social interaction between people. A multiplayer mobile game utilizing gestures would enable players to physically interact with one another without being in the same location. Gesture recognition may be used as a mobile exertion interface [3], a type of interface that deliberately requires intensive physical effort. Exertion interfaces improve social interaction, similar to games and sports that facilitate social interaction through physical exercise. This may change the way people perceive mobile gaming, as it now improves social bonding and may improve overall well-being and quality of life.

Visual, auditory and haptic information should be combined in order to alter the user's perceptions. By utilizing video glasses as visual feedback, earphones as auditory feedback and the mobile phone's vibration mechanism as haptic feedback, a pervasive mobile system can be created to provide a ubiquitous personal gaming experience. Gesture recognition is considered as a natural way to interact with such a system.

Gesture recognition algorithms have traditionally only been implemented in cases where ample system resources are available, i.e. on desktop computers with fast processors and large amounts of memory. In the cases where a gesture recognition has been implemented on a resource-constrained device, only the simplest algorithms were considered and implemented to recognize only a small set of gestures; for example in [5], only three different gestures were recognized.

We have developed an accelerometer-based gesture recognition technique that can be implemented on a mobile phone. The gesture recognition algorithm was optimized such that it only requires a small amount of the phone's resources, in order to be used as a user interface to a larger piece of software, or a video game, that will require the majority of the system resources. Various gesture recognition algorithms currently in use were evaluated, after which the most suitable algorithm was optimized in order to implement it on a mobile phone [6]. Gesture recognition techniques studied include


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hidden Markov models (HMMs), artificial neural networks and dynamic time warping. A dataset for evaluating the gesture recognition algorithms was gathered using the mobile phone's embedded accelerometer. The algorithms were evaluated based on computational efficiency, recognition accuracy and storage efficiency. The optimized algorithm was implemented in a user application on the mobile phone to test the empirical validity of the study.

## CURRENT IMPLEMENTATIONS

Choi et al. [7] used accelerometer data acquired from a mobile phone's built-in accelerometer. They were able to recognize digits from 1 to 9 and five symbols written in the air. During their experimental study, they were able to achieve a 97.01% average recognition rate for a set of eleven gestures. The recognition rate was cross-validated from a data set of 3082 gestures from 100 users. This was done using a Bayesian network based approach, with gesture recognition done on a PC connected to the mobile phone.

Pylvänäinen [8] employed an accelerometer-based gesture recognition algorithm using continuous HMMs, with movements recorded using an accelerometer embedded in a mobile phone, but gesture recognition was still performed on a desktop PC. A left-to-right HMM with continuous normal output distributions was used. The performance of the recognizer was tested on a set of 10 gestures, 20 gesture samples from 7 different persons, resulting in a total of 1400 gesture samples. Every model for each of the 10 gestures had 8 states. 99.76% accuracy was obtained with user-independent testing. Pylvänäinen argued that an extensive set of gestures (i.e. more than 10) becomes impractical due to users having to learn all the different gestures.

With gesture recognition one should distinguish between postures, involving static pose and location without any movements; and gestures, involving a sequence of postures connected by continuous motions over a short time span [2]. Crampton et al. [1] developed an accelerometer-based multi-sensor network to recognize both postures and gestures. The wearable sensor network detects a user's body position as input for video game applications, providing for an immersive game experience. Mahalanobis distance is used as a nearest-neighbour means of classification. This improves on using Euclidian distance as a metric, as it takes into account the correlations of the data set and is scale-invariant. They argue that the more accelerometers are used, the more accurately gestures and poses can be differentiated. This should be taken into account when developing a gesture-based system, and is discussed further later in the paper.

Current accelerometer-based motion-sensing techniques in mobile phones are either based on tilt or orientation, allowing for simple directional movement control in games. Camera-based methods for gesture recognition are also becoming more popular. A company called GestureTek [19] enables mobile phones with built-in cameras to be used as motion-sensing devices. In the case of camera-based computer vision algorithms, the necessary image processing can be slow, which creates unacceptable latency for fast-moving video games and other applications [20]. Camera-based sensors are also deemed power-hungry, which is a problem considering that the amount of power consumed during operation is of utmost importance in a mobile device.

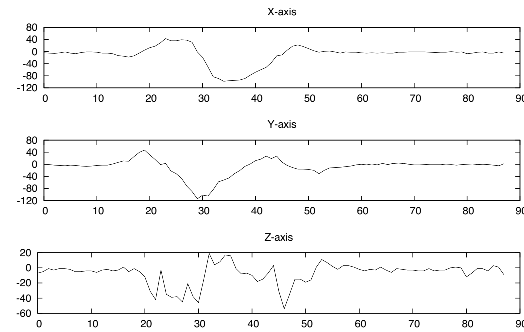


**Figure 1. Raw sensor data sampled from the Nokia N95's accelerometer**

## IMPLEMENTATION AND RESULTS

In [9], we describe how various gesture recognition techniques were evaluated, after which the most suitable algorithm was optimized in order to implement it on a mobile device. We make use of the Dynamic Time Warping (DTW) algorithm, introduced by Sakoe and Chiba [10] in a seminal paper in 1978. The DTW algorithm used was originally implemented in C by Andrew Slater and John Coleman [11] at Oxford University Phonetics Laboratory. The DTW algorithm non-linearly wraps one time sequence to match another given start and end point correspondence.

Sensor data was collected using a Nokia N95's embedded 3-axis STMicroelectronics LIS302DL accelerometer. The Symbian 3rd Edition SDK's Sensor API was used to gather raw sensor data using an interrupt-driven sampling method. The data was filtered using both a digital low-pass filter (LPF) and a high-pass filter (HPF). In figure 1 the raw sensor data gathered from the mobile phone's accelerometer is shown for all the three axes.

A total of 8 gestures with 10 samples per gesture were collected. As the DTW algorithm is essentially a type of template-matching technique, only one training sample per gesture was required for the DTW algorithm to perform the gesture recognition correctly. The 8 gestures used in this study can be observed in figure 2. The gestures used were obtained from a study done by Bailador et al. [12]. The DTW algorithm was able to correctly classify a total of 77 of the 80 samples, for an overall accuracy of 96.25%. The algorithm was optimized [9] for the mobile phone and the recognition time was reduced from around 1000 ms to under 200 ms.

The gesture recognition algorithm was ported to the mobile device by making use of Nokia's Open C platform [13]. Open C is a set of POSIX libraries to enable standard C programming on Symbian Series 60 devices.

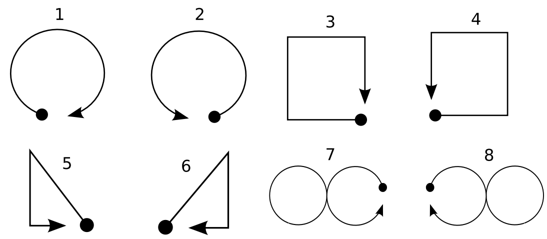


**Figure 2. Gestures used in this study**


**Figure 3. User application running on the mobile device**

A user application was implemented to test the real-world functionality of the gesture recognition algorithm. The user application was developed in the Python programming language and executed on the mobile phone using Nokia's Python for Series 60 (S60) version 1.4.1 utilities [14]. Using Python allows one to rapidly prototype a graphical user interface (GUI) and other functionality by making use of the built-in APIs to provide, for example, sound and graphics capabilities. An example of the user application running on the mobile device is shown in figure 3.

The gesture recognition algorithm (written in C) was linked into the Python program as a dynamically linked library (DLL). Wrapper code was created for the C algorithm in order to link it into the Python program. The user application was converted into a standalone Python program on the Symbian device through the Ensymble developer utilities for Symbian S60 [15]. It can also run as a script in the Python for S60 shell.

To have the system learn a new gesture, the user can select the `New Gesture` command from the pop-up menu. When the user starts moving the phone, the application records the gesture until the phone stops moving. The recorded gesture is then stored as a reference gesture on the phone. To recognize a gesture, the user selects the `Recognize` command from the pop-up menu. The application records the test gesture as soon as the user starts moving the phone. When the device stops moving, the application executes the gesture recognition algorithm and displays the recognized gesture as a graphic on the screen.

Nokia's Python for Series 60 does not provide built-in support for vibro-tactile feedback, but third-party utilities have been developed to overcome this. For Series 60 3rd Edition devices (like the Nokia N95) a third-party module called `misty` provides vibration support, and for Series 60 2nd Edition an earlier package called `miso` was developed. These capabilities will probably be added to the Nokia Python library in future.

Haptic feedback was added to the user application by utilizing the vibro-tactile capabilities of the mobile phone when a gesture is recognized. Visual feedback is provided by displaying a graphic of the gesture on-screen. Auditory feedback was added by having the recognized gesture spoken out loud using the text-to-speech functionality of the Nokia Python Audio API.

Personal media viewers, such as the Myvu Crystal [16], allow for a full-screen mobile viewing experience. When combined with a mobile phone such as the Nokia N95 with an embedded accelerometer, our gesture recognition algorithm and a mobile game, the pervasive mobile gaming system as described in the previous sections becomes possible. The Myvu glasses can be connected to the Nokia N95 via the Nokia AV connector, a 3.5 mm stereo headphone plug.

It is envisioned that personal media viewers such as the Myvu will enable mobile gesture-based gaming opportunities until true see-through head mounted displays become less expensive. With the Myvu video glasses it is possible to look above or below the screen, which allows one to walk around. This makes it possible to use the video glasses for urban gaming, or other applications where the user is required to physically walk around while still wearing the video glasses.

Another possible application would be body mnemonics, an interface design concept for portable devices that uses the body space of the user as an interface [17]. Different body positions may be used as markers to remember computational functionality or information such as phone book entries. For example, the user might move the mobile phone to the shoulder or head to access a specific sub-menu or program on the phone. Continuous audio or tactile feedback relating to the user's motion or gesture trajectories may be provided. It is believed that this kind of tightly coupled control loop will support a user's learning processes and convey a greater sense of being in control of the system [18]. User interfaces or functions can now be logically or emotionally mapped to the user's body, completely changing the perception of interacting with a mobile device.

## CONCLUSION

Gestures can change the way we interact with computers and mobile devices. This is evident in new user interfaces such as the multi-touch interface introduced by the Apple iPhone. The multi-touch interface adds motion gaming capabilities to the iPhone, albeit in a different sense than using accelerometer-based gesture recognition. This paper describes a cost-effective mobile system that can be implemented with readily available hardware and realizable software on a mobile phone. An optimized gesture recognition algorithm that require minimal resources was described and implemented on a mobile phone.

Accelerometer-based techniques have an advantage above camera-based techniques, i.e. that computationally intensive calculations are not required for accurate movement information, as measurements are directly provided by the sensors. Sensor-based techniques also have the advantage in that they can be used in much less constrained conditions and are not reliant on lighting conditions or camera calibration [21].

To provide a more immersive experience, wireless video glasses may be developed that does away with cumbersome cabling. For the video glasses to be connected to a mobile phone, the wireless technologies used will most probably have to be Bluetooth or Wi-Fi, as these technologies are already available in mobile phones. This is an avenue for further exploration, since as of this writing no true wireless video glasses have been developed.

Possible pitfalls for gesture recognition in mobile phones include user acceptability: Will a user feel comfortable waving his or her arms around in a public space? Haptic feedback is also important for user acceptance. The Nintendo Wii, for example, incorporates this by providing both auditory and vibro-tactile feedback when performing a gesture. A user must know the set of gestures that a system recognizes and gestures requiring high precision over a long period of time can cause fatigue. Therefore the gestures must be designed to be simple, natural and consistent. If the gestures prove to be tiring or strenuous, any possibility of altering the user's perceptions will be limited.

When only one accelerometer is used, the accuracy in detecting the various gestures is reduced. With the Nintendo Wii, for example, the basic motions it detects can easily be cheated with partial movement [1], which reduces the immersive perception of a video game. Utilizing multiple accelerometers increases accuracy at additional cost. Adding additional accelerometer-based sensing devices to a mobile gaming system should not be technically complex, as Bluetooth may be used for communicating with the mobile phone.

Location-based games, also known as urban gaming, can utilize a mobile phone's GPS receiver to provide a realistic, augmented reality-type gaming experience. This may be combined with the methods described in this paper to improve even further on the alteration and modification of the user's perceptions. Hand gestures can also be used in 3D virtual environments to provide a more natural and immersive user experience [2], truly altering users' perceptions in viewing and experiencing their environment.

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# CREATION OF SYMPATHETIC MEDIA CONTENT

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### ABSTRACT
Taking ground in the *enactive view*, a recent trend in cognitive science, we propose a framework for the creation of sympathetic media content. The notion of sympathetic media content is based on two concepts: synesthetic media and empathic media transmission.
Synesthetic media is media that make use of multiple and alternative senses. The approach is to reconsider traditional media content from a different perceptual point of view with the goal of creating more immersive and affective media content. Empathic media transmission will consist in encoding the emotional content of media into multi-sensory signals. The encoded emotions are then mediated to the audience through actuators that provide the physical manifestation of the multi-sensory information.
The two points, synesthetic media and empathic transmission, are addressed through the study of the relation between senses and emotions and the development of suitable methods for encoding emotions into multiple senses, in the frame of an efficacious transmission of emotions to the audience. The extraction of emotional information from media and the conception of a wearable, unobtrusive device are considered too. It is claimed that such a framework will help the creation of a new type of media content, ease the access to more immersive and affective media, and find applications in numerous fields.

### Author Keywords
media, enaction, emotion, sensors, perception, senses

### ACM Classification Keywords
H.5.1 Multimedia Information Systems — Artificial, augmented, and virtual realities,
H.5.2 User Interfaces — User/Machine Systems

### INTRODUCTION
An emerging trend in cognitive science is the *enactive view* [6, 7] of sensorimotor knowledge. In this approach, perceiving is to understand how sensory stimulation varies as we act. In particular it implies the *common coding theory* [8]: actions are coded in terms of the perceivable effects they should generate. More in detail, when an effect is intended, the movement that produces this effect as perceptual input is automatically activated, because actions and their effects are stored in a common representational domain.



The underlying process is the following [9, 10]: first, common event representations become activated by the perceptual input; then, there is an automatic activation of the motor codes attached to these event representations; finally, the activation of the motor codes results in a prediction of the action results in terms of expected perceptual events. The enactive view and its corollaries support the concepts of:

- Synesthetic media,
- Empathic media transmission.

After a detailed definition of the new notion of sympathetic media as synesthetic media combined to an empathic transmission, its practical implementation is discussed. Namely, the way to encode emotions and to transmit them through multi-sensory channels is presented as well as the design of a device to achieve this aim.

### DEFINITION OF SYMPATHETIC MEDIA
Sympathetic media is the combination of synesthetic media and empathic transmission.
**Synesthetic Media:**
In cognitive science, synesthesia (Greek, syn = together + aisthesis = perception) is the involuntary physical experience of a cross-modal association. That is, the stimulation of one sensory modality reliably causes a perception in one or more different senses. Specifically it denotes the rare capacity to hear colors, taste shapes, or experience other equally startling sensory blendings whose quality seems difficult for most of us to imagine. A synesthete might describe the color, shape, and flavor of someone's voice, or seeing the color red, a synesthete might detect the "scent" of red as well. Transmission of emotions (for an enactive view on emotions, see [11]; on vision, see [12]), tones, moods or feelings intrinsically contained in media or that a creator intends to transmit via a media to an audience relies heavily on only two senses, the audition (music or speech) and the vision (images or text). On the contrary, human communication relies on a wide range of senses. Moreover, this reliance on only two senses fails in some cases to convey sufficient information to break cultural barriers or to reach audiences with sensory disabilities. The efficiency of information transmission, including emotions [13], can be limited due to an overloading of the visual and aural channels, for example by textual information such as subtitles that is perceived through vision and imply a cognitive effort. The idea of using alternative sensory channels to create more immersive, affective or realistic context and content for the audience is not new,

especially in the fields of Ambient Intelligence [14], Immersive, Perceptual or Affective Computing [15], and Human-Computer Interaction [16]. To take an example, most Virtual Reality (VR) rooms include several kinds of sensory outputs (wind [17], scent, force, haptic or temperature [18]) other than vision or audition. Nonetheless, most of these works remain not easily accessible to audiences. Either because of their bulky nature (dedicated spaces for VR) or because there is no seamless integration of the extra sensory information in the media that contains them. Moreover, these works are mostly dedicated, and somehow limited, to re-create perceptual sensations identical to the ones that are virtually embedded in a media (for example, the vibration of some game controllers for simulating shocks). Few works try to reconsider a given media [19] from a totally different perceptual point of view.

**Empathic Media Transmission:**
In cognitive science empathy is the recognition and understanding of the states of mind, beliefs, desires, and particularly, emotions of others. It is often characterized as the ability to "put oneself into another's shoes", or experiencing the outlook or emotions of another being within oneself; a sort of emotional resonance. For instance, if an observer sees another person who is sad and in response feels sad, that individual is experiencing empathy. Empathy can occur in response to cues of positive emotion as well as negative emotion. To qualify as empathy, the empathizer must recognize, at least on some level, that the emotion she or he is experiencing is a reflection of the other's emotional, psychological, or physical state. In addition to widen the sensory bandwidth, it is necessary to develop empathic media transmission, able to embed emotional cues in sensory-based coding of perceived events. The encoding is done directly into the physical expression of these additional senses by using suitable actuators integrated in a wearable, non-intrusive device. The audience who receives this multi-sensory information through the device and is thus in a state of partial sensorimotor immersion, will decode it for inducing emotions that ought to be identical to the emotions the creator of the media content intended to transmit.

Thanks to the synesthetic property of the newly defined media, and the empathic transmission of emotions that are contained in media, a more emotional link between the media and the audience is created. This is something already achieved for example in cinema through the background music or visual clues. The goal here is to improve the empathic relation to the media. How much this empathic link can be reinforced without breaking the duality audience / media is an interesting subject going beyond the scope of this presentation.

## SENSES TO EMOTIONS

Following our definition of sympathetic media as a combination of synesthetic media and empathic transmission the translation / encoding of virtual emotional information into real / physical sensory information transmitted to the audience through actuators must be addressed. Two ways are proposed.

The first way to adress the problem of inducing emotions into the audience, is by extending the classical approach. This is done by adding sensory channels to the already present ones, usually sound and image. The relation of senses to emotions is studied for determining the most efficient ways to induce emotions from multi-sensory content. This includes the study of the attainable richness that a given sense or combination of senses can provide to encode virtual emotional content embedded in media content.

The second way to achieve the transmission of emotions is based on the enactive view and is thus favored. The method is to induce the emotional cause from its physiological consequences as perceived by the experiencing person. There is some evidence that this afferent feedback can modulate emotions (this is at the basis of the somatic-marker hypothesis [4] as well as the facial feedback hypothesis [1]). For example, a person experiencing stress or shame might have the feeling of a rise of the temperature. In the right context, rising effectively the temperature might help to induce the intended emotions, here stress or shame. Another technique is to use actuators to divert attention or generate subtle changes of emotional disposition [3]. Techniques such as surveys might help for this study by determining the best sensory channels and types of signals to use for inducing given emotions, with in mind works in cognitive science (enactive view), psychology and physiology.

To better see the difference in these two approaches, that are not exclusive, a second example is proposed. An emotion like sadness could be induced through visual (in a movie, dark atmosphere, rain, faces of the actors, etc...) and auditory (use of a certain type of music) clues. This is the classical approach. Sadness might be induced too by, for example, lowering the temperature and exercising slight pressures at appropriate locations on the body of the audience. While it can be argue that the first approach is already doing a good job at transmitting emotions, even without widening the sensory bandwidth; the second approach might be used in case of the absence of given sensory channels (for example, a radio program), the absence of a right context (looking at a movie on a portable device) or for audience with sensory disabilities.

## SOFT AND HARDWARE FOR SYMPATHETIC MEDIATION

Existing media can be manually annotated or the emotions being automatically extracted. Given the difficulty to automatically extract emotional content from a given media, especially in the case of real-time applications, manual encoding will the first step in the creation of sympathetic media. Emotional tags could be considered to annotate the media in a way quite similar to the subtitles tracks on a DVD. An encoding module must be developed that encodes emotions to senses thanks to sets of rules and algorithms.

The hardware can be separated into two elements. One that supports the processing unit (notably the encoding module) and a transmitter and is interfaced with the media. This first element communicates with a second element that is a wearable device constituted of a receiver and the actuators. For this hardware part, we propose to design and conceive a wearable [22], unobtrusive, non-invasive, multi-actuators device, that will bring sympathetic media into homes in a similar way new technologies have brought cinema into

homes through the Home Cinema.
Assessment of available actuators that can serve our purpose of providing relevant and efficient physical sensations and of being integrated in a wearable device will be conducted. As a first step, only actuators that act in non-invasive and external fashion relative to the human body will be considered. These actuators are, for example, actuators that can induce the following perceptual inputs: vibration, pressure, temperature, touch,... All these actuators act through the skin. Non-invasive actuators that act on internal organs of the human body (such as the galvanic vestibular simulation [20, 21]) will not be considered here but their existence will be discussed.
The design itself is another concern that can nonetheless be eluded at this stage. This device will contain a minimum of processing parts, except what is necessary for wirelessly communicating with the encoding module and for sending the received signals to the actuators. Because the actuators are non-invasive, the device which main function is to support these actuators will be non-invasive too. Nonetheless, most of the actuators are contact actuators and act through the skin. It implies that the device will be somehow attached to the body. For limiting the invasive feeling, the device will be for example designed as an armband. The future addition of other types of actuators will certainly lead to a reconsideration of the design, including location on the body.

## FUTURE WORKS

Three types of future improvements can be foreseen.

- At the level of the senses in relation with the actuators. The progress in cognitive science and in nanotechnology make possible to think of new types of actuators that will be able to directly act on the brain of the audience without necessarily being invasive, and even directly induce emotions through electromagnetic signals [5], [2]. It should be noted that even in this case, encoding is necessary and that this type of brain stimulations can be somehow considered as a sense. Such actuators will inevitably rise ethical questions. At the same time, it opens the door to more immersive and affective virtual communication or experience.

- At the level of the emotions through their automatic extraction. The progresses in computing power, cognitive science, psychology, or semiotics makes us think that both the understanding of how emotions are induced and how to extract them automatically from media content will improve. The outcome of these advances will be useful to the future of this research.

- By implementing a mirror function to the whole system. The proposed system is aimed at transmitting emotions from a media to an audience. By adding sensors to the wearable device that could monitor the emotional state of the audience, a bi-directional empathic communication could take place with the possibility of interacting with the media. The media could "react" to the emotional feedback of the audience.


## ACKNOWLEDGEMENTS

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# Aural Antennae

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**ABSTRACT**
Aural Antennae are portable devices which translate sound impulses into vibrotactile stimulus. By swapping audio sensation for haptic sensation we illustrate one variety of artificial synesthesia. The compact devices can be worn to act as electronic travel aids for the hearing-impaired or used for augmented reality applications. Using a simple model of the audio scene's background noise, the device triggers when there is a large change in sound intensity from a specific direction.

**Author Keywords**
augmented reality, haptics, sensory substitution, hearing aids

**ACM Classification Keywords**
H.5.2 Haptic I/O
H.5.5 Sound and Music Computing
B.4.2 Input/Output Devices

## ARTIFICIAL ANTENNAE

Suppose for a moment that your body was covered with several extremely long antennae. Like an insect, you use these antennae to probe about space, tapping and feeling the world that surrounds you.

For some, such a scenario is just a much-reduced plot of a Kafka story. However, we view this scenario in another light; our research group is preoccupied with how the precepts can be transformed to reproduce atypical experiences. We find motivation to create sensation similar to what the antenna-endowed insect feels.

Indeed, there are some surprising upshots to having antenna. It has been observed, for instance that cockroaches "use their antennae to detect a wall and maintain a constant distance" [2]. Antenna and cilia provide a variety of tactile spatial awareness. Some crude televised experiments with house cats and duct tape also show that felines use their hair to modify their gait and assess the space surrounding them [9].

Now suppose that you were covered with antennae which could pick up and localize minute aural signals. What would it be like to feel higher frequency audio signals in a manner to similar to how we already feel low-frequency bass?



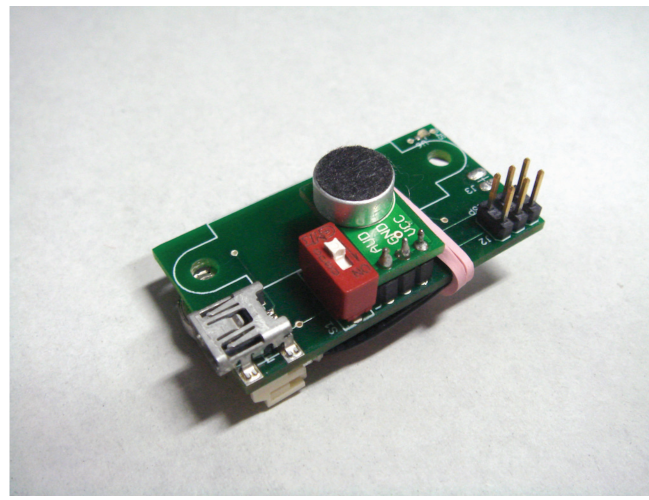

**Figure 1. An Aural Antenna converts a signal from an electret microphone into vibrotactile stimulus.**

## HEARING IMPAIRMENT AND PROSTHESES

The Tadoma or Hofgaard method is a simple technique where those suffering from hearing loss feel the movements of a speaker by touching the parts of the face and neck used in speech production [17]. It has been used since the 1890s as a method for speech-reading [14].

As early as 1936, Gault discussed "hearing through the skin" and worked to develop mechanical apparatus for sound localization [7]. The development of vocoding techniques in the 1940s in turn spurred a variety of haptic audio systems modified to provide haptic stimulus at various loci on the body [17]. By the 1980s, wearable systems were constructed in which "speech sound generates a characteristic tactile pattern that observers can learn to identify" [20].

Wearable auditory systems gave way to implantables which were capable of "direct electrical activation of the auditory nerve" [24]. Further information about the neural basis of audition has been provided by studies of macaque monkeys using fMRI giving evidence integration of tactile and audio stimuli in the auditory cortex [11].

## TRANSFORMATION OF PERCEPTION

Portable electro-mechanical systems make possible the creation of pattern converters or intermediaries that sit between our sense organs and the real world. The somatic nervous system, reflex arcs, and even muscles are organs whose artificial stimulation allows the transformation of perception.

That electrical activity has the ability to interact with the human percepts has been long known: "In his 1820 dissertation, Bohemian physiologist Johann Purkyne reported that a galvanic current flowing through the head upset balance and equilibrium" [6]. This technique has recently been employed by researchers who have built wearable devices to alter sense of balance as well as provide a "virtual sense of acceleration" [13].

Cutaneous rabbit illusion is an interesting perceptual illusion in which a series of taps produced by actuators at discrete locations feel as if they are interspersed between the actuators under particular timing conditions [8]. This phenomena has been exploited by a variety of haptic devices to provide stimulation in areas between actuators. For instance a 3 x 3 "rabbit" display composed of vibrator was used to communicate directional cues [22].

Another phenomena which has been exploited to transform perception is that of sensory substitution. Early attempts looked at using vibrating stimulators to convey visual pictures using an array built into a dental chair [1]. Experiments showed that visually impaired participants could "learn to recognize ... the layout of objects on a table in depth and in correct relationship."

Synesthesia (literally: joining of perception) has been induced in humans using a variety of methods, including electrical stimulation [5]. Less invasively, it may also be simulated through the use of devices which map the information of one senses onto another. This is the case with Fingersight devices, including one that allows wearers to feel optical edges as oscillations of a solenoid mounted above the fingertip [21].

We have developed a number of systems that seek to augment the percepts and specifically make use of the body or reflexes as part of interaction [18]. Earlier work on laser-based tracking systems [15] led us to think of how optical based information might be felt by users, which led us to radar and antennae as metaphors for interaction.

## HAPTIC ANTENNAE

We began to experiment with the concept of artificial antennae as part of device illustrating another concept: Haptic Radar [4]. This is a project that seeks to augment spatial awareness by creating radar out of sensors which act to extend the range of touch for the skin.

As most humans have a copious amount of hair located on their head (at least at some point in their life), and our heads are something we wish to protect, we reasoned a headband device would be a good first form factor to test.

We devised a system linking pairs of infrared rangefinders to motor vibrators into a circular arrangement. An earlier paper, Augmenting spatial awareness with Haptic Radar, details experimental results concerning the Haptic Radar. Most saliently, we found that 86% of untrained participants could use the system to move to avoid objects they could not see [3].

Following these initial experiments, we began a redesign with the aim to make individual, compact, Haptic Antenna. To replace the Arduino board, we selected an ATMEL ATtiny13 RISC microcontroller for its compact size (4 mm x 4mm). The process of reading from infrared rangefinder and controlling a vibrating motor requires a minimum of computational resources so this 8-bit microcontroller operating at 20 MHz is adequate.

After recreating and testing the system on breadboard, we added a 100 milliampere-hour lithium-ion polymer battery as well as charging circuitry. After testing this through-hole technology circuit, we designed and fabricated a surface-mount technology printed circuit board (using the freely available Eagle printed circuit board CAD software.)

After further testing and circuit board revisions, we have arrived at a Haptic Antenna in a much more portable instantiation. The device melds a microcontroller, infrared rangefinder, motor-vibrator (a common part in portable phones), battery and electronics. Altogether, these components occupy 25 $cm^3$, which is a factor of 34 times smaller than the previous version's electronic system.

## AURAL ANTENNAE

During this process we came to ask ourselves: what if people felt directional sound as opposed to distance information? Imagine that a car is honking behind you but that you cannot hear it because of a hearing impairment or environmental noise. Now imagine that the honking could be felt on the body at the location nearest to the car's horn.

As a starting point to test this concept we have been building prototype audio-to-touch sensory substitution devices. Aural Antennae are compact, worn modules which produce vibrotactile stimulus in response to audio signals emanating from a particular direction.

### Principle of Operation

Our current prototype builds upon the precious Haptic Antennae platform. Instead of a range finder, we attach a daughter board containing an electret microphone, conditioning resistors and capacitors as well as an OPA344 operational amplifier configured with a gain of $G = 100$.

The analog voltage output of the amplifier is digitized using the ATtiny's internal 10 bit analog to digital converter. The microcontroller's firmware samples the microphone at approximately $f_s = 9000Hz$.

After each sample, the microcontroller computes a simple moving average ($SMA$) over the previous $k = 10$ samples (1). The absolute difference ($\delta$) is then computed between the current sample $s_t$ and $SMA$ (2).

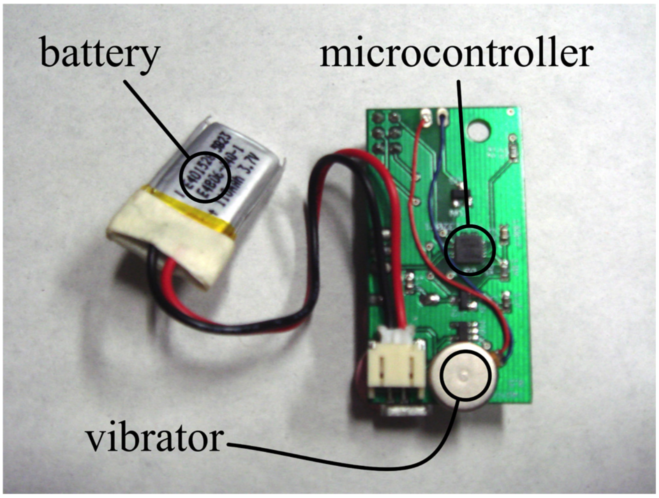


**Figure 2. An Aural Antenna module incorporating lithium-ion polymer battery, 20 MHz, 8-bit microcontroller, and vibrotactile motor.**

$$SMA = \frac{s_t + s_{t-1} + \cdots + s_{t-(k-1)}}{k} \quad (1)$$

$$\delta = |s_t - SMA| \quad (2)$$

If $\delta$ is greater than $\frac{2^{10}}{10}$ (10% of the dynamic range of the analog to digital converter), then the vibrator is activated with 100% duty cycle until the next sample is processed. This moving average works as an extremely rudimentary adaptive background noise filter. The vibrating motor is controlled by a MOSFET transistor whose gate is tied to a digital output pin of the ATtiny microcontroller.

Our initial experiments with Haptic Antennae indicated that blindfolded participants readily interpreted the vibrotactile stimulus and associate it with approaching objects. We expect that similar phenomena will be observed in forthcoming experiments with the aural antennae.

The device exploits our innate ability to process (in a parallel manner) haptic stimulus applied to skin or the Vellus hair which covers most areas of our bodies. Other recent work on electronic travel aids [16] as well as the use of vibrotactile cuing in virtual environments [12] make use of this phenomena. Experiments have also documented that strong haptic stimulus can induce a startle reflex [25], which may be useful in emergency situations.

## EXTENSIONS

While independent modules may be worn simultaneously, when networked together the augmentations provided by the devices would be greatly enhanced. We are in the process of evaluating low-power wireless chips such as Zigbee to incorporate into the modules. We anticipate that wireless antennae would be able to work together to provide "rabbit" perceptual illusions of motion between the actuators.

Making use of shotgun-type microphones has improved the directionality of our initial prototype. The use of laser-microphones might increase range significantly. With network capabilities we could create a worn antenna array capable of sound localization using time-of-arrival.

One can imagine a type of wearable simultaneous localization and mapping (SLAM) system. This could be a fusion of antenna-array sound localization and laser ranging and detection (LADAR). Such a system might use a Bayesian network to estimate object location based on data provided by both audio and optical sensing systems.

Another extension of this work is in the area of actuation. The "pancake" style vibration motor we are using (KOTL C1030B028F) has the advantage of being compact, but presents substantial initial friction which makes response somewhat limited. Other researchers have reported on the use of air puffs and acoustic cues to elicit startles [23]. Still other researchers have thoroughly investigated using electrical stimulation to provide haptic cues [10].

## AS OTHER SPECIES HEAR

We have developed an example of aural antennae which provide haptic feedback. Often thinking about haptic devices is constrained by our experience of our existing senses. We have instead sought to break with this convention by seeking to emulate insect perception.

Thinking more openly, we can imagine a myriad of new biomimetic ways of seeing the world. Compound eyes and ocellus suggest worn garments that have thousands of cameras. Mimicry of insect's abilities to acutely detect subtle vibrations [19] and act on this information could lead to extension of touch in the manner that optics have extended the sight.

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# Learn Traffic State Based on Cooperative Localization

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**ABSTRACT**

A key problem of monitoring the traffic state is the localization and tracking of vehicles and passengers. In this paper, we present a new cooperative localization technique which makes use of collaboration of mobile phones for traffic monitoring. Instead of relying on the signal strength only, our cooperative localization approach utilizes additional connection information among mobile phones to improve the localization accuracy. It separates mobile phones into different clusters by some short-range links such as Bluetooth, then locates the members in a cluster simultaneously. We design a simulation experiment and the results show that our method is able to catch the main trace of all the members in a cluster. In this way, the traffic flows can be monitored.

**Author Keywords**

Traffic monitoring, Cooperative localization, Wi-Fi networks

**ACM Classification Keywords**

H.5.3 [Information Interfaces and Presentation (e.g., HCI)]: Group and Organization Interfaces - Collaborative computing

## INTRODUCTION

In modern society, the demand for traffic monitoring systems that can detect position, velocity, density, and flow rate in a street is increasing. Traditional monitoring approaches include GPS, video monitoring etc. However, GPS as a standalone system is not sufficient for an increasing number of transport applications due to limited visibility to the satellites within the urban canyons. Video monitoring is able to record the whole traffic state, but it takes large human efforts to analyze the traffic data. Since the prevalence of mobile phones, cellular networks are once under consideration for user localization. But the low localization accuracy of a few hundred meters makes it not practical in real world.

Recent years, Wi-Fi is popular around the world. Many cities carry out 'Wi-Fi City' projects to implement large-scale coverage, especially in the important streets. Wi-Fi based localization gets an accuracy of about 20 meters outside. As more and more mobile phones are equipped with wireless cards that can receive Wi-Fi signals, it is possible to monitor the traffic state by Wi-Fi networks. A mobile phone receives Wi-Fi signals from several access points (APs) and the signal strength implies the distance from the mobile phone to APs. There are various methods to determine the mobile phone location according to the signal strength, which we will discuss later. However, due to the noisy and fluctuant characteristics of Wi-Fi signals, the location estimation by a single mobile phone may be rather biased. Although some filters such as [3] are advised for smoothing, the results seem not apparently improved in some bad situations.

In this paper, we propose a novel cooperative localization in Wi-Fi based networks, which makes use of collaboration of mobile phones to learn the traffic state. As far as we know, this concept is completely new in Wi-Fi based localization domain. In the traditional non-cooperative scenario, a mobile phone infers the location only from its own received Wi-Fi signals. While in a cooperative scenario, several mobile phones nearby are combined in a cluster by some short-range links to determine locations simultaneously. For example, Bluetooth, which is commonly used on mobile phones can be used to detect the other devices in a short range (usually $10 \sim 20$ meters). The devices within the valid range is considered as a cluster. The mobile phones in the same cluster can exchange data about their traces. Although each single trace may be inaccurate, it is more likely to find a reliable trace of the cluster by integrating the trace information together. Figure 1 illuminates such a scenario. In addition to signal strength, connectivity information or distance measurements among phones in a same cluster are utilized to improve localization accuracy. One problem with the cluster is that the cluster members are dynamic due to their mobilities and it has to be updated periodically.

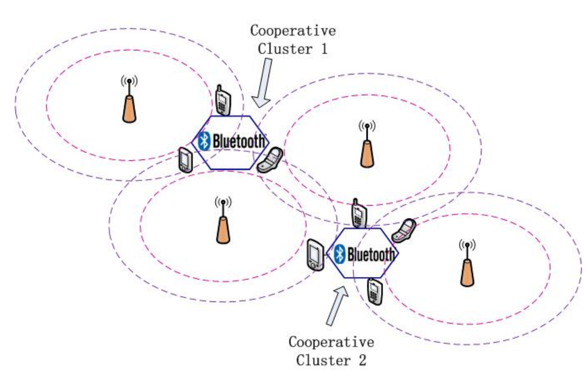



**Figure 1. The cooperative localization scenario in Wi-Fi networks.**

## RELATED WORK

Let us consider the localization problem in the similar fields such as robots and wireless sensor networks. The robots also interact with the environment and each other through imperfect sensor measurements corrupted by noise. Consequently, the concept of cooperative localization is introduced, where groups of robots combine sensor measurements to implement cooperative localization. [8] demonstrates the utility of introducing a second robot to aid in the tracking of the exploratory robot's position.

In wireless sensor networks, cooperative localization uses connectivity information (such as who is within the communication range of whom or estimated distances between neighbors) to derive the locations of the nodes in the network. [10] first builds a relative map through a multidimensional scaling, then with three or more anchor nodes, the relative map can be transformed and absolute coordinates of all the nodes are computed.

[5] proposes a cooperative positioning technique by utilizing the additional information obtained from short-range links like WiMAX/Wi-Fi to enhance the location estimation accuracy in cellular networks. However, it just fuses these two kinds of signals together and its cooperative positioning refers to fusion of different sensor data.

## WI-FI BASED LOCALIZATION METHODS

In general, Wi-Fi based localization research can be classified into two main categories: deterministic techniques and probabilistic techniques.

Deterministic techniques [1], [6], [2] use deterministic inference methods to estimate a user's location. The RADAR system developed by Microsoft Research [1] proposes nearest-neighbor heuristics and triangulation methods to infer a user's location. It maintains a radio map which tabulates the signal strength received from different access points at selected locations. Each signal-strength measurement is then compared against the radio map and the coordinates of the best matches are averaged to give the location estimation. The accuracy of RADAR is about three meters with 50 percent probability. The LANDMARC system [6] exploits the idea of reference points to alleviate the effects caused by the fluctuation of RFID signal strength. The accuracy is roughly one to three meters. However, the placement of reference tags should be carefully designed since it has a significant effect on the performance of the system. Moveover, the RFID readers are so expensive that it is infeasible for localization in a large area. In [2], an online procedure based on feedback from users was employed to correct the location estimation of the system.

Another branch of research is the probabilistic techniques [9], [11], [4] which construct a conditional probability distribution over locations in the environment of interest. In [4], Ladd et al. use probabilistic inference methods for localization. They first use Bayesian inference to compute the conditional probability over locations, based on received signal-strength measurements from nine access points in the environment. Then, a postprocessing step, which utilizes the spatial constraints of a user's movement trajectories, is used to refine the location estimation and reject the results with significant change in the location space. Depending on whether the postprocessing step is used or not, the accuracy of this method is 83 or 77 percent within 1.5 meters. In addition, Roos et al. [9] compare the performance of the non probabilistic nearest-neighbor method with that of two probabilistic approaches. The results show that the two probabilistic approaches produce better results than the nearest-neighbor method and the average location estimation error is below two meters. Furthermore, the time-series analysis technique [11] was introduced to study the correlation among consecutive samples received from the same access point over time. The authors reported that better accuracy can be achieved by taking such correlation into account.

Since Hidden Markov Model (HMM) can utilize both single samples and user trajectories in the form of sequential knowledge [4], we adopt it to solve the tracking problems. HMM is used to model the user traces by treating physical locations as hidden states and the signal strength measurements as observations. Each user trace is denoted as $T = \{l_1, l_2, ..., l_n\}$ and $l_i = (x_i, y_i)$ is considered as a discrete physical location with $x$ and $y$ coordinates. $O = \{o_1, o_2, ..., o_n\}$ is defined as observation space and $o_j = \{s_1, s_2, ..., s_m)$ is a set of signal strength measurements from $m$ different access points. In this way an HMM can be defined as a quintuple $(T, O, \lambda, A, \pi)$, where $\lambda$ is prior probability of signal distribution. $T, O, \lambda$ can be learned from some collected traces. Transition matrix $A$ describes how a person travels through the state space, which is constrained by physical locations and mobile velocity. $\pi$ is an initial location-state distribution encoding where the user initially may be. Generally, it is set by a uniform distribution if there is no prior knowledge about user locations. In the online localization phase, given an observed signal sequence $\widetilde{O} = \{\widetilde{o_1}, \widetilde{o_2}, ..., \widetilde{o_n}\}$, the well-known Viterbi algorithm [7] can be used to infer the most probable physical space sequence $\widetilde{T}$.

## COOPERATIVE LOCALIZATION

In a cooperative scenario, not a single but a group of mobile phones determines their locations together. The primary discrimination of the group is that each member is close to others and has a similar direction of movement. We call this group a *Cooperative Cluster*, as shown in Fig.1. The members in the same cluster communicate and exchange data with each other. Then the integrated information can be used to improve respective localization results since more constraints are added. In traffic flow monitoring, overall trends is focused on rather than single trace of each vehicle. While in a large-scale area, the distance between nearby mobile phones can be ignored. That's to say, each member in a cluster shares a similar trace, which represents most of the members' trends. We will mainly discuss the solution to this problem in the following part.

The discrimination of cooperative clusters depends on links that have shorter range such as Bluetooth, UWB, Zigbee.

Mobile phones within the range for a while are considered to have similar behaviors and can form a cooperative cluster. We prefer Bluetooth because its prevalence on mobile phones. Bluetooth is a standard and communications protocol primarily designed for low power consumption with a short range in each device. It enables these devices to communicate with each other when they are in range. Maximum permitted power of about $2.5mW$ can cover an area of circle with a radius of about 10 meters. Therefore, we use Bluetooth to detect whether the mobile phones are in a same cooperative cluster or not. The request to keep in touch with each other for a while guarantees the same direction of movement, and it does not make sense if mobile phones pass by toward the contrary direction.

After cooperative clusters have been divided, we predict the direction of each cluster using the integrated information gathered from members of the cluster. Suppose there are $n$ members in a cluster in a time period $t_1$ to $t_p$, indicated by $\{M_1, M_2, ..., M_n\}$. We apply the HMM method introduced ahead on each member $M_i$ separately to get a trace $T_i = \{l_1^{(i)}, l_2^{(i)}, ..., l_p^{(i)}\}, i = 1, 2, ..., n$. We propose a Trace Least Square (TLS) algorithm to find the optimized trace $T_c = \{l_1^{(c)}, l_2^{(c)}, ..., l_p^{(c)}\}$ of the cluster. TLS addresses to the following optimization problem:

$$\arg\min_{T_c} \sum_{i=1}^{n}\sum_{j=1}^{p}(l_j^{(c)} - l_j^{(i)})^2 + \sum_{j=2}^{p}(l_j^{(c)} - l_{j-1}^{(c)})^2 \qquad (1)$$

The first term penalizes the discrepancy between $T_c$ and $T_i$, and the second term keeps $T_c$ as smooth as possible.

However, this optimization is unsolvable due to $p$ parameters in all. Consider the trace information is time dependable, we break it into single time period and it is equivalent to:

$$\begin{cases} \arg\min_{l_j^{(c)}} \sum_{i=1}^{n}(l_j^{(c)} - l_j^{(i)})^2 & \text{if } j = 1 \\ \arg\min_{l_j^{(c)}} \sum_{i=1}^{n}(l_j^{(c)} - l_j^{(i)})^2 + (l_j^{(c)} - l_{j-1}^{(c)})^2 & \text{if } j > 1 \end{cases} \qquad (2)$$

It can be explained that the location at $t_1$ is decided by all $l_1^i, i = 1, 2, ..., n$, and the location at $t_j, 1 < j \leq p$ is depended on not only all $l_j^i, i = 1, 2, ..., n$ but also the location at $t_{j-1}$. Therefore, the optimization is easily solved and we get:

$$l_j^{(c)} = \begin{cases} \frac{1}{n}\sum_{i=1}^{n} l_j^{(i)} & \text{if } j = 1 \\ \frac{1}{n+1}(\sum_{i=1}^{n} l_j^{(i)} + l_{j-1}^{(c)}) & \text{if } j > 1 \end{cases} \qquad (3)$$

All the members in a cluster can be represented by the trace $T_c$. The work flow of the algorithm is prescribed in Fig.2. As mobile phones are not static, the clusters need to be updated periodically. Therefore, the overall algorithm is in a circulation.

## SIMULATION EXPERIMENTS

To evaluate the performance of cooperative localization, we make a simulation experiment in an indoor environment. A Wi-Fi wireless environment is established on the 3rd floor of our academic building, with an area of about $30m \times 15m$. The whole layout of the test-bed is shown in Fig.3, and 5 TENDA APs are deployed around. We choose the hallway to simulate a street, and two persons take different mobile phones to represent the passengers. One mobile phone is an O2 Xda Atom Life smartphone and the other one is a Nokia N95, both with Bluetooth and Wi-Fi wireless cards.

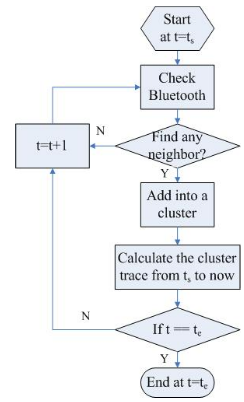



**Figure 2. The work flow of cooperative localization.**

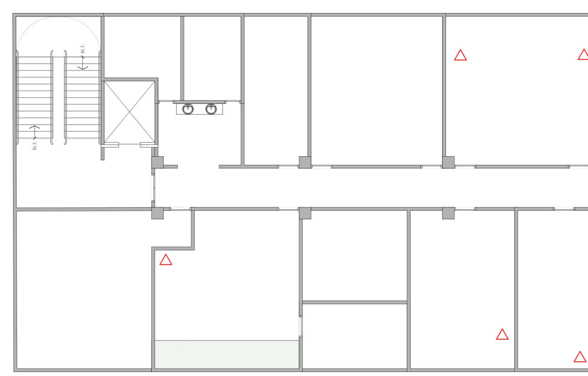
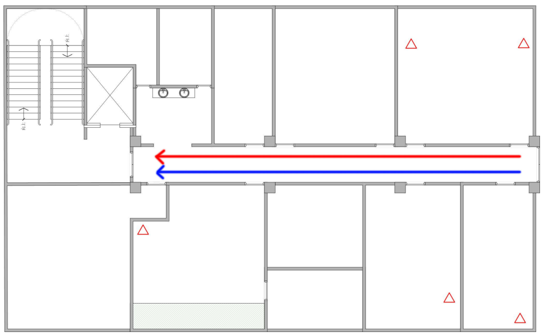


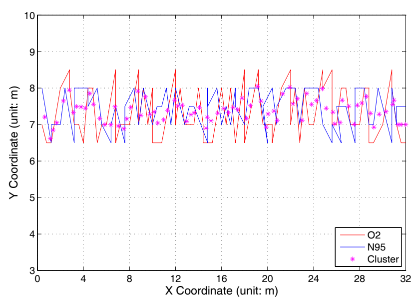
**Figure 3. The whole layout of the test-bed.**

We design two different traces to simulate the traffic state. The first one is that these two persons go straight forward side by side, as shown in Fig.4(a). The red line denotes the actual trace of the person with O2, and the blue one is with N95. As they are always in the Bluetooth range, they are considered to be in a cluster. We apply our cooperative localization to track each one separately and the cluster also. The tracking traces and the cluster trace are illustrated in Fig.4(b). It is obvious that the tracking traces got by one mobile phone separately are quite fluctuant, although we have given geographic constraints in the HMM models. However, the cluster trace reflects a more smooth trace that represents the overall trend of members. It can be inferred that our cooperative localization can catch a group of traffic objects that have similar behaviors.

The second trace we design is one person (with N95) turns into a room halfway as shown in Fig.5(a). After they get

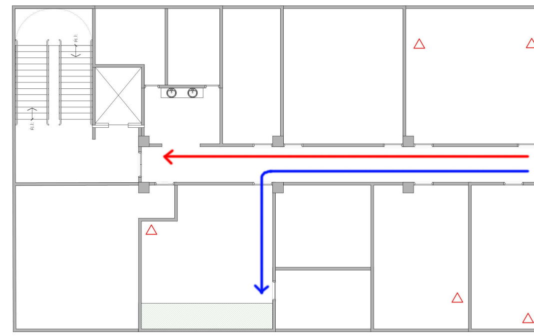


(a) Actual traces.

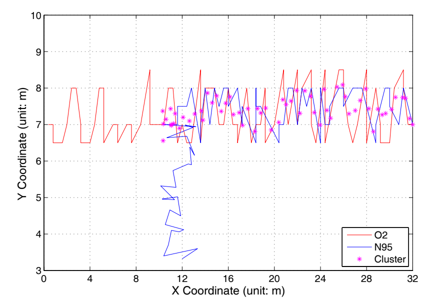



(b) Tracking traces and cluster trace.

**Figure 4. Two persons go straight forward side by side.**



(a) Actual traces.




(b) Tracking traces and cluster trace.

**Figure 5. One person turns apart halfway.**

apart from each other, the Bluetooth signals are blocked by the wall and these two mobile phones can not get in touch again. Figure 5(b) presents the tracking result of this trace. Each single trace is still rough due to the noisy signals while the cluster trace is relatively smooth. Moreover, as the two phones exceed the range of Bluetooth, the cluster is broken up and the cluster trace stops at the turning point accordingly. It indicates that our cooperative localization can divide the mobile phones into exact clusters, make sure the members in a cluster have similar mobile trends.

## CONCLUSION AND FUTURE WORK

In this paper, we originally propose a new cooperative localization technique in Wi-Fi based networks to learn traffic state. Unlike the cooperative localization in robots and wireless sensor networks, our cooperative localization makes use of collaboration of mobile phones to separate them into different clusters. Then their behaviors can be represented by the cluster trace. We simulate it in wireless environment and the simulation results show the effectiveness. In the future, we will make actual traffic experiments and improvement on the algorithms further.

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# Spatial coverage vs. sensorial fidelity in VR

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**ABSTRACT**
With this paper we wish to promote a discussion about the different forms that an immersive VR system can take. This will be done by reflecting on a controversial concept: that of a totally immersive (understood as multimodal) but partial (understood as limited to a part of the body) virtual reality interface. The proposed concept of total/partial immersiveness may be seen as a new orthogonal dimension in the taxonomic classification of systems in the 'virtuality continuum' introduced in [2]. An interesting aspect of the proposed configuration is the possibility for it to be wearable. We will briefly describe the motivation for this new taxonomic dimension from a theoretical point of view, as well as explain the practical reasons that lead us to this concept. This will be done by discussing earlier work from one of the authors that illustrates the possibilities of a total immersive VR system but also pinpoints a number of inescapable limitations.

**Author Keywords**
virtual reality, immersive system, multi-modal, haptic

**ACM Classification Keywords**
H.5.1 Multimedia Information Systems — Artificial, augmented, and virtual realities,
H.5.2 User Interfaces — Haptic I/O

**INTRODUCTION**
Since the sixties and pioneered by the Sensorama simulator (a multimodal system created by Morton Heilig in 1962 [3]), lots of immersive systems were developed with different technologies and goals in mind. The main driving force was perhaps the entertainment industry with its clear goal of immersing the user as much as possible in a simulated environment governed by laws and rules of a specific gameplay. In this context, total immersion could be contemplated as the Holy Grail of Virtual Reality since it would afford the gamer to forget for a moment the (physical or social) constraints of the real world. However, researchers on the emerging field of Virtual Reality kept innovating with other goals in mind such as developing systems for training, learning, medical therapy and data visualization. Anticipating the development of highly immersion-capable technology, it appeared relevant to answer the question of how much immersion was going to be really necessary to succeed in each and all of these goals. Unsurprisingly, it turns out that the answer is extremely dependent on each particular goal. Moreover, it soon became clear that the sense of subjective *presence* in a virtual environment does not necessarily account for the level of objective sensorial *immersion* [4]. It may even be the case that immersion in an almost (but not completely) perfect simulation would provoke the user to distantiate himself from the rendered environment (there may be an 'uncanny valley' [1] for artificial *reality* as a whole, not just with respect to realistic humanoid robots). In an effort to clarify the relation between immersion and presence in the virtual environment, as well as related concepts such as coherent spatial perception and realistic interaction, some authors developed a taxonomy of virtual reality systems [2] which is useful as it introduces the concept of a 'virtual continuum' spanning the realm of the completely real to the completely virtual world, and qualifiy whatever is in between these extremes as 'mixed reality'.



**Figure 1. photograph of the 'Time Machine'**

We would like to discuss in this workshop the possibility of a total immersive interface (that is, reproducing with high fidelity most basic sensorial modalities and therefore belonging somehow to the totally virtual), whose action is restricted to a part of the body (and therefore making it impossible to classify it as an interface completely rendering a virtual environment). There has been a lot of research on enhancing a Head Mounted Display with binaural sound and other kinds of actuators; in a way, such a device would be the archetype of a total/partial immersive system, but we would like to discuss the possibility of deploying such configuration to other

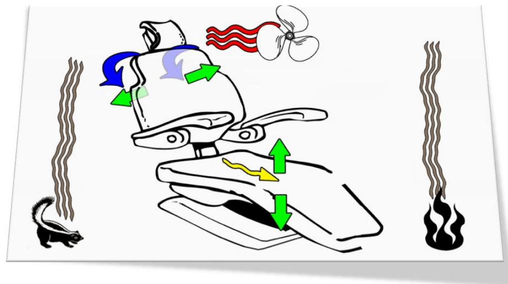

**Figure 2. Schematic picture of the actuators**

parts of the body (not necessarily encompassing all the sensorial organs). An example would be a box with an aperture for introducing a limb: when the user does so, he will experience as if his arm or leg is in another environment, say, a space filled with water and sea creatures he can touch and feel as real. Of course, one can argue that body propioception, vestibular sensation and visuospatial input are all basic senses that a 'total immersion interface' should be able to reproduce, and that this is in direct contradiction with the idea of a partial interaction with the body. However, in certain cases this is an apparent limitation: compelling presence within the simulated environment may be effective with this sort of interface - even though not all the sensorial apparatus is engaged, in particular thanks to task-oriented (bottom-down) perceptual blindness [5]. Of course, there has been some research on interfaces capitalizing on the limitations of human attentional span or the physical limitations inherent to the visual organs (the best known being the foveal displays [5]). We are however interested in another issue: that of an artificially generated *sense of presence of a part of the body* within a virtual environment. Evidence for compelling partial presence (i.e. partial body relocation) is described in [6]. Lastly, a practical motivation for the proposed concept is its compatibility with a wearable realization.

## TOTAL IMMERSIVE SYSTEMS

A total immersive system needs to deal with at least two fundamental problems: the first is how to properly generate artificial sensory stimuli; the other is how to avoid the stimuli from the real world to interfere with the simulation (i.e. achieving sensory deprivation). Futuristic brain-computer interfaces may achieve both goals at once (c.f the 'neural plug' in the movie the Matrix, described earlier by pioneering writer William Gibson in his 1984 novel Neuromancer). Present day more or less invasive BCI enable elementary motor control [7] or generate sensations that would overlap with the external world stimuli if these are present [8], [9]. More conventional systems such as the CAVE [10] or HMD-based VR systems may instead capitalize on real world stimuli in order to enhance the realism of the immersiveness, but this is done at the expenses of the freedom of the simulation (i.e., one must constrain certain aspects of the simulated world such as the orientation on space, gravity and ground texture). With respect to the CAVE, the HMD-based configuration enables a limited form of body sensory deprivation - perhaps by immersing the rest of the body in a liquid or making the user relax on a bed or chair. The latter approach has been tried in an earlier experiment by one of the authors [11]. The intent of the experiment was to create a realistic sense of presence in the virtual world (a WWI battlefield), while at the same time cutting the subject from the real world sensory input. But can we imagine a system capable of totally immersing a part of his body in another world, while still capable of creating a (partial) sense of presence and sufficient emotional arousal?

**Figure 3. redering of the virtual environment**

## EARLIER WORK

'Time Machine: VERDUN 1916' [11] is an immersive system build by one of the authors that 'sends' users back in time at the site of Verdun (a battlefield during World War I). The system achieves a high level of immersion thanks to a HMD and number of different actuators described in the following (figure 2).

A commercial stereoscopic HMD (the Z800 3DVisor from eMagin with a diagonal FOV of approx. 40 deg) and inertial head tracking was used to render the simulated environment (figure 3). Thanks to the information provided by the inertial sensors, the user was able to look around while tied on a modified dentist chair. The chair could tilt and vibrate as a whole (to simulate explosions) then providing some form of vestibular stimulation, and was also covered with dozens of tactile actuators to simulate the ground texture (as the wounded avatar was being dragged on the floor). A belt covering the torso was fit with sixteen vibrators and was used to render the footsteps of a rat walking over the lying body (figure 4).

The HMD is fitted with noise cancelling ear bud speakers, but a pair of large isolating headphones seemed more efficient in reducing interferences from the real environment. Additional speakers and a subwoofer were used to render low frequency sounds produced by the shock waves of virtual explosions. Since air flow can greatly enhance the feeling of presence on an open (virtual) space, a fan was installed to simulate wind as well as heat waves. Finally, an air-pump connected to a box containing chemicals (figure 5) would bring the smell of powder and dead corpses.

**Figure 4. photograph of the vibrators inside the chair and the belt**

The Time Machine was exhibited at the 2007 Laval Virtual international conference on VR. During a five day long exhibition, more than 300 people tried this immersive experience. Nobody was indifferent and some people were disoriented for a couple of minutes when 'coming back to the reality'. Also, two individuals asked to stop the 'Time Machine' because they grew scared. But of course, the machine was not conceived to function as a ghost train in a fun fair: there was no gratuitous surprise, nor rendering of blood or explicit scenes of fighting. One can wonder what aspect of the experience was more scary for these people: the emotionnaly charged context (i.e. the simulated battlefield), or the fact that they were immersed in a realistic, multimodal VR environment for the first time in their lives. From the technical point of view, this experiment demonstrates that low-cost immersive systems are not dreams anymore; also, it shows that the combination of a relatively low number of discrete multi-modal actuators is enough to create a completely immersive experience and make forget the low view angle of the HMD for example.

The team received two Awards at Laval Virtual; the best prize of the Student competition and the best prize of the IVRC Jury with an invitation to participate to the final step of the International Virtual Reality Contest in Japan.

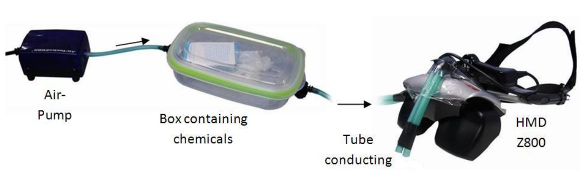


**Figure 5. photograph of the odor system and the HMD**

## DISCUSSION

A subject having tried the system says: "I've never been immersed in such a way. I've never been emotionally immersed, and that's really an incredible experience. That's exactly the kind of immersion I was waiting for in a virtual world. There was no interactivity apart from the head movement, but maybe thats the reason why it worked" [12].

This comment is enlightening: the experience is believable precisely because the story being simulated matches the limitations of the interface: the subject is a wounded soldier, and as such *cannot move*. There may be many cases when a proper design can get around the limitations of the interface (in this case, it's inability to arbitrarily generate artificial propioceptive stimulation); however, one problem faced with the Verdun simulator was its bulkiness, immobility as well as the necessity of one or more technical operators for a unique subject in the machine.

## CONCLUSION

There is some evidence that realistic auditory and haptic stimuli might be more important than realistic visuals when treating some types of phobia using VR systems [13]. This means that a total/partial immersive system not involving the sense of vision may be able to accommodate this type of simulation. An example would be for instance a wearable globe extending on the forearm that would create the impression of walking spiders and/or the temperature of virtual bodies. An early prototype of such a device is described in figure 6 [14]. From the point of view of the taxonomy described in [2], the

**Figure 6. photograph of the 'Ants glove' [14]**

total/partial immersive system can be seen as the counterpart of the 'window-on-the-world' mixed reality systems (these are monitor based, non-immersive video displays showing real scenes upon which computer generated imagery is electronically overlaid). Indeed, the proposed configuration can be seen as a window on the *virtual* world, not necessarily encompassing the visual senses, but instead the rest of the perceptual modalities. Perhaps a better analogy would be that of a spatio-temporal wormhole or a portal to another world. It is partial in the sense of it being a window located at a specific place in (real) space where the user can introduce a part of the body. As said before, this makes compatible the notion of partial/total immersion with that of a wearable interface, as opposed with total immersive systems where the user is completely immersed in the virtual world. An second potential advantage of such system could be that if there is an uncanny valley for artificial environments, as suggested in the introduction, then it may constitute an advantage that these systems secure a cognitive distance between the rendered environment and the user's 'reality'.


## ACKNOWLEDGEMENT

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# Ubiquitous Systems Evaluation (USE '08)

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## INTRODUCTION

Following on from last years' successful workshop in Innsbruck, USE '08 brings together practitioners from a wide range of disciplines to discuss best practice and challenges in the evaluation of ubiquitous systems. Experience has shown that evaluating ubiquitous systems is extremely difficult; approaches tend to be subjective, piecemeal or both. For pragmatic reasons, individual approaches to evaluation risk being incomplete and comparisons between systems can be difficult. Therefore the development and adoption of standard evaluation strategies is essential in order to quantify the contribution of new techniques objectively. Without such techniques, the state of the art remains unclear.

Six high quality submissions were accepted to this years' workshop. Each of which went through a selection process consisting of multiple peer reviews by members of the programme committee. The workshop included presentations of these papers and group discussions on the issues facing the advancement and adoption of evaluation techniques in the ubiquitous systems community.

The organisers would like to thank the Program Committee for their contributions to this workshop, all of the authors, and the workshop participants. The workshop website is located at http://www.useworkshop.org.

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# A Quantitative Evaluation Model of Group User Experience

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**ABSTRACT**
This paper explores the problem of user experience evaluation, in particular the quantitative evaluation of group user experience, in the ubiquitous computing environments. Firstly, the classification and definition of four different categories of user groups are proposed and the notion of group user experience is introduced. Secondly, we analyze the quantitative evaluation of group user experience for different user groups and establish a uniform evaluation model for group user experience. Particularly, we employ two quantitative metrics, user rating and user attention duration, as the main criteria for evaluating user experience. At the same time, the intercommunication and differences among group members in the capacity of information acquisition, the degree of correlation with other members and the weight of impact to the overall group user experience are taken into account to form a general quantitative evaluation model of group user experience for different user groups. Finally, we evaluate the effectiveness of the proposed model with preliminary experiments.

**Author Keywords**
Ubiquitous computing, evaluation model, group user experience

**ACM Classification Keywords**
C.4 [Performance of Systems]: Modeling Techniques, H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces—Evaluation/methodology, I.6.5 [Simulation and Modeling]: Model Development.

## INTRODUCTION

With the rapid development of ubiquitous computing technology, the evaluation, especially the quantitative evaluation, of ubiquitous computing systems has become an imperative research topic. However, the evaluation of ubiquitous computing systems is extremely difficult because of the inherent characteristics of these systems, such as adaptability, heterogeneity and invisibility.

Ubiquitous computing takes a user-centered approach that focuses on providing users with personalized services, such as personalized item recommendation, personalized information presentation, etc., in an unobtrusive way. It aims at creating more attractive and more personalized user experience, therefore the evaluation of user experience become an important aspect of ubiquitous systems evaluation. Furthermore, individuals tend to be members of groups. For instance, an investigation about the museum, which has been widely adopted as a validation platform for ubiquitous computing technologies, showed that only 5% visitors went to the museum all alone, while 45% participated in a guided tour, 30% came with children and 20% went to the museum with friends [8]. As a consequent, in order to certify whether ubiquitous computing systems have enhanced experiences of both individuals and groups effectively, evaluation models for user experience especially group user experience become indispensable.

This paper attempts to build a uniform quantitative evaluation model for group user experience, based on the in-depth analysis of the concept of user experience and the classification of user groups. We employ two quantitative metrics, user rating and user attention duration, as the main criteria for evaluating user experience, and at the same time take into account both the intercommunication and the diversity among group members (e.g., the receptivity of information, the familiarity with the other members and the impact extent to the group) to form a general quantitative evaluation model of group user experience for different user groups.

The rest of this paper is organized as follows: Section 2 discusses previous work relevant to this paper. In section 3, we present the classification of user groups and the notion of group user experience. Section 4 describes the evaluation model of group user experience according to different user groups and proposes a uniform model of group user experience for different user groups. Preliminary experiments are presented in section 5. Finally, Section 6 concludes the paper.

## RELATED WORK

A very limited number of research works have been conducted on the quantitative evaluation of user experience by so far. Masthoff, J. et al. [5] discussed, based on Interactive TV, the quantitative evaluation of satisfaction experienced by individuals when sequences of TV programs are recommended according to different kinds of algorithms. This work aimed to model and to predict the satisfaction experienced by individuals, where satisfaction is treated as an affective state. It proposed modifications to the algorithms to deal with the effect on an individual's satisfaction of that of others in the group. As for the qualitative evaluation of user experience, several


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frameworks with respect to different aspects of concern have been proposed. Cawthon, N. et al. [2] put forward a conceptual model to evaluate the aesthetic effect within user experience, and suggested that it was imperative to develop a user-centered evaluation method that concerns more than task efficiency metrics. Mahlke, S. et al. [4] proposed a research approach to the experimental study of emotional experience and its connections to other components of user experience, and put forward a model of user experience that integrates interaction characteristics, instrumental and non-instrumental quality perceptions, emotional user reactions and overall judgments of system quality. Mourouzis, A. et al. [7] presented a qualitative evaluation framework for specifying and measuring the user oriented interactive products and especially emphasized the determinant influence that accessibility performs when it comes to the evaluation of user experience.

All the above mentioned evaluation models for user experience have several common grounds. First, all these models concentrate on the evaluation of individual user experience, and none of them deals with the evaluation of group user experience. Secondly, most of these models emphasize the importance of the emotion factor, which is something quite difficult to evaluate, while seldom have they analyzed or evaluated user experience from the perspective of knowledge acquisition. Lastly, all these models, except for the one proposed in [5], evaluate user experience in a qualitative rather than a quantitative manner. The main difference between our work and the existing ones is that we focus on the quantitative evaluation of group user experience from the perspective of knowledge acquisition.

## DEFINITION AND ANALYSIS OF GROUP USER EXPERIENCE

### User Experience

To build an evaluation model of group user experience, we must understand the meaning of user experience. Various definitions of user experience have been proposed. Cawthon, N. et al. [2] argue that user experience is "a subject commonly tied to interactive applications – typically software and web interfaces which holistically describes the relationship a user has when using an application and the resulting product of this interaction"; Goto, K. [3] defines user experience as "the overall perception and comprehensive interaction an individual has with an company, service or product"; and in Wikipedia [11], which is a free web-based on-line knowledge base, user experience is defined as "a term used to describe the overall experience and satisfaction a user has when using a product or system".

From these definitions, we can safely draw a conclusion that user experience is something people feel before, during and after they have interacted with a system, service or product, in that, user experience is to some extent an emotional state. However, considering that emotion is something really difficult to evaluate, in this paper we would not concentrate on the emotional aspects when it comes to user experience, but rather on user's knowledge experience, where knowledge comprises the user's cultural, historical and aesthetic acquisitions. For instance, when visiting a museum, the user experience mainly refers to the experience aroused by the cultural and historical knowledge acquired from the exhibits.

### Classification of User Groups

Generally speaking, the relationship and familiarity among members in different kinds of user groups vary from one to another, leading to distinct individual behaviors in different groups. For instance, when visiting museums with a tourist group, people tend to concentrate on the nature and the content of the exhibits, and there is hardly any intercommunication as their attention is more focused towards what they see than towards their own social group. On the contrary, people touring with their family would typically focus on their family members, trying to make the exhibition understandable and the visit enjoyable. On the other hand, when touring with friends, people are usually concerned not only with what they see but also the intercommunion with their friends.

Considering the diversity of user groups, it is useful to categorize them in a systematic manner that makes it easier to distinguish and comprehend and also facilitate the evaluation of group user experience. We, therefore, introduce a classification scheme for user groups based on the criteria of whether the positions of group members are equal and how familiar group members are with each other. Thereby, user groups can be divided into homogeneous groups and heterogeneous groups according to the relationships among group members. Homogeneous groups refer to the groups in which positions of members are equal and members have the same privileges. Friends and tourist group belong to this kind of groups. On the other hand, heterogeneous groups are defined as groups in which members are unequal and have different privileges. Family is of this kind of groups. Similarly, according to the extent of group members' familiarity to each other, user groups can be divided, in another dimension, into tightly coupled groups and loosely coupled groups. Tightly coupled groups are those whose members are close to each other and the intercommunication plays an important role. Family and friends fall into this type. On the contrary, loosely coupled groups refer to the groups in which members are relatively estranged and the intercommunication is not so frequent and important. Tourist group is of this kind.

As a consequence, we introduce four distinct categories of user groups — the tightly coupled homogeneous groups, the loosely coupled homogeneous groups, the tightly coupled heterogeneous groups and the loosely coupled heterogeneous groups.

### Group User Experience

Users can be either individuals or members of groups; similarly, user experience can be categorized into either experience of an individual user or the overall experience of a group of users. We, therefore, introduce the concept of group user experience. In contrast to individual user experience that describes an individual's experience of knowledge, culture, history or aesthetics, group user experience describes the overall experience acquired by a user group, including not only each member's direct individual experience but also the indirect experience acquired through intercommunication among group members. For instance, suppose that you are visiting a museum together with several friends, you can acquire experience from what you see, which is direct experience, and at the same time you can also acquire experience from what your friends see through intercommunication with them which is indirect experience. Group user experience is the composite of both each group member's direct experience and indirect experience.

Apparently, different types of user groups would result in different kinds of evaluation models of group user experience. Consider tightly coupled heterogeneous user groups, such as a family, children are superior to their parents when they visit a museum because, as we have mentioned above, parents do not care what they see themselves so much as what their children see. From this point of view, the experience of children is just the experience of their parents. Therefore, the evaluation model of this kind of user groups should give a heavier weight to the members with higher priority than the others and should take the intercommunication among members into account. On the other hand, the evaluation model of loosely coupled homogeneous groups should give the same weight to each member and should not calculate the intercommunication.

In the following section, we will introduce a general quantitative evaluation model of group user experience which is suitable for different kinds of user groups.

## QUANTITATIVE EVALUATION MODEL OF GROUP USER EXPERIENCE

At the beginning of this section, we list the notations to be used in the evaluation model as follows.

- $G$ : a user group.
- $u$ : a group member.
- $i$ : a item.
- $R(u,i)$ : the rating for item $i$ given by group member $u$ .
- $Impact(u,i)$ : the revised rating for item $i$ given by group member $u$ .
- $A(u)$ : the items that have been visited by group member $u$ .
- $A(G)$ : the items that have been visited by any member of group $G$ .
- $G(i)$ : the members who have visited item $i$ .
- $E(u,i)$ : the experience of user $u$ acquired from item $i$ .
- $E(u)$ : the direct experience of user $u$ .
- $E(u)'$ : the indirect experience of user $u$ .
- $E(G)$ : the overall experience of user group $G$ .

### Quantitative Evaluation of Individual User Experience

We first introduce the quantitative evaluation model of individual user experience. For quantitative evaluation, quantitative parameters must be selected in advance. Currently, the most widely used evaluation parameter is user rating, which thereby is also adopted as one of the parameters in this paper. One hundred scales, from 1 (the lowest experience) to 10 (the highest experience), are designed for the value range of user ratings. To improve accuracy, user ratings are revised via the following two steps.

***Normalization***. It is possible that an individual's rating may be too low or too high. This can be revised through normalization. We apply normalization to user ratings as follow.

$$GroupAverRating(i) = \frac{\sum_{v \in G(i)} R(v,i)}{|G(i)|}, i \in A(u), \tag{1}$$

$$IndividualAverRating(u) = \frac{\sum_{i \in A(u)} R(u,i)}{|A(u)|}, \tag{2}$$

$$Normalized(R(u,i)) = \frac{R(u,i) \times GroupAverRating(i)}{IndividualAverRating(u)}, i \in A(u). \tag{3}$$

In the above equations, $GroupAverRating(i)$ is the average rating for item $i$ given by members of group $G(i)$ and $IndividualAverRating(u)$ is the average rating of user $u$ .

***Making the rating quadratic***. An investigation by Masthoff, J. showed that the relationship between user experience and the ratings they give are not linear, that is, for example, the difference between the rating 6 and rating 7 is not the same as the difference between the rating 9 and 10. Quadratic is a better measurement than linear [6]. We use the following equation to apply quadratic.

$$Quadratic(R(u,i)) = R(u,i) \times R(u,i) . \tag{4}$$

Combining equations (3) and (4), we have the revised user rating $Impact(u,i)$ as

$$Impact(u,i) = Quadratic(Normalized(R(u,i))) . \tag{5}$$

After revision through the above mentioned two steps, $Impact(u,i)$ is a more accurate evaluation parameter than the original user rating. However, even though two users give the same ratings to a certain item, it is still very likely that their experiences on this item are different. This may be caused by several distinct factors, an important one of which is the user attention duration. So, besides user ratings, we import the user attention duration as another evaluation factor. In this paper, we introduce user attention duration though $T(u,i)/To(i)$, in which $To(i)$ is the average attention duration of historical users on item $i$, and $T(u,i)$ is the attention duration of user $u$.

Combining the user rating and the user attention duration, we define the experience of user $u$ on item $i$ as

$$E(u,i) = Impact(u,i) \times \frac{T(u,i)}{To(i)}. \quad (6)$$

Based on equation (6), we introduce the definition of individual user experience as

$$E(u) = \sum_{i \in A(u)} E(u,i) = \sum_{i \in A(u)} Impact(u,i) \times \frac{T(u,i)}{To(i)}. \quad (7)$$

**Quantitative Evaluation of Group User Experience**

As we have mentioned, group user experience include not only each member's direct experience but also indirect experience. In other words, group user experience is the sum of each member's direct experience and indirect experience. At the same time, different types of user groups would result in different kinds of evaluation models of group user experience. In this section, we will discuss the quantitative evaluation of group user experience according to the four different types of user groups.

*Case 1: Tightly Coupled Homogeneous Groups*

For a tightly coupled homogeneous group, on the one hand, the relationships among members are equal and the members have the same privileges. This means that each member's direct experience has the same weight in the evaluation model of group user experience. On the other hand, members are close to each other and the intercommunication plays an important part, so the indirect experience should be taken into account in forming group user experience. We define the quantitative evaluation model of group user experience for this kind of user groups as

$$E(G) = \sum_{u \in G} [E(u) + E(u)'], \quad (8)$$

with $E(u)' = \theta(u) \times \sum_{\substack{i \in A(G) \\ i \notin A(u)}} Impact(u,i)' \times \frac{T(i)'}{To(i)}$, and $\theta(u)$ ($0 \le \theta(u) \le 1$) is the receptivity of user $u$ when communicating with the other members; $Impact(u,i)'$ is the revised average rating for item $i$ given by group members who have visited item $i$; $T(i)'$ is the average attention duration of item $i$ given by group members who have visited item $i$.

*Case 2: Loosely Coupled Homogeneous Groups*

Similarly to the tightly coupled homogenous group, on the one hand, members of a loosely coupled homogenous group have the same privileges and each member's direct experience has the same weight in the evaluation model. On the other hand, members of this kind of groups are estranged to each other and the intercommunication can be ignored. Therefore, we define the quantitative evaluation model of group user experience for this kind of user groups as

$$E(G) = \sum_{u \in G} E(u). \quad (9)$$

*Case 3: Tightly Coupled Heterogeneous Groups*

For a tightly coupled heterogeneous group, on the one hand, the relationships among members are unequal and members have different privileges. This means that each member's experience has different weight in the evaluation model. On the other hand, members are familiar to each other and the intercommunication plays an important part, so the indirect experience should be taken into account. We define the quantitative evaluation model of group user experience for this kind of user groups as

$$E(G) = \sum_{u \in G} \{\omega(u) \times [E(u) + E(u)']\}. \quad (10)$$

In equation (10), $\omega(u)$ ($0 \le \omega(u) \le 1$) is the influence of user $u$ to the overall group user experience.

*Case 4: Loosely Coupled Heterogeneous Groups*

Similarly, the evaluation model of group user experience for loosely coupled heterogeneous groups is defined as

$$E(G) = \sum_{u \in G} [\omega(u) \times E(u)]. \quad (11)$$

It must be pointed out that although group members of tightly coupled user groups are familiar to each other, generally speaking, during their intercommunication not all the items are discussed, maybe only those most impressing and interesting items are involved. This means that the indirect experience a user acquired is usually less than $E(u)'$ as defined in equations (8) and (10). Therefore, we introduce a parameter $\varepsilon$ ($0 \le \varepsilon \le 1$) to describe the discussion lever of a user group, where $\varepsilon$ relates to the familiarity extent of group members. Similarly, for a loosely coupled user group, although its members are estranged to each other, there still is intercommunication and the indirect experience should been taken into account. As a consequence, the evaluation model of group user experience for two types of homogenous user groups can be defined in a uniform format as

$$E(G) = \sum_{u \in G} [E(u) + \varepsilon \times E(u)']. \quad (12)$$

Similarly, the evaluation model of group user experience for two types of heterogeneous user groups can be defined in a uniform format as

$$E(G) = \sum_{u \in G} \{\omega(u) \times [E(u) + \varepsilon \times E(u)']\}. \quad (13)$$

According to equations (8)-(13), we find that quantitative evaluation models of group user experience for different types of user groups have a similar format. In fact, equation (12) is a special modality of equation (13), where the value of $\omega(u)$ is 1. Therefore, the quantitative evaluation models of group user experience for four different categories of user groups can be expressed in a uniform format using equation (13).

During the above discussion, user groups are divided into four categories, and the quantitative evaluation model of group user experience for each kind of group has been studied separately. However, an actual user group could be much more complex, and a single user group may include several independent and distinct subgroups, for instance, a tourist group may comprise several subgroups of family and friends. For such complex and mixed groups, the evaluation model will become much more complicated. Inspired by [1] in which a method for combining subgroups' preferences have been proposed, we divide a mixed group into several subgroups and each subgroup falls into one of the four group types previously defined. The experience of each subgroup is calculated separately and the overall experience is acquired by aggregating each subgroup's experience. Evaluation model of such user groups is defined as

$$E(G) = \sum_{G_i} \Phi(G_i) \times E(G_i)\,, \tag{14}$$

with $\Phi(G_i)$ represents the influence of subgroup $G_i$ to the whole group and $\Phi(G_i) = \phi(G_i) \times \frac{|G_i|}{|G|}$, where $\phi(G_i)$ ($0 \le \phi(G_i) \le 1$) is the weight of subgroup $G_i$.

## PROTOTYPE IMPLEMENTATION AND EXPERIMENT

The museum has proved to be an effective platform for the demonstration and evaluation of innovative ubiquitous computing techniques, because of the inherent mobility of potential users, a wide diversity of attractive materials for presentation, and the potentials of tourism and associated markets [9].

We have developed a prototype system of intelligent museum named iMuseum to evaluate ubiquitous computing techniques [10]. It provides adaptive and personalized services, such as route navigation, exhibit recommendation and information presentation, on both the individual and group level. In iMuseum, the primary goal is to produce a multifaceted system that accompanies visitors and augments their overall museum experience. In order to validate the evaluation model of group user experience proposed in this paper, we designed an experiment based on iMuseum.

### Experimental Design

We assume that a group of three visitors (Jim, Eva and Ben) are visiting the museum and this group may fall into one of three different categories, i.e. family, friends and tourists. They have visited ten exhibits (marked A-J) and their ratings have been given in Table 1, where blanks denote that the visitor did not visit that exhibit. The ratings range from 1 to 10, and a larger rating represents a better experience.

According to group types, we have designed three different scenes for our simulative visitors to mark their overall experience:

Scene 1: Assume that Jim and Eva are husband and wife, and Ben is their child. The simulative visitors are required to give the perceived overall experience of these three persons respectively.

Scene 2: Assume that Jim, Eva and Ben are peer friends. The simulative visitors are required to give the perceived overall experience of these three persons respectively.

Scene 3: Assume that Jim, Eva and Ben are members of a tourist group and they did not know each other before this tourism. The simulative visitors are required to give the perceived overall experience of these three persons respectively.

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| Jim | 8 | 7 | | 6 | 7 | | 4 | | 3 | 7 |
| Eva | 7 | 7 | 6 | | | 10 | 8 | 2 | | 9 |
| Ben | 9 | | 8 | 8 | | 10 | 6 | 8 | 9 | 8 |

**Table 1. Ratings by a group of three viewers**

### Experimental Results and Discussion

As a preliminary experiment, we did a survey on fifteen simulative visitors asking them to give their perceived overall experience of Jim, Eva and Ben respectively corresponding to the three scenes designed above. The result of the survey is showed in Table 2.

| Scene 1 | | | Scene 2 | | | Scene 3 | | |
|---|---|---|---|---|---|---|---|---|
| Jim | Eva | Ben | Jim | Eva | Ben | Jim | Eva | Ben |
| 8 | 9 | 9 | 8 | 8 | 9 | 7 | 8 | 9 |
| 8 | 9 | 10 | 7 | 8 | 8 | 7 | 8 | 8 |
| 6 | 7 | 8 | 6 | 6 | 7 | 5 | 6 | 7 |
| 8 | 8 | 9 | 8 | 8 | 8 | 6 | 7 | 8 |
| 7 | 7 | 9 | 6 | 7 | 8 | 7 | 7 | 8 |
| 7 | 7 | 8 | 6 | 8 | 8 | 9 | 8 | 9 |
| 8 | 8 | 9 | 7 | 8 | 9 | 8 | 9 | 9 |
| 8 | 9 | 9 | 7 | 8 | 9 | 7 | 8 | 8 |
| 7 | 7 | 8 | 7 | 8 | 9 | 7 | 7 | 8 |
| 7 | 8 | 9 | 7 | 8 | 9 | 7 | 8 | 8 |
| 8 | 9 | 9 | 7 | 8 | 9 | 6 | 7 | 9 |
| 8 | 9 | 9 | 7 | 8 | 8 | 5 | 7 | 8 |
| 8 | 8 | 9 | 8 | 8 | 8 | 7 | 8 | 8 |
| 7 | 8 | 9 | 7 | 8 | 9 | 7 | 6 | 8 |
| 6 | 7 | 8 | 7 | 8 | 9 | 7 | 7 | 8 |
| 7.4 | 8 | 8.8 | 7 | 7.8 | 8.5 | 6.8 | 7.4 | 8.2 |
| 24.2 | | | 23.3 | | | 22.4 | | |

**Table 2. Experimental data in the three scenes**

Analyzing the experimental data, we can draw the following conclusions:

1) For a given role, her (his) average ratings differ from one scene to another. In the case at hand, scene 1 receives the largest rating, with scene 2 the moderate and scene 3 the smallest. This indicates that individual user experience varies with scenes, and this variance is probably due to the different relationship and familiarity among the group members.

2) For a given scene, the average ratings differ from one role to the other. In this experiment, Jim gives the smallest rating, with Eva the moderate and Ben the largest. At the same time, it is noticed that the average overall ratings of these three individuals are uniformly larger than their corresponding original ratings. This shows that the individual experience of a group member comprises not only the direct experience but also the indirect one.

3) The group user experience differs from one scene to the other. In this case, scene 1 owns the largest rating, scene 2 owns the moderate one, and scene 3 owns the smallest rating. It shows that group user experience is relevant to the group types, and that the experience of tightly coupled groups is usually better than that of loosely coupled groups.

It should be mentioned that this is a preliminary experiment. Only part of the proposed model has been validated, and values of several parameters in the model, such as $\theta$ and $\phi$, have not been given. Our future work will concentrate on more delicate experiments to decide the parameter values empirically.

## CONCLUSION

Our work focused on the quantitative evaluation of group user experience, especially the user's knowledge experience, where knowledge comprises the user's cultural, historical and aesthetic acquisition. The main contribution of this paper was the provision of a uniform quantitative evaluation model of group user experience for different types of user groups, in which user rating and user attention duration were employed as two quantitative evaluation factors, and both the intercommunication and the diversity of group members were taken into account. Finally, we did a preliminary experiment which partly validated the effectiveness of the proposed evaluation model of group user experience.

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# Usability Study of Indoor Mobile Navigation System in Commercial Facilities

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**ABSTRACT**
In this paper, we describe a field experiment of an autonomous mobile system to navigate users and to estimate the self-position indoors, where it is impossible to receive a GPS signal. Many users utilize positional information systems of GPS. However, because positional information computed using GPS signal is available only in the locations with satellite signal reception, it is difficult to use GPS for positioning in indoor environments. Therefore, we have developed an indoor navigation system to provide ubiquitous information service like that of a portable navigation system that can be used inside commercial and office buildings. The navigation system can display user's position that is estimated by beacon signal using license-free radios. We carried out a field experiments in large-scale commercial facilities to evaluate the usability of the navigation interface and availability of the indoor navigation service on a smart phone. As a result, we found that the users would like to have some functions of indoor navigation systems.

**Author Keywords**
Positioning, Position estimation, Indoor navigation, Smartphone, Cell phone, Wireless beacon

**ACM Classification Keywords**
C.5.5 [Computer System Implementation]: Services

**INTRODUCTION**
When considering various services for mobile terminal using systems like our indoor positioning system, we must consider what services the users' preference, functions of the service, the operation interface, and the screen view. For instance, human-navigation services in outdoor environments rarely require notice to users about vertical movements or positions. However, in indoor public spaces, where it is impossible to use GPS, such as commercial facilities, users might use elevators and escalators to go to the target location.


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For a usability study of indoor navigation services, we conducted a field experiment in large-scale commercial facilities to investigate the usability of the indoor navigation service on a mobile terminal. Our indoor navigation system might be developed so that it can guide a user around commercial facilities. Moreover, the system must be evaluated by typical users.

We describe the usability of an indoor navigation system on a smart phone to use position information in an indoor environment, and results of the experiment. Furthermore, we discuss effective indoor navigation functions and the interface considering users' opinions obtained through the experiment.

**FEATURES OF THE INDOOR NAVIGATION SYSYTEM**
We have developed an indoor navigation system considering usability. The indoor navigation system service has the following features.

- Showing the current position of the user in a floor map.
- Changing the floor map according to the user's position.
- Showing routes from a current position to a destination.

Figure 1 shows a user's current position expressed using a circle in the center of the display screen. As the user moves from left to right on a floor, the user's position in the screen is updated by the navigation system. Moreover, when the user moves to another floor, the system automatically recognizes the current floor and changes the user terminal map to the floor map.

Usually, a navigation route is displayed on a floor map on the terminal screen as shown in Fig. 2(a). When the user reaches the points of navigation events, such as an intersection on the route or in front of an escalator or elevator, a guidance picture like that shown in Fig. 2(b) is displayed on the screen along with a beep sound. The screen presents guidance to lead the user to the destination. The guidance is shown using multimedia: natural language, pictures (e.g., icons, arrows), and photographs of the location. Consequently, the user can reach the destination merely by following the guidance. Advice by the screen announcement includes right turn, left turn, floor changing via escalator or elevator, and destination arrival.

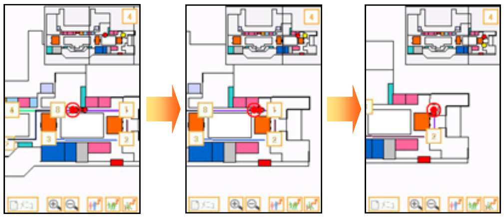

**Figure 1. Example of Positioning Result.**


(a) Map View. (b) Navigation View. (c) Arrival Guide.

**Figure 2. Example of Routing Guide Screen.**

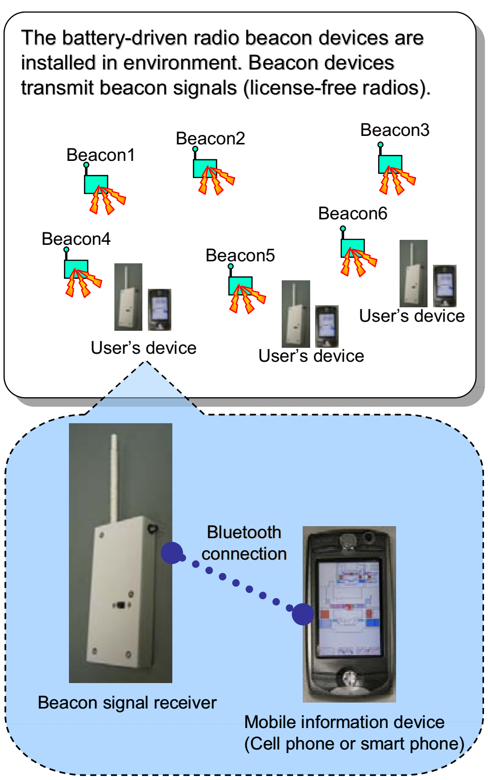


**Figure 3. Architecture of Positioning System.**

As depicted in Fig. 3, the position is estimated on a smart phone with a beacon receiver that receives signal data transmitted from radio beacon devices installed in indoor environments. The radio beacon device is small and light-weight. Therefore, it is possible to attach it in an inspection door on the ceiling. A beacon receiver to be carried with the user is small and cable-less.

## EXPERIMENT IN COMMERCIAL FACILITIES

In this experiment, we intend to collect diverse opinions from ordinary users. The users actually operated the user terminal of the indoor navigation system in the building and reported widely various opinions about the navigation system.

### Experiment Environment

We conducted an experiment to investigate users' demands for the service in a large-scale commercial building. The building is known as not only as a shopping center but also as a sightseeing area in Yokohama City. We selected the building so that the participants in the experiment would be able to seek and obtain various services in the real world.

To guide the users to various destinations, we created a database of locations in the building, e.g., stores, bathrooms, sightseeing spots, and so on. A smart phone with a touch pen interface (FOMA M1000; NTT docomo Inc.) was selected as the target terminal with which a user can input many destinations graphically. The interface is highly interactive; the user merely pushes the intended image on the screen, such as a picture of a store, using the touch pen.

The field experiment was conducted at Yokohama Landmark Plaza building, which is adjacent to the Yokohama Landmark Tower[1]. As shown in Fig. 4, Yokohama Landmark Plaza has five floors; each floor in the building has shops, restaurants, hair salons, and so on. The floor area is about 10,000 $[m^2]$; the center part of a floor is the blow-by. Therefore, the user can receive the positioning signal sent by the radio beacon devices installed on each ceiling on other floors.

Radio beacon devices were installed in the second floor, the third floor, and the fourth floor: the user can use the navigation system from the second floor to the fourth floor. The radio beacon devices were installed at a ratio of one unit for about 200 $[m^2]$ on those floors. It is not necessary to install the radio beacon devices uniformly because the user can specify a self-position if the beacon receiver carried by the user can receive one or more beacon signals.

The field experiment was carried out for five days during November 2007. Several kinds of participants took part in the experiment. The disaggregated data are of 37 participants: 5 students, 27 homemakers, and 5 elderly people. The participants in the experiment move inside the building, using the smart phone and beacon receiver, as shown in Fig.

[1] Mitsubishi Estate Co. Ltd.: The Landmark Tower Yokohama 2-2-1, Minatomirai, Nishi-ku, Yokohama, Japan.

5, and operate the indoor navigation system by referring to the user manual.

The participants experienced one or more scenarios among 11 scenarios prepared in advance. Each scenario assumes a situation and purpose of the navigation, e.g., shopping with young men and women, sightseeing with the family, and so on. Users chose scenarios that were suitable to their own attributes, and moved around in the building according to the scenario using the navigation system.

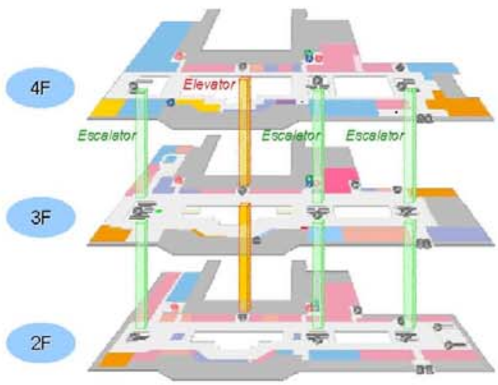


**Figure 4. Floor Map of Yokohama Landmark Plaza.**

**Figure 5. Indoor Navigation Image in Experiment.**

### Experimental Results

To investigate the usability of the indoor navigation system, we administered the following questions to solicit opinions about the experiment.

*A) A question about whether the user understood that they were led in some direction by watching the map and guidance picture on the screen of the smart phone.*

*B) A question about whether the guidance picture was displayed at the right time; in other words, the user was able to watch the picture immediately before encountering a cross over points on the displayed route, before riding an elevator or before riding on escalators.*

*C) A question about whether the user was able to input easily a setup of the destination shown by the navigation menu.*

*D) A question about whether the indoor navigation service with the user's cellular telephone would be useful—whether the user would like to use the service.*

The questionnaire results in the experiment are shown in Fig. 6.

*(a) Navigation screens.*

Regarding the questionnaire result (Fig. 6(a)) about guidance of the navigation displayed while the user moves to a destination, about 30% of participants responded that the indicated direction can be recognized by comparing the photograph image of the screen and the surroundings. More than the half understood by comparison several times.

That is, we understood that 80% or more of the participants were able to reach to the destination without becoming lost; it was possible to select a correct passage by the navigation system. Therefore, it is considered that guidance to a destination using the navigation system indoors was effective.

*(b) Display timing of guides.*

As shown in Fig. 6(b), from the questionnaire related to the viewing timing of the guidance advice, about 60% of participants answered that the displayed screen showed timing neither good nor bad.

We considered the following as factors of the result.

1) In our system, a guidance picture is displayed at a point that is distant from a fixed distance, immediately before an intersection, near an elevator or an escalator. Therefore, when the guidance picture is shown at a location with no turning point, it is also true that the users might have difficulty recognizing the point. We are developing a technique for adjusting the guidance points to resolve this problem.

2) As another factor, it is considered that each user has different timing to watch the smart phone screen; the timing changes from moment to moment. For example, although a user stopped to check the guidance screen, in subsequent guidance, the user checked the screen for subsequent guidance while walking. In such cases of a walking check, the user felt that the guidance screen was shown later than when they stopped to check because the user had moved forward several meters by the time they recognized the guidance screen. Moreover, a fast walker might be shown the screen much later. To solve that problem, we consider appending function that modifies the timing for the guidance according to the walking speed acquired in real time by another sensor.

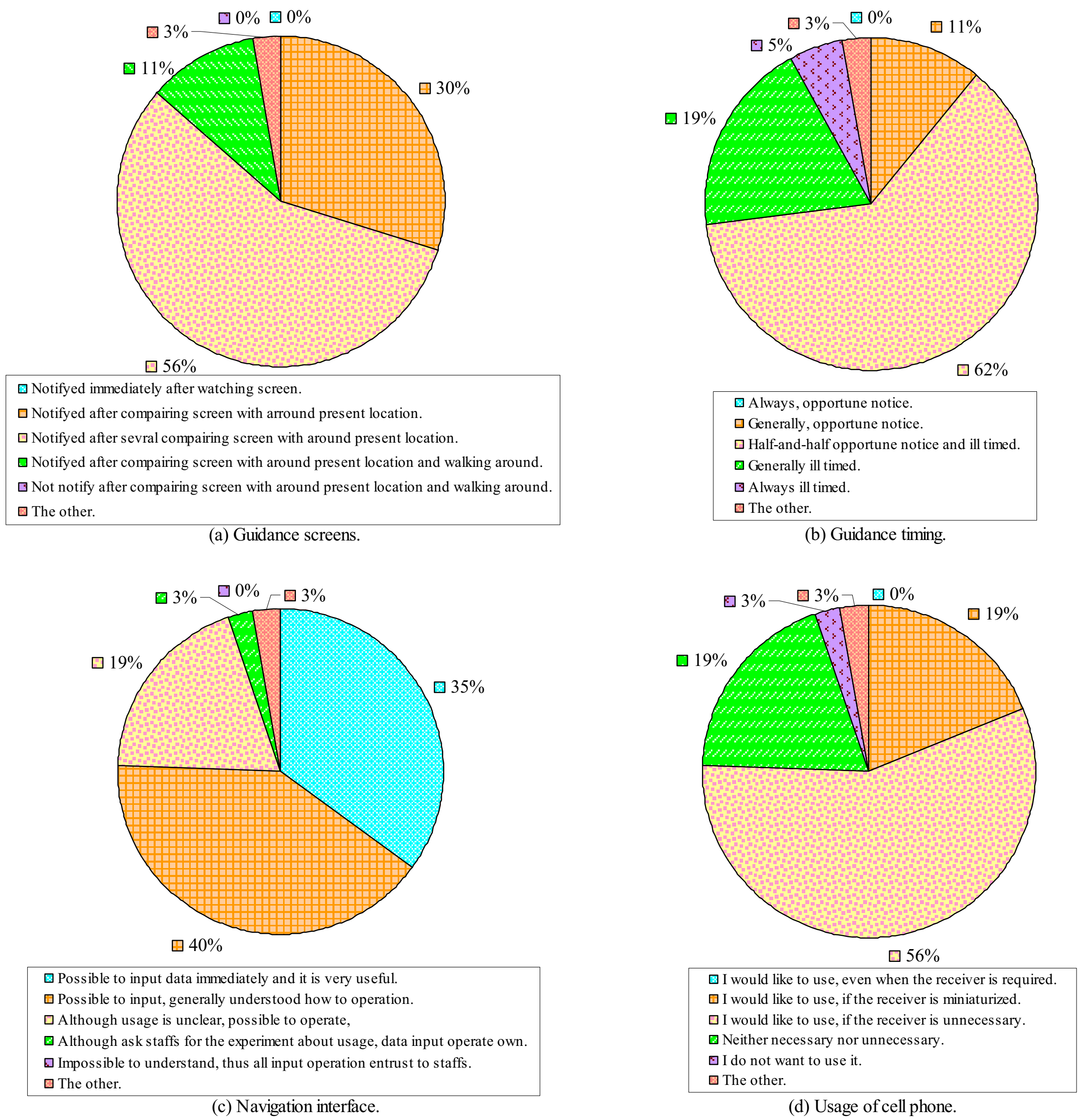


**Figure 6. Result of Questionnaire in the Experiment.**

3) The difference of guidance timing also occurs from precision error. The error results from the difference between a user's position and estimated position in the system. Although the precision of location estimating changes according to number of radio beacon units installed in the environment, not many units can be installed in a building as a practical consideration. For that reason, other sensors can be attached to the user's device to enhance the positioning precision.

*(c) User interface.*

In the questionnaire about an input to smart phone of the destination of the navigation in experiment, almost all participants responded that they were able to understand the operating instructions and used the navigation function (Fig. 6(c)).

We consider that anybody can use the input interface easily because the interface of the smart phone design is easy to understand. For instance, the destination is chosen by touching a picture images and illustrations of shops, restaurants, and so on.

*(d) Users' needs for cellular telephone services.*

Although users utilized the smart phones prepared for us in the experiment, we found users' preference use of the service by which the indoor navigation service is also carried out in a cellular telephone. The questionnaire results depicted in Fig. 6(d) show that about 74% of participants answered that they would like to use such a system if the beacon receiver were miniaturized, or if the beacon receiver were unnecessary.

Conversely, it is a minority view that the user would not like to use the service in a cellular telephone. Therefore, although users' needs for indoor navigation are high, for popularization of services, it is important that usage conditions also include the device configuration.

## Discussion

Based on the result of the experiment conducted at Yokohama Landmark Plaza, we can discuss users' needs for indoor navigation services. Results of the questionnaire to participants provided feedback that the users desire use of the indoor navigation service if the service can operate in popular, practically used devices such as cellular telephones.

Moreover, in the opinions of participants, users were unsure whether the walking direction matched the map aspect on the smart phone's screen when the user was walking using the indoor navigation service, after moving to another floor by escalator or elevator, after turning a corner, and so on.

The disorientation occurred because the map screen display aspect on the user's terminal is fixed. Although the sense of direction depends on the person, in some situations, the users noticed no difference between a self-direction in the real environment and the aspect of map displayed on the small screen. Also, the floor design of Yokohama Landmark Plaza has similar architecture throughout the entire area. To reduce loss of motion by disorientation, heading up of the map through self-direction using an electronic compass sensor in the cellular telephone must be effective, which is our future work for this system.

We were acquired users' opinions about the advantages and disadvantages of our indoor navigation system because evaluated the system by the several kinds of users. The system was evaluated by two survey methods, that is, one is description format and the other is group discussion. Although group discussion can hear the detailed opinions of the users, the survey method takes much time and energy. In the feature, we would like to consider how to effective interview methods.

## REATED WORK

In recent years, position information services such as navigation services have received much attention in the context of civil life, home life, industry, and so on. In outdoor situations, car navigation systems that specify self-position and which provide directions to the destination are useful as a substitute for human navigators to such locations. Moreover, when advanced traffic information systems [1][2] are applied to car navigation systems, it is also possible to show a route with consideration of traffic and accident information related to the present.

However, because the systems have difficulty receiving signals of Global Positioning System (GPS) in indoor environments, some alternative positioning systems are proposed to use GPS in the locations where it is impossible to receive a GPS signal from real satellites. The Pseudolite-GPS [3] and GPS Re-radiation [4] Systems are well known as alternative systems to utilize GPS.

Pseudolite-GPS is a system using a transmitter that emits the pseudo-GPS signal generated by simulations. However, the system has difficulty receiving signals at close distance and at distant locations from the transmitting antenna. Moreover, it is difficult to obtain correct time synchronization accurately between the system and GPS satellites. The GPS Re-radiation System receives real GPS signals in open field areas, then forwards them with a cable, and transmits them to indoor environments. The system cannot be used in areas that cannot also receive GPS signals outdoors. Additionally, it is necessary to install many GPS receiving antennas outdoors to raise the position tracking precision.

Therefore, various non-GPS methods are often applied to indoor positioning systems. Active Bats [5] and Cricket [6] are techniques that can detect positions by receiving signals sent from transmitter devices. Typically, these systems increase the number of installed devices if the areas to recognize the user's position become broad.

In practice, RADAR [7], PlaceLab [8], EKAHAU [9], and AirLocation II [10] are methods using the strength of radio electric field of Wi-Fi signals. Improving these methods' positioning precision is difficult because the electric field strength becomes unstable for changing of Wi-Fi radio transmission power. Ubisense [11] uses ultra wideband technology (UWB) for positioning, but it is impossible to recognize the self-positions of users on their own portable devices.

We have developed an indoor positioning system in consideration of the shortcomings of the systems described above. The system can operate on a portable information terminal such as a cellular telephone by receiving radio beacon signals from beacon devices installed in the environment. The system operates autonomously without server access; the installed beacon devices can be driven using batteries attached to the devices. Consequently, our system also preserves user privacy.

## FUTURE WORKS

In our system, a guidance picture is displayed at a point distant from a fixed distance. Therefore, we are developing a technique for adjusting guidance points to resolve this problem. Moreover, to show guidance pictures with optimized timing on the screen, we consider an appending function, which modifies it according to walking speed, which is acquired in real time by another sensor. Furthermore, we are considering enhancement of the positioning precision to attach other sensors in the user's device [12]. Future systems might incorporate miniaturization of the beacon receiver, integration as IC of the device, and integration with cellular telephones.

## CONCLUSION

For this study, we have developed a system for an indoor navigation service that is intended for implementation not only on smart phones but also on cellular telephones. Moreover, we presented results of an experiment in Yokohama Landmark Plaza for an indoor navigation system conducted using beacon devices.

Yokohama Landmark Plaza has a blow-by in the center of each floor above the ground floor, which means that it is difficult for users utilizing the service to recognize motion to another floor. In the building, many customers come to shops and restaurants; the people are passing through using the passages. We carried out the experiment to investigate this indoor navigation service in such a realistic environment.

In the experiment, we administered questionnaires to elicit comments related to experiences of indoor navigation in the commercial building. Consequently, we acquired useful opinions related to the navigation system and position information services, such as the interface, its operation ability, and the screen information. Moreover, we confirmed the possibility of correct function for navigation service using indoor position information in this real environment.

## ACKNOWLEDGMENTS

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# Clinical Proof-of-Concept – A Evaluation Method for Pervasive Healthcare Systems

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**ABSTRACT**

Pervasive Healthcare – i.e. designing pervasive computing technologies for healthcare usage – is an especially promising area within pervasive and ubiquitous computing research. However, it is extremely difficult to evaluate such systems because establishing clinical evidence for medical benefits would require longitudinal, randomized, double-blind, placebo-controlled trials involving a homogeneous patient population and medical condition. This would not only require huge resources in terms of clinical staff and patient participation, but would also require the technology to be fully developed and ready for large scale use. The latter is simply not feasible when doing technological research into new types of pervasive healthcare technologies. In this paper, I suggest the method of 'Clinical Proof-of-Concept' as a method for evaluating pervasive healthcare technologies in order to establish the clinical feasibility of the technology before entering large-scale clinical trials. The method has been applied in a couple of cases and I report on lessons learned from this.

## INTRODUCTION

Applying Ubiquitous and Pervasive Computing technologies for healthcare purposes is gaining increasing interest and is growing into a research field of its own called 'Pervasive Healthcare' [3, 1]. The research questions and the technologies being investigated within Pervasive Healthcare are quite diversified ranging from using biomedical sensor technology for patient monitoring and prophylactic treatment, to mobile and context-aware systems inside hospitals. Pervasive Healthcare has a lot in common with established medico-technical research areas like biomedical engineering, medical informatics, and telemedicine, but is distinct in its fundamental approach and goals; pervasive healthcare systems are often designed for patients and not for clinicians, and they embody technologies growing out of the ubiquitous computing research, including sensor technology, context-aware and mobile computing, large interactive displays, etc. Similar to Ubiquitous Computing research, Pervasive Healthcare research is specifically targeted towards technology – i.e. aiming at understanding, designing, building, and testing new types of pervasive computing technologies for healthcare purposes.


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A common methodological approach to ubiquitous computing research is to design and implement a technical 'Proof-of-Concect' for a proposed new ubiquitous computing technology or application, and subsequently evaluate this implementation in a limited setup. Marc Weiser defined the concept of a technical Proof-of-Concept as:

> *The construction of working prototypes of the necessary infrastructure in sufficient quality to debug the viability of the system in daily use; ourselves and a few colleagues serving as guinea pigs.* [8].

Looking at the research questions posed by pervasive healthcare, this research approach seems to be lacking some rigor in order to investigate whether the technology solve health related challenges. We would, for example, never be able to understand or evaluate to which degree a technical prototype for elderly people would be successful, if it is only tried out by our colleagues in a research laboratory.

From a medical perspective a technical proof-of-concept is not acceptable for introducing new medical technology or treatment. In most healthcare systems, clear clinical evidence needs to exist before a new medical technology is put into use for patient treatment. *Evidence-based medicine* [7] is the clinical methodological approach for establishing this evidence. Evidence-based medicine categorizes different types of clinical evidence and ranks them according to the strength of their freedom from the various biases that beset medical research. The strongest evidence for therapeutic interventions is provided by systematic review of randomized, double-blind, placebo-controlled trials involving a homogeneous patient population and medical condition. In contrast, patient testimonials, case reports, and even expert opinion have little value as proof because of the placebo effect, the biases inherent in observation and reporting of cases, and difficulties in ascertaining who is an expert.

Such strong evidence is, however, impossible to obtain while we are still in the research and development phase of new technology. So an important question is how we can strike a balance between these two extremes; design and implement limited technical proof-of-concepts which at the same time are suited to provide sufficient clinical evidence for further research and development

In this paper, I suggest a methodological approach called 'Clinical Proof-of-Concept' which is aimed at creating initial clinical evidence for the medical benefits of a pervasive healthcare technology. This approach has been used in a couple of cases and I will report on these cases, how the clinical proof-of-concept was carried out, and what we learned from these cases.

The contributions of this paper is the presentation of the methodological approach of a Clinical Proof-of-Concept together with specific examples of its use in two cases. By suggesting this approach, it is my aspiration that more pervasive healthcare technologies can be subject to initial evaluation and scrutiny before entering large scale clinical trials, while at the same time actually being put into test in a limited real-world deployment. Using this approach, a more incremental and experimental approach to the construction of pervasive healthcare technologies can be achieved, which in the end will lead to developing more appropriate and usable pervasive healthcare technologies. At the same time, the approach would enable us to reject and dismiss those technologies, which show little clinical promises before large amount of resources are spent on developing the technology and running clinical trials.

## CLINICAL PROOF-OF-CONCEPT

To rephrase the definition from Marc Weiser, I am defining a Clinical Proof-of-Concept (CPoC) as:

> *The construction of working prototypes of the necessary functionality and infrastructure in sufficient quality to investigate evidence for improving health in daily use for a suitable period of time; a limited but relevant set of people serving as subjects.*

More specifically, the technology should be a working prototype that is usable (but not necessarily user-friendly), works on its own, and is focused on addressing specific research questions. This technology should be deployed in a real clinical setup, should be used by real users (researchers are hands-off), for a short, but sufficient period of time, which – depending on the research question – may range from 1 day to 3 months.

For example, you may want to test a system for monitoring hypertension and evaluate if users are able to control their own blood pressure over time, thereby reducing hypertension, which again – according to medical literature – have a positive effect on a wide range of heart diseases. In this case, a CPoC would involve a technical prototype which runs on its own and is able to monitor blood pressure, but it may not be particular secure, robust, or integrated in a country-specific healthcare system. It should, however, be able to run with limited interference from the researchers, while some 'Wizard-of-Oz' techniques may be applied. The deployment would include a limited amount of people – e.g. 10 – which is not statistically significant for hard medical evidence, but sufficient for establishing the viability of the technical setup and its use in a real-world deployment. And the trial may run for a couple of weeks – rather than the months normally required for a clinical trial.

The methods used during this CPoC should be targeted at collecting evidence, which demonstrate that the technology seems promising in addressing its specific goal. It may be relevant to gather initial clinical evidence for the medical benefit of the technology. For this purpose, trying to measure some clinical effects is essential during the CPoC. For example, in order to establish any clinical effect in the monitoring of hypertension, blood pressure data may be compared over the time span of the CPoC and questionnaires regarding the patients' awareness and handling of their blood pressure may be issued and analyzed.

Even though the clinical evidence may be biased by different factors and hence not as strong as would be required in Evidence-Based Medicine, providing initial clinical evidence for the working of the technology is still essential in order to justify further development and evaluation. Furthermore, the Clinical Proof-of-Concept may simultaneously work as a 'dry-run' for testing the data collection methods, which later are to be used during the clinical trial. For example, if a questionnaire is handed out to the participants, this questionnaire and the timing of it may be subject to change based on experiences obtained during the clinical proof-of-concept.

Apart from establishing initial clinical evidence, a core purpose of a CPoC is to investigate the usefulness and usability of the proposed solution. To a certain degree, I would argue that this is the *main* purpose of a CPoC for two reasons. Firstly, the clinical benefit of a pervasive healthcare technology may be significantly diluted if the technology is hard to use for the patient. For example, it is obvious that if the blood monitoring technology is hard to use, then limited effect on hypertension management may be found during the clinical trial. Secondly, it is essential to catch and remedy such usability problems in an early phase before resources are invested in developing the technology, producing it in large numbers, and deploying it for a clinical trial.

These arguments may seem trivial. However, some sort of usability problems are often hard to discover and are often unexpected. By running a CPoC which actually puts the technology to a test in a real-world setting with real users for a certain period of time, many of the more complex usability problem may surface. And often, ideas for changing and improving on the technology arise when seeing it in actual use and by working closely together with the users to find a solution to the problem.

Methods for usability inspection would typically be qualitative in nature, involving observations, questionnaires, and studies of perceived usefulness and usability.

Figure 4 show the temporal progression of research methods as the technology is developed and mature. Time-wise,

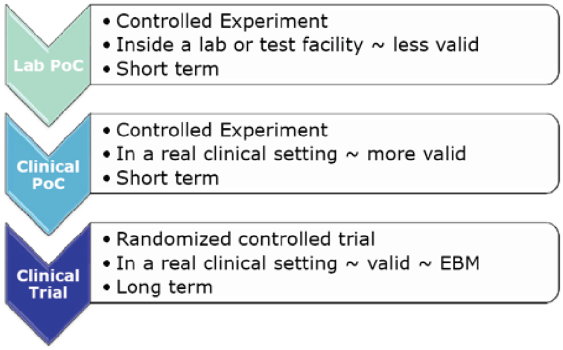


**Figure 1. The timing of a Clinical Proof-of-Concept is between a laboratory proof-of-concept and a full clinical trial.**

a clinical proof-of-concept lies in between the technical laboratory proof-of-concept and a full-scale clinical trial.

## CASES

In order to illustrate how a CPoC can be used in pervasive healthcare research, I will use two cases as examples. The first case is concerned with home-base blood pressure monitoring, and the second case is concerned with developing context-aware technologies for improving patient safety inside the operating room. These two case are very distinct in many respects – technology, users, deployment settings, and goals – but as such, they illustrate the breath of the CPoC approach.

### Blood Pressure Monitoring

The first project was concerned with home-based monitoring of hypertensive patients. Hypertension is a direct cause of a number of heart diseases, including congestive heart failure and stroke, and substantial clinical evidence indicates, that frequent blood pressure monitoring helps prevent hypertension [6]. For this reason, many pervasive healthcare projects have addressed hypertension. This project was done in 2002 when state-of-the-art blood pressure monitoring was based on a cuff. Our goal was to deploy the technology in a limited pilot study and perform a CPoC (even though we did not call it that at that time). The technology for home-based monitoring consisted of a suitcase with a traditional blood pressure monitor, a PDA, and a GSM modem as shown in Figure 2.

In this project, the suitcase were given to the patients by their general practitioner (GP). The system had three main features: (i) it allowed the patient to measure the blood pressure several times a day and this data was sent to a central server for the GP to observe; (ii) the GP could prescribe medicines and the patient could indicate that (s)he was complying to the prescription; and (iii) it enabled communication between the patient and the GP, using both text and voice messaging.

During the first months of a longer deployment period, we carried out a series of interviews and field studies of this home-based monitoring and treatment system. This study

**Figure 2. A patient using the home-based monitoring system in a briefcase for monitoring her blood pressure.**

was focusing on studying issues of medical treatment, division of work, communication, patient self-understanding, and the technology in actual use [2]. Our study – in accordance with most medical studies of home-based monitoring of hypertension – gave evidence that this kind of blood pressure monitoring provides more accurate measurements. Our findings, however, also revealed that the relationship between the GP and the patient changed when this new computer-mediated home-based treatment for hypertension was introduced. More specifically, we found four specific aspects of this transformation caused by pervasive monitoring and treatment technology:

- A new division of work emerged, which transferred the act of monitoring and interpreting the blood pressure data from the GP to the patient.
- The medical treatment of hypertension and the life quality of the patient was improved. However, new demands for monitoring the incoming data and the patient's progression in treatment were inflicted upon the GP.
- The communication pattern between the patient and GP was fundamentally changed from a contextual rich conversation to an asynchronous message exchange.
- Because the patient was more involved in the monitoring and treatment of hypertension, he or she became more self-aware on the nature of high blood pressure and what affects it.

This clinical CPoC was insufficient to establish clinical evidence for improved hypertension treatment of the patients. For this purpose, the time frame of the study was too short, the sort of methods applied insufficient for determining clinical evidence, the number of patients were too small, and no control group was involved. The study, however, were sufficiently large to study, understand, and argue that this kind of home-based monitoring would transform the patient-GP relationship and make the patient capable of managing their own blood pressure in a more efficient way. And since previous clinical studies have shown that regular self-conscious attention to your blood pressure reduces the risk of hypertension, this was clearly a strong indicator that this kind of technology would be useful.

At the same time, the CPoC revealed a series of usability and deployment issues which needed to be looked into before running larger scale trials involving a larger amount of patients and GPs. The technology were subsequently improved and deployed in a large clinical trial with 10 GPs, 120 patients, and a control group.

### Context-aware Patient Safety

The Context-aware Patient Safety and Information System (CAPSIS) monitors what is going on inside the operating room and use this information to show timely medical data to the clinicians, and to issue warnings if any safety issues are detected [4]. CAPSIS monitors events like the status of the operation; the status and location of the patient; location of the clinicians who are part of the operating team; and equipment, medication, and blood bags being used inside the operating room. This information is acquired and handled by a context awareness infrastructure, and a special safety service is used for overall reasoning which actions to take or warnings to issue. The goal is to supplement human safety vigilance with a machine reasoning counterpart.

CAPSIS was deployed and tested in a CPoC where it was used for one day by a full surgical team performing simulated operations inside an operating room. In total, 8 operations were executed during the day, involving both operations with no warnings as well as different types of warnings, including wrong patient, wrong operating table, wrong blood, and incomplete team. In addition, medical records, radiology images, and the operation checklist were presented on displays using the context-aware triggers. A picture from the CPoC is shown in Figure 3. Everything were done exactly as real surgeries, except that no real patients were involved and the acting patients were not sedated or actually cut. The acting patients, were, however treated as any real patient, including being admitted to ambulatory surgery and scheduled in the scheduling system.

The goal was to provide objective measurements on the usefulness and usability of our design while, at the same time, investigate the detailed user reaction to the system and the user interface in a more qualitative fashion. For this purpose, we used a *multi-method evaluation setup* where we (i) asked the users to perform the operations while thinking aloud, (ii) investigated perceived usefulness and usability based on a questionnaire [5], and (iii) made a semi-structured follow-up interview.

Based on this evaluation, the clinicians concluded that the system would be very useful for ensuring patient safety and was very easy to use. Most of the patient safety issues monitored by CAPSIS were found to improve patient safety, and several of the findings resonate with the recommendations from the state-of-the-art regarding patient safety. Moreover, the CPoC revealed a series of usability issues which we had not captured previously, despite several prototyping sessions. By actually deploying the technology inside the OR, and asking the operating team to use the technology during close to real-world surgeries, a wide range of issues surfaced which would have not been found otherwise. Especially issues regarding the physical working environment of an OR and the tight teamwork taking place during surgery surfaced. Some examples of issues that were discovered during this CPoC include;

**Figure 3. The deployment of the system inside the OR; the surgeon and the sterile nurse read medical data on the screen to the right while the scrub nurse interacts with the patient safety system on the screen to the left.**

- The user interface had to be improved in several place, including issues like coloring, highlighting, and font size on the screen due to the distance from the operating table to the screens.
- The procedures regarding attaching a RFID enabled armband to the patient needed to be scrutinized because patient safety now was depending on that this was done correctly. If the wrong armband was attached to a patient, unpredictable and potential severe safety hazards may occur.
- Better support for handling and registering scanning of blood bags were needed. When moving from a limited test in a lab to a CPoC in the OR where a substantial volume of blood may be needed, the existing method for checking correct blood did not scale to e.g. 10-20 blood bags. The reason for this was due to a number of highly interlinked aspects, ranging from the organizational procedure for ordering and getting blood, to the physical layout of the OR, and the way the RFID technology were working.
- Lack of triangulation, which is the medical safety term for ensuring that a safety check is done by combining the patient, the procedure, and the clinical staff. Even though this was part of the overall systems design, triangulation did not work inside the OR on the individual level.
- The operating team had to change their safety procedures just before surgery in order to leverage the capabilities of the system.

It is important to note, however, that this CPoC setup is not providing ‘hard clinical evidence’ for improved patient safety inside the OR. We do not know if this system – if build and deployed – would improve on patient safety. This would require a randomized clinical trial over a longer period of time involving a control group, which again would require a full working system ready for large-scale and long-time deployment. Providing such Evidence-Based Medicine is, however, not the purpose of a Clinical Proof-of-Concept; it is rather to investigate the feasibility of the proposed solution for further development. By asking the involved clinicians how they perceive the system's potentials for improving patient safety, we are given sound indications regarding the feasibility and directions for further development.

Beside this indication of potential clinical evidence for improving patient safety, the core benefit from running this CPoC is the different problematic issues regarding the current prototype which must be addressed before making a larger clinical trial. As illustrated above, these issues are a mixture of technical, usability, physical, and team-oriented aspects which need to be addressed in concert. But most importantly, these complex and interrelated issues would probably never have been found without running a CPoC. The next step would be to incorporate the suggestions for improvement and then apply more rigorous clinical methods for evaluating the degree to which the system improves on patient safety. Note, however, that the only reason for such an investment is based on the fact, that the CPoC indicated that the system potentially would improve patient safety.

## DISCUSSION

What have we learned from our use of clinical proof-of-concepts so far?

First of all, a CPoC reveals a wide range of technological problems and issues. For example, in the blood pressure monitoring project, the CPoC revealed all sorts of problems with wires, handling software updates, and sustaining power on the devices while not in use. In the patient safety project, the CPoC revealed all sort of issues ranging from the working of the RFID technology to the use of the software on large touch-screens. Hence, a CPoC is useful in determining the sort of technological issues which are related to real-world use by real users for a longer period of time and on a larger deployment scale.

Second, even though a CPoC seldom is done in a way which justify any ‘hard’ clinical evidence, it is still useful in order to both provide initial clinical evidence for a potential medical effect, as well as providing important information on how this clinical effect should be collected. For example, the clinicians in the patient safety project unanimously agreed that the system had the potential for improving patient safety inside the OR. This do not count as clinical evidence, but nevertheless it encourage further development. At the same time the CPoC revealed that the methods used for evaluating the system were appropriate for judging perceived usefulness, but they were not appropriate for providing clinical evidence for the improvement of patient safety during surgery. Hence, a new methodological setup is required in any subsequent clinical trial.

Third, because the technology is deployed in a real setting for a non-trivial period of time, a CPoC is well-suited for investigating the usability of a pervasive healthcare system. Especially non-trivial usability problems which arise from complex interaction between different types of technologies, users, real deployment settings, and long-term use may be discovered during a CPoC. For example, the blood-pressure monitoring CPoC revealed that it was hard for some patients to type a message to the GP and this functionality was hence changed to use voice messages instead of text messages. And in the patient safety project, as wide range of usability issues regarding the user interface were found.

Fourth, due to the real-world deployment a CPoC helps reveal and evaluate the physical usage of the technology. The physical aspects of the technology is especially important for pervasive healthcare systems since medical devices and systems are notoriously tied to monitoring or influencing physical properties of a human body or a physical environment in homes or hospitals. For example, a wide range of issues regarding the physical handling of the blood-pressure cuff and the handling of the PDA were revealed during the CPoC. This subsequently lead to the design of a cartoon-like step-by-step instruction card, which were place on the front of the suitcase, as shown in figure 2. In the patient safety project, the physical layout of the OR, the physical handling of patients, blood bags, and instruments turned out to have significant impact on the use of the system.

Finally, often pervasive healthcare systems needs to exist and work in a larger social and organizational context. A CPoC is equally suited for initial investigation of the impact arising from this larger deployment context. Especially in the blood-presure project we found a significant change in the division of work and communication between the GP and the patient, and the CPoC revealed some of the important details of how the technology would potentially influence the way the treatment of hypertension were achieved. In the patient safety project, the CPoC helped judge the fit between the system and the complex and dynamic teamwork taking place inside an OR.

## CONCLUSION

In this paper, I have proposed to apply a Clinical Proof-of-Concept as a methodological approach for evaluating pervasive healthcare systems. A CPOC involves a focused study in a real-world deployment setting, involving real patients and users, while being limited in time, scope, and clinical rigorousness in the methods applied. By being a stepping stone in the middle of a laboratory-based evaluation and a full-scale clinical trial, the CPoC is able to provide valuable information regarding the clinical applicability of the system, its usability, and issues regarding the physical and organizational deployment of the system. In this way a CPoC is a more dedicated and cost-effective approach for establishing initial clinical evidence as well as being a invaluable source for improving the technology at a stage before resources are invested in final development and clinical trials.

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# The Challenge of Evaluating Situated Display based Technology Interventions Designed to Foster 'Sense of Community'

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**ABSTRACT**
In this paper we discuss the obdurate problems associated with evaluating the extent to which technological interventions – in particular those based on mobile and ubiquitous technologies – can be judged to have 'improved a sense of community ' in their given deployment settings. We report on experiences gained from several deployments of ubiquitous systems that share this design goal, and analyze common issues we observed during real life use of these systems. Based on these we discuss some of the key challenges for evaluating ubiquitous systems of this genre.

**Author Keywords**
Technological intervention, mobile and ubiquitous computing, CSCW, long-term deployment, evaluation, methods, community, situated displays.

**ACM Classification Keywords**
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION
Our research is interested in the design of technical systems that may prove useful in promoting or 'affording' some sense of community. McMillan and Chavis [11] identify four inter-related elements associated with sense of community:

i. *membership*,

ii. *influence*,

iii. *integration and fulfillment of needs*, and,

iv. *shared emotional connection.*

A number of technical systems based around ubicomp technologies, most notably situated displays, have recently been developed and deployed with the intention of supporting sense of community. A good overview of this work is provided in [14] with one of the first systems of this genre being GroupCast [10]. Typically such systems focus on highlighting the technical difficulty associated with implementing the system or the methods used to ensure appropriate and well-informed design. However, in addition to the difficulty of successfully designing and implementing systems, the evaluation of their 'success', i.e. their ability to foster and support a sense of community, is also a challenging problem, due to a number of issues. For example, when deploying technologies to support community it is likely that social practices will shift in order to accommodate the new technology. Furthermore, it is likely that the technology will be tailored by its users, sometimes in unanticipated ways (i.e. through appropriation) to accommodate the social practices it is intended to support. For example, technology can reshape notions of space and proximity and thus the boundaries of 'community', re-conceptualizing what it means to be local, connected etc. Hence, community is an achieved social construct, a 'persuasion', of mutual ties, orientations and obligations, pointing to the ability of technology to reshape and redefine how people see themselves [13].

One of the difficulties of evaluating how well a given technological intervention may support notions of community is that the effect of the intervention is dependent on the interaction between a combination of technologies and their affordances (including those brought about through the placement of the technologies) and particular communities and their dynamics. Furthermore, the evaluation techniques themselves must adapt to these dynamics, evolving alongside the system.

In [15] we discuss the need to consider the following factors when designing technologies to support notions of community:

1. *membership* - recognisable members and membership categories, allied with recognisable boundaries
2. *identity and representation* - how people can represent themselves and manage their 'identities'
3. *managing spatial relations* - need to manage spatial relations to integrate the real and the virtual


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4. *rhythms* - the highly predictable rhythm of everyday activity sets the grounds for shared expectations and comprehension of behaviour - successful communities carry intelligible rhythms of interaction and awareness - which vary according to the community and is linked to issues of awareness and 'sense of place'.
5. *community development* - the community should be able to reflect and learn from experience, to develop ‘robust sociality'
6. *history and change* - the ability to develop a history through recording and archiving various interactions

The remainder of this paper is structured as follows. In section two we describe our general approach towards the design, deployment and evaluation of technology interventions (where sense of community is at least one of the aims) in a range of settings. Next, in section three, we summarise two of our current deployments for which we wish to evaluate their effectiveness in supporting sense of community. These two deployments comprise the Wray Photo Display, a touch screen based interactive system, which is situated in the Post Office of a rural village in the North of England, and the Campus Coffee Display, a wall-mounted broadcasting screen, which is situated in a café at the intersection of Newcastle University’s campus and the city’s main shopping area. In this respect both systems are located within the activity zone of established local communities and visitors to the area. Finally, we discuss the pertinent issues that we have experienced when considering the evaluation of these systems.

## APPROACH

It is apparent from related literature and our own research that it is essential to understand the social and physical richness of a given setting in order to avoid inappropriate design. Consequently, our approach draws from a range of approaches including ethnographic studies, use of cultural and technology probes [6], focus groups and design workshops. We have investigated several settings in the course of our studies including Lancaster University campus, a public café, and domestic settings such as family homes and residential care facilities.

By using a range of settings we aim to increase our confidence in the generality of our findings. Our methodology is iterative: observe, design and deploy, observe etc., where these stages are closely coupled and all hold key (technical and practical) challenges.

Our general approach is one of ‘co-realisation’ [5] whereby technical modification is rooted in ongoing ethnographic study. The evaluation approach, therefore, both informs and is being informed by the evolving character of the system to reflect the dynamic relationship between the system and its socio-spatial context.

## SYSTEM DEPLOYMENTS

We have experienced ‘community’ use with several of our deployed systems based around ‘situated’ displays. For example, with the Hermes office door display system (that enabled office owners to post awareness related messages on digital displays situated outside their office) we describe in [2] how usage of the system was considered by many users as directly relating to notions of community, e.g. one door display owner made the following comment when asked why he used the system:

*“there is a community associated with my doorplate, you know people have to be able to get to my doorplate, and that probably makes them one of the staff or colleagues, and that affects what information I could put on there and I don’t want burglar Bill with his web browser to go – oh look [name]’s in such-and-such I’ll go and burgle his house now.”*

In the following sub-sections we describe two of our current technology deployments that are undergoing evaluation and which were designed to support notions of community.

### The Wray Photo Display

The Wray Photo Display [16] is deployed in the Post Office of a rural village situated in the North of England. The system enables members of the village to post photos (or short video clips) to be shown on the display and to create and moderate their own photo categories. The photo display was conceived as a technology probe and has run continuously (capturing log data) in its current location (see figure 1 below) since October 2006.

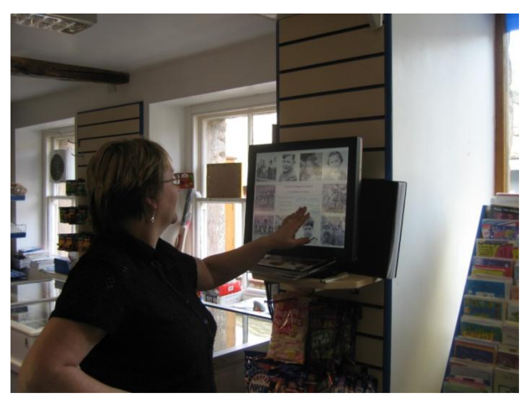

**Figure 1. The Wray Photo Display situated in the Village Post Office. The Comments Book can be seen just to the right of the display.**

In order to evaluate the usability and usefulness of the system we have held a number of participatory design workshops and focus groups. However, perhaps the most useful single method for obtaining qualitative feedback regarding the system has been via a comments book which has been placed next to the display since its first deployment. This book has enabled both members of the village and visitors to the village to express their opinions regarding the display and its content. To date over 60 individual comments have been left in the comments book but suggestions for additional functionality have also been left via e-mail. A page from the comments book containing a comment relating to issues of community is shown in figure 2.

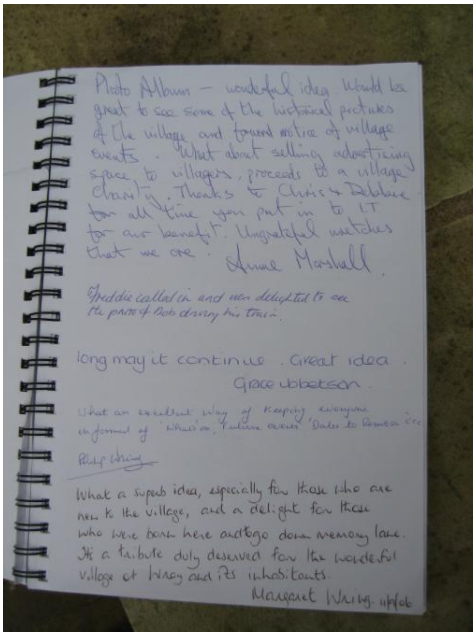


**Figure 2. A Sample Page from the Wray Photo Display Comments Book.**

The last comment on this page reads:

*"What a superb idea, especially for those that are new to the village, and a delight for those who were born here and to go down memory lane..."*

It is interesting to note that this comment speaks of notions of *membership*, *identity* and *history* that were introduced earlier. Indeed the most popular category of photos viewed on the display is that of historical photos.

### Campus Coffee

The Campus Coffee system at a local café (see figure 3) has been running continuously for about two years now [7,8]. It provides information about upcoming cultural events in the quarter of the city where the café is located. The initial version of the system delivered content updated by the researchers and was designed to be non-interactive and slow-paced. As a new addition to other modes of local information in the café, it functions as a low-key technology probe.

In order to assess the customers' perception of the system as a source of local information and to look into options for further community engagement through the incorporation of interactive features, we conducted brief in-situ questionnaires, observations and focus group sessions. In line with previous findings, users most frequently classified their use of the system as opportunistic, i.e. glancing at it while waiting at the counter. Nevertheless, the display was perceived as being beneficial as a reminder about upcoming local events and complementary to other similar community resources, such as the weekly newsletter. The slow pace of the presentation was also positively received as being in line with the general 'feel' and use of the café.

In the course of the focus study we discussed with the participants three alternative designs of a more interactive system that would enable customers to interact with the display through their mobile phone. The proposed interactive features would provide a means for visitors to the café to comment either on the cultural events currently being shown on the screen, or on objects exhibited at nearby museums, or on user-defined topics. Feedback from the focus study indicated that, although the public nature of the display might serve well the promotion of community activities, the ownership of the content, its management, and the protocols of content contribution (including the interaction mechanisms) would be difficult to negotiate in such a socially and politically diverse environment.


**Figure 3. The Campus Coffee display 'in the wild'.**

Regarding this latter finding, we return to the comment made in the introduction, and the fact that here what is being evaluated is the product of both setting and technology.

## ISSUES

In applying our approach to these deployed systems, we have come across a series of recurring issues, which we discuss in this section.

*How long does a deployment need to be in place?*

Both the Wray Photo Display and Campus Coffee systems have been deployed for relatively long periods of time – especially in the context of typical ubicomp systems. However, the question remains: how long does a deployment need to be in place before it can sensibly be evaluated against success criteria based on improved community and coordination in the setting? A key element of our research methodology is the use of substantial deployed installations. The long term use of novel technologies, especially their collaborative and community effects, cannot be deeply understood through short-term experiments or 'toy' installations. This development and deployment enables longitudinal studies as well as being a technology demonstrator for dissemination and inspiration.

*What are appropriate techniques for evaluating technology probes with respect to community?*

We have utilized both qualitative and quantitative measures but to-date it is the use of qualitative methods that have yielded most insight. One problem with the use of quantitative measures based on log analysis, for example, is that it is difficult to produce figures on how many different members of a community view the content (not least how they feel about the content). With the Wray system, we did not wish for the interaction design to require viewers of the content to log themselves in and out of the system, as is often the case with similar systems [10,4]. There is the possibility of exploring the use of monitoring devices such as web cams but these, of course, introduce numerous and difficult privacy and control issues, see [12] for an initial discussion on this topic. We have also highlighted additional complexity added to this issue by the need to adapt our evaluation approach to individual communities and technologies.

*How to introduce the system to the community?*

The Wray Photo Display was introduced as a working interactive system, and has evolved over time in response to user feedback. With the Campus Coffee system we took a slightly more conservative approach by repurposing an existing non-interactive and very ambient system with the scope to introduce interactive aspects in response to user consultation. While both systems are relatively similar in the function they provide, specifically the delivery of community/locale related content, the reaction to them has been quite different. In particular, the interactive features associated with the Wray Photo Display have been received enthusiastically, but with the Campus Coffee system the suggestion of altering the design concept of the existing technology deployment to one in which a great degree of community-generated content could be entered and displayed received negative reaction. It is interesting to speculate on how the Campus Coffee deployment would have been received if the initial deployment had been based on this suggested design concept. The implication for evaluation being that the way a technology intervention is introduced can have a significant impact on the adoption and appropriation of the technology (to support sense of community).

## CONCLUDING REMARKS AND FUTURE WORK

In this paper we have discussed the difficult issue of how to evaluate the success of technology interventions that have 'supporting notions of community' as their design goal. The two systems presented in this paper, which both share the aforementioned design goal, are based around situated display technologies and have been deployed for relatively long periods of time and received daily use. The Wray Photo Display system has certainly received positive comments from members of the community; however, questions over its 'inclusivity' still remain. With the Campus Coffee system it has been interesting to observe the cost/benefit analysis that has led participants of a focus study group to favor calm/controlled content presentation over potential haphazard community generated content. Clearly part of the cost/benefit analysis taking place in this case is informed by the participants' use of the café in the first place. Therefore, it highlights strongly the fact that with the technology interventions discussed in this paper, what is being evaluated is the product of both setting and technology – and this reveals the emphasis in *situated* displays. Furthermore, it indicates that an evaluative approach that would investigate the correlation between community dynamics and system usage patters and perceptions might be particularly helpful in the design of sustainable community-centered technology.

As part of our future work, we hope to extend our use of qualitative evaluation methods but also explore further the potential of more quantitative methods, such as the use of 'Sense of Community Index' developed from the field of psychology [3, 9]. We also hope to explore how to design and evaluate technology interventions to support a sense of community in further different and (again difficult to study) sensitive settings, including rural townships in South Africa.

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# Situvis: Visualising Multivariate Context Information to Evaluate Situation Specifications

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**ABSTRACT**

One of the many challenges faced when evaluating context-aware ubiquitous systems is to gain some understanding of the constant influx of context data into the system. Elsewhere, context has been distilled into more natural abstractions called *situations* with the aim of making these systems more understandable and intuitive to develop applications for, though codifying and manipulating these situations still presents problems. We introduce Situvis, a tool we have developed based on the Parallel Coordinates Visualisation technique, which assists users by visually representing the conditions that need to be present for a situation to be triggered in terms of the real-world context that is being recorded in their system, and allows the user to visually inspect these properties, evaluate their correctness, and change them as required. We describe the use of our tool with a small user study.

**Author Keywords**

Context, context-aware systems, situations, situation programming, visualisation, visual data mining

**ACM Classification Keywords**

D.1.7 Visual programming,
H.1.2 Human information processing

## INTRODUCTION

In context-aware systems, context data is derived from multiple heterogeneous sensors. These sensors may be networked physical instruments in the environment (measuring factors like temperature, noise volume or humidity) or software sensors retrieving information from the web or various data feeds. These context data are voluminous, highly multivariate, and constantly being updated as new readings are recorded.

*Situations* have been proposed as a higher-level abstraction of context data [8], freeing the user from having to deal with raw context and allowing more expressive adaptations. Situations are more natural for users to work with, as they define commonly-experienced occurrences such as a user "taking a coffee break", or being "in a research meeting", without requiring the user to understand any of the dozens of distinct sensor readings which may have gone into making up these situations. Situations are thus a natural view of a context-aware system, whereas the individual pieces of context are each "a measurable component of a given situation" [10].


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As the context information available to a context-aware system at any moment is so extensive, dynamic and highly dimensional, it is a significant challenge for a system observer to ascribe significance to changes in the data or identify emergent trends, much less capture the transient situations that are occurring amid the churn of the data.

The visualisation of large and complex *multivariate data sets*, such as those that context-aware system developers work with, is becoming increasingly crucial in helping those developers to organise and distill data into usable information [2]. Interactive visualisation tools help the viewer perform visual data analysis tasks: exploring patterns and highlighting and defining filters over interesting data.

Here, we present Situvis, a scalable visualisation tool for illustrating and evaluating the makeup of situations in a context-aware ubiquitous system. Our tool is based on well-founded situation specification semantics. By incorporating real situation traces and annotations, Situvis assists system developers in constructing and evaluating sound and complete situation specifications, affording them a better understanding of the situation space, and the reliability of modelling with situations based on real, recorded sensor data. It is a framework that allows developers to understand, at a high level, how their system will behave given certain inputs.

The following section provides a formal description of situation specifications and a review of some challenges faced when working with context and situations. We then describe the details of the Situvis tool, including a demonstration of its utility, followed by an informal evaluation and discussion of its properties.

## CONTEXTS AND SITUATIONS

### Situation specifications

Based on our experience with modelling context for adaptive systems [4, 10], and from the extensive literature on the subject [5, 6, 8], we can make some observations: the incoming sources of context are viewed as a finite number of variables: either nominal or categorical values, e.g., activity levels {idle, active, highly active ...}; or quantitative ordinal values which may be defined over some known interval, e.g., noise level in decibels {0, 140}.

Location information will typically arrive as individual values for an object's $x$, $y$ and $z$ values, and may be recorded by numerous disparate positioning systems, but is modeled as a higher-level abstraction to make it easier to reason with. We have previously completed research that allows component $x$, $y$ and $z$ coordinates to be composed into a symbolic representation, given some domain information [15], and so can work with locations as readable as "Simon's office" or "Coffee Area". Our visualisation tool can accept either raw sensor data or these higher-order categorised data.

Situations are high-level abstractions that serve as a suitable model with which to develop context-aware systems. In order for a system to be able to recognise situations, they must first be specified. The semantics of situation specification can be seen in the work of Henricksen [8] and Loke [11]. Based on this work, we make some assumptions about situation specification so that situations specified using declarative languages such as these could simply be "plugged-in" to our tool.

Situation specifications are boolean expressions (sometimes called assertions in computer programming)—they are either true or false, denoting occurrence and non-occurrence, respectively. Assertions may be composed using the logical operators AND ($\wedge$), OR ($\vee$), and NOT ($\neg$), resulting in richer expressions. Domain-specific operators can be defined to complement these operators. For example, for location we could define a "distance" operator. The distance operator may take two arguments and return a numerical value of the distance between them. Domain-specific operators are also required for situation specification. For example, for many context dimensions an essential operator is one that takes a value and a range and returns true if that value exists within the range.

We can thus define a situation specification as a concatenation of one or more assertions about contexts, which leads us to the following formal definition:

*A situation specification consists of one or more assertions about context that are conjoined using the logical operators* AND *($\wedge$),* OR *($\vee$), and* NOT *($\neg$). Assertions may comprise further domain-specific expressions on context, given that the required semantics are available.*

### Properties of context-awareness

Situation specifications are essential in achieving two very important properties of context-aware systems: *soundness* and *completeness* [11]. A system is sound if it does not give false positives when determining a situation; it is complete if it contains specifications for all situations to be detected.

Related to these properties is *perceptual distinguishability*. If a system state exists that involves multiple situations, the observer should be able to distinguish between those situations. It may be the case that two situations' specifications are satisfied by a given occurrence. In the case of compatible situations, this could be due to one situation's specification subsuming another. If the specifications are incompatible, however, we must have a means to re-evaluate them. Situations are generally specific to behaviours, and, as a result, their compatibility requirements are determined by the compatibility requirements of behaviours.

The adaptive systems that we are concerned with are user-centric, and so user feedback is an important aspect of their evaluation. Situation annotation is a particularly useful mode of feedback for us, because it allows us to contrast situation specifications with actual traces of these situations. It also exposes the subjective nature of situations. However, to develop sound and complete situation specifications, it is necessary to capture two facets of reality: those situations that our specification must successfully characterise; and those situations that it should not. Therefore, the annotated situations are an important guideline, but the traces of undesired situations are also important to avoid false positives.

Situations can range from the very simple to the very complex, depending on the number of contextual components they are defined over. The more complex a situation becomes, the more difficult it is to pick out similarities or differences between multiple situations in aggregate, without the support of a visual analytics tool. This ability is important because the similarity of one situation to another determines the possibility of them occurring together or in sequence within a small period of time.

### Visualisation of context data

There exist myriad visualisation techniques, from time-series to multi-dimensional scatter plot methods, which can be adapted to the exploration of multidimensional context data. Our focus here is not only on the exploration of such context data, but also the scope of the higher order situations, their specification, and data cases which fall outside the set boundaries. The Table Lens, a focus+context visualisation, supports the interactive exploration of many data values in a semi-familiar spreadsheet format [14]. In practice, due to the distortion techniques employed, users can see 100 times as many data items within the same screen space as compared with a standard spreadsheet layout. Rather than showing the detailed numeric values in each cell, a single row of pixels, relating to the value in the cell, is shown instead. The Table Lens affords users the ability to easily study quantitative data sets, but categorical values are not well supported.

An alternative to a single visualisation are co-ordinated, linked visualisation techniques employing brushing and querying. Three linked views of multi-dimensional data—using a Principal Components Analysis (PCA) view, interactive brushing, and dimensional querying with parallel bargrams—are employed in the Antenna Design Gallery [12]. Here the actions or queries in any one window or view are reflected in all. A user selecting a range within a given dimension reduces the data cases in the PCA view, and in the element values highlighted in the other bargrams. This encourages exploration of a large, multivariate data set, as different facets of the data can be seen in each view.

## PARALLEL COORDINATES

Parallel Coordinate Visualisations (PCVs) are a standard two-dimensional technique ideally suited to large, multivariate data sets [9]. The technique excels at visually clustering cases that share similar attribute values across a number of independent discrete or continuous dimensions, as they can be visually identified through the distribution of case lines within the visualisation [3]. The user can see the full range of the data's many dimensions, and the relative frequencies at which values on each axis are recorded. These features are visible in Figure 1, which shows context data from our user study, which we will describe in the next section.

PCVs give users a global view of trends in the data while allowing direct interaction to filter the data set as desired. A set of parallel horizontal axes are drawn, which correspond to attributes of the readings in the system. In our case, the readings are records of context data at a certain time, with each axis representing a sensor in the system. Then, a set of $n$-dimensional tuples are drawn as a set of purple *polylines* which intersect each axis at a certain point, corresponding to the value recorded for that attribute. Discrete and quantitative axes can be presented in the same view.

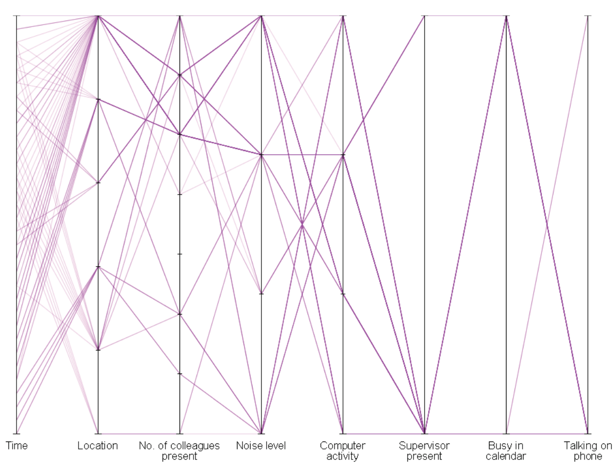


**Figure 1. Our Parallel Coordinates Visualisation. This is a view of 96 overlaid context traces with 8 data dimensions gathered over 3 days. Strong correlations can be seen between the three days recorded: the subject spent the majority of all three days at their desk (the first value on the "Location" axis), with some deviations due to coffee breaks or visits to their supervisor's office at irregular times.**

As all the polylines are being drawn within the same area, the technique scales well to large data sets with arbitrary numbers of attributes, presenting a compact view of the entire data set. Axes can be easily appended or removed from the visualisation as required by the dimensions of the data.

As Parallel Coordinates have a tendency to become crowded as the size of the data set grows larger, techniques have been designed to cluster or elide sub-sets of the data to allow the dominant patterns to be seen [1]. Direct interaction to filter and highlight sections of the data encourages experimentation to discover additional information.

Hierarchical clustering [7] uses colour to visually distinguish cases that share a certain range of values into a number of sets, increasing the readability of the diagram. We use a similar technique to group case lines that are assigned to a certain situation, colour-coding these as a group. Different situations can be colour-coded so that the interplay of the context traces that correspond to them can be easily seen.

## EVALUATING SITUATIONS WITH SITUVIS

### Description & case-study

Situation-awareness is commonly applied to adaptive systems as a means to introduce useful cues for automatic behaviour adaptation. System developers are tasked with codifying situations that their system should respond to by tying together loose configurations of sensor readings. Because of the constant fluctuation in the values of these sensor readings (due to minute changes in the property being measured, or due to the accuracy of the sensor), situation definitions are frequently composed of a set of ranged intervals that give the developer some more latitude to cover more of the sample space than if they had to define a situation for every possible combination of sensor readings. When these ranges are all logically conjoined and the value from each sensor falls within range concurrently, the behaviour attached to this situation is invoked.

Situvis is built using Processing [13], a Java-based visualisation framework which supports rapid prototyping of visualisation techniques.[1] Each context dimension is represented in Situvis as a vertical axis. Each axis is divided equally based on the number of values that could be recorded for this dimension. For example, the axis for location contains six points representing the symbolic locations that we chose to include in our analysis. A situation trace is represented as a polyline—a line drawn starting at the leftmost axis and continuing rightwards to the next adjacent and so on, intersecting each axis at the point that represents the value that the context has in that situation trace. For example if, in a given situation, a user's computer activity level is "idle", and their location is "canteen", and these two axes are adjacent, then a line will be drawn between those two points. Each situation trace is plotted on the axes and the result is a view of all of the situations, significant and insignificant, that occurred in the system over a period of time.

In order to carry out our case-study, we required real context data with which we could characterise situations. We chose to gather context data and situation annotations manually over a three day period. While the capabilities exist to collect these context data automatically, we chose to collect the data through manual journaling, so that we did not

[1] You can read more about Situvis and interact with a demo of the software at http://situvis.com.

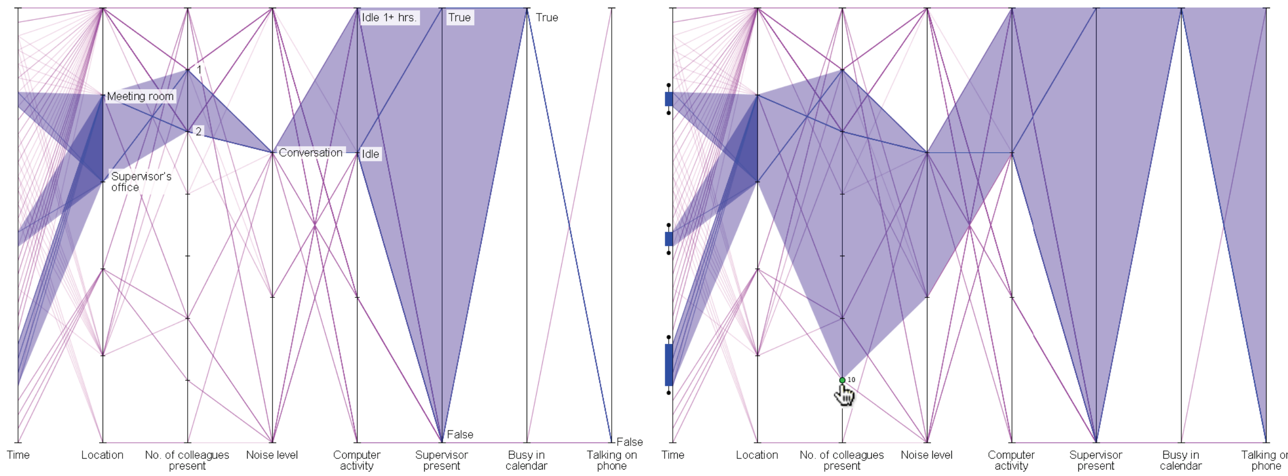


**Figure 2. A view of the Situvis tool showing 3 days of a user's context, with traces annotated as being in a "meeting" situation highlighted (left). These situations occurred at many different times throughout the day in two different locations, with a range of values for the other contexts. The user can interactively expand or contract the situation definition along any of the axes. In this case, they have chosen to modify the situation specification to allow for more colleagues to be present, the noise level to be greater and the possibility of talking on the phone (right).**

need to factor in issues with the aggregation, uncertainty or provenance of the context data.

Our trial subject recorded their context every fifteen minutes (10am–6pm) for three consecutive weekdays. They captured context in the form of time, location, noise-level, number of colleagues present, their supervisor's presence (true or false), their phone use (either taking a call or not), calendar data (being busy or having no appointments), and computer activity. For simplicity, the noise-level was recorded on a 4-point scale of quiet, conversation, chatty, and noisy. Likewise, computer activity level was scaled as idle for an hour or more, idle for less than an hour, active, and highly active. We defined six symbolic locations: meeting room, canteen, sports center, supervisor's office, subject's desk, and a lecture theatre. Figure 1 shows a view of the Situvis tool with all of these traces plotted together in one view.

The subject also annotated what, if any, situation they were in at the time of data capture. These annotations are used in Situvis to identify situations that require specification in the system.

### Specifying situations with context

Situation specifications are structured according to the definition we discussed previously. Situvis enables a developer to select all occurrences of a given annotated situation, and add further cases to this definition using interactive brushing of polylines, or by dragging a range indicator on the left of the axis to expand or contract the range of values covered by this specification. The user can evaluate existing situation specifications overlaid against actual trace data and see where they need to be modified.

An example of this process can be seen in Figure 2. The trial subject annotated multiple occurrences of a "Meeting" situation. By selecting these traces, it is evident what context dimensions characterise them. We can see that "Time" and "Supervisor presence" are not useful due to the multiple split lines on their axes. Hence they are ineffective when defining constraints. The specification is clear from the other dimensions, however, and could be expressed as:

$$\begin{aligned}
&\{1 \geq \text{No.colleagues} \leq 2\} \wedge \\
&\{\text{Location} = (\text{meeting room} \\
&\qquad \vee \text{ supervisor's office})\} \wedge \\
&\{\text{Phone use} = \text{none}\} \wedge \\
&\{\text{Computer activity} \geq \text{idle}\} \wedge \\
&\{\text{Noise-level} = \text{conversation}\} \wedge \\
&\{\text{Calendar} = \text{busy}\}
\end{aligned}$$

None of these values alone can characterise "Meeting", as the trace data illustrates. Furthermore, each dimension may not always be available. Situvis allows one to identify combinations of dimensions which, when taken together can provide a good estimation of the situation. For example, "Location" taken with "No. of colleagues" is a good indication of "Meeting", as the interval that they create does not contain polylines that characterise different situations. This can also give system developers an insight into which sensors in their system are the most useful, and which types of sensors they should invest in to gain the most added benefit in terms of the expressiveness of their system.

### Situation evolution

When existing specifications are overlaid on the trace polylines, the developer can see where specifications are too strong or weak. Constraints that are too strong will cause the system to sometimes fail in determining when that situation is occurring. Constraints that are too weak may be wrongly interpreted as an occurrence of the specified situation, when in fact a different situation is occurring. When the overlaid situation encompasses traces that are not relevant, the user can strengthen the constraints. Similarly, the user can weaken constraints to include traces that happen to fall outside the existing specification.

We hypothesise that as more trace data is added and annotated, the constraints that we have defined for "Meeting" may be too strong. By overlaying our specification on top of the polylines, it will be obvious where constraints need to be strengthened, weakened or even excluded altogether. Situvis enables a developer to drag the boundaries of specifications to change the polylines that they cover, essentially changing the constraints of the situation.

### Situation evaluation

Context-aware adaptive systems are very sensitive to incompatible behaviours. These are behaviours that conflict, either due to device restrictions, such as access to a public display, or due to user experiences, such as activating music playback while a meeting is taking place. Situations are closely tied to behaviours—they define envelopes in which behaviour occurs. As a result, their specifications are directly responsible for compatibility requirements. By harnessing this factor, we can address another key aspect of situation evaluation.

Conceptually relating situations to each other from a behaviour compatibility standpoint is an overwhelming task for a developer. We recognise that there are two situation relationships that may lead to incompatibility:

**subsumption** if $a$ subsumes $b$, and $b$ occurs, then $a$ will certainly occur.

**overlap** if $a$ overlaps $b$, then $a$ and $b$ may co-occur.

Our tool allows multiple situation specifications to each be coloured distinctly. When two or more situations are shown together, the overlap in their constituent contexts is clear, as well as the scope of their dissimilarities. This view allows the developer to alter constraints where necessary, while the overlap and subsumption relationships are refreshed and displayed on-the-fly. A screenshot of this scenario is seen in Figure 3.

## DISCUSSION

We have shown, using a case-study, the utility of Situvis in the situation specification and evaluation processes. The traditional approach to situation specification is subject to limitations: context constraints are based on static definitions of these concepts in knowledge representation structures (e.g., ontologies); they are derived from a developer's conceptual understanding of certain situations; and do not contain methodologies for ensuring soundness and completeness. To address these limitations, Situvis presents a developer with a reference point for situation specification and evaluation through the display of actual trace data and situation annotations. The relevance of context to a specification is made clear, and contrasting situation traces can be used as a guide for specification.

Context-aware systems are dynamic—sensors, users and habits are constantly changing. Hence, we cannot expect situation specifications to remain static. It must be possible to

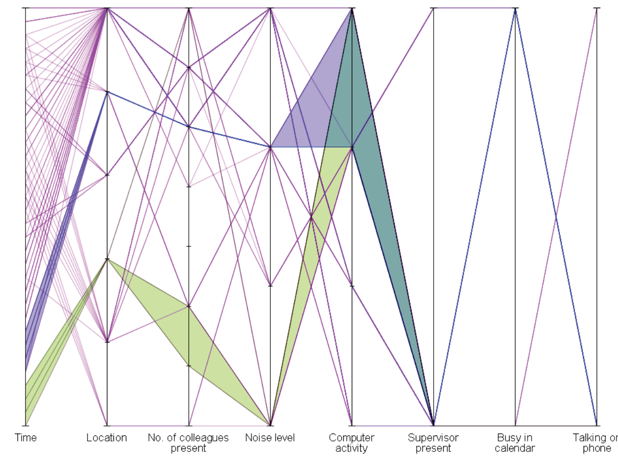


**Figure 3. A view of two distinct situations. The higher blue range is a meeting situation, whereas the lower green range is a seminar that occurred after normal work hours. The dissimilarities between these situations are clear from the tool, and the specifications can be further teased apart if required.**

re-evaluate them accordingly. Current approaches entail the modification of constraints based on data logs or experience. Situvis allows developers to visually overlay specifications on traces, and tailor their constraints as a result. Unlike traditional methods, Situvis clearly depicts cases where constraints are too strong or too weak.

In addition, we have identified a scenario that a tool like Situvis could address in the future. It is concerned with the notion of *closeness* of situations. Two situation specifications are close if small changes in context can cause an evolution from one to the other, a property easily identified from context constraints. Close situations may be significant as the transition step from one to the other is small in terms of probable context changes. Visualising these relationships in Situvis will allow a developer to identify the following: suggestions of areas where the situation associated with a behaviour may be incomplete; and points where the system behaviour may be unstable. The former is used to increase developer awareness of situation-behaviour associations that they may have omitted. The latter is useful for highlighting obtrusive behaviours associated with close situations—points where a see-saw-like cycle from one to another may occur in a short time frame, resulting in an erratic user experience. One can thus introduce inertia by strengthening constraints, making the transition step between them larger.

Some contexts may be relevant only when combined with other dimensions. Ideally, we would display all of the context information that is available in the system for a particular situation annotation. A developer could then eliminate contexts that are not useful based on visual analysis. However, we have yet to evaluate the feasibility of this approach in large-scale systems.

Some other context dimensions are also not easily represented on a line. In particular, Location, with its domain relations like subsumption, is difficult to represent in two dimensions. We are researching techniques to flatten hierarchies for a more intuitive representation.

## CONCLUSIONS AND FUTURE WORK

We have presented Situvis, a tool in development which uses a Parallel Coordinate Visualisation to illustrate situation traces and specifications. The tool assists developers in describing situations through direct interaction, providing a natural interface for a developer of context-aware systems. By stacking many instances of context together in one view, it becomes simple to inspect the correlation between situation specifications and the actual situations that occur during deployment. Situvis enables a developer to evaluate the soundness and completeness of situation specifications within the framework of real data.

By visually analysing the overlap of situation specifications within their system, the developer can identify where multiple situations require similar context values to be activated. Such overlaps may imply problems in the situation specifications, as conflicting behaviours may be triggered by conceptually similar situations. Thus, the developer can compare situations against others, and change the situation's specifications to become stronger or weaker as necessary.

We are developing a metric of the closeness of situations for use in evaluating soundness and completeness. Close situations may frequently occur one after the other, which may lead to unpredictable system behaviour from a user's perspective. We hope that the Situvis tool will prove useful in helping to avoid this oscillation.

A weakness of the current version of the Situvis tool is that it does not explicitly support probabilities in situation specifications. In many context-aware applications, robust probabilistic inference is a requirement to handle the naturally fuzzy data in the system. We are considering the addition of an overlay which will allow users to set up a probability distribution, though this requires a more in-depth study of the treatment of uncertainty in situations.

We are ongoing in our investigation of properties of situations that can be exploited for further evaluation. For example, Situvis could also be used by users of the context-aware system as a gateway to user programming: helping them to unroll the cause of a situation activation, so that they can gain insight into why the system began to behave as it did.

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# Simulation Framework in Second Life with Evaluation Functionality for Sensor-based Systems

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### ABSTRACT
This paper describes a simulation framework for sensor-based systems utilizing "Second Life", a popular virtual three-dimensional multi-user online world. With this platform, the components of a sensor-based system can be mapped to (or, represented by) virtual counterparts. The intuitive user interface of Second Life and its comprehensive visualization support evaluation tasks of ubiquitous computing applications. Developers can directly control and manipulate virtual counterparts of real devices. In this way, different settings of a sensor-based system can be tested. The main contribution of our work consists of a bi-directional interface between sensor-based systems and Second Life.

### ACM Classification Keywords
I.6.7 Simulation and Modeling: Simulation Support Systems—*Environments*

### General Terms
Design, Experimentation

### Author Keywords
Simulation, testbed, sensor-based systems, evaluation, Second Life

### INTRODUCTION
Ubiquitous computing environments and sensor-based systems are highly active fields of research. Many exciting new devices are being developed and the amount of powerful and versatile sensors is rapidly increasing through the advances in embedded systems and technological evolution.

The implementation, testing and evaluation of new ubiquitous systems in a real environment are laborious tasks. Significant time and effort has to be spent on designing and testing prototypes and simulators in order to avoid unforeseen problems, e. g. , regarding optimization, before the system is actually installed. While simulators for specific types of sensors are available, it is still difficult to evaluate a heterogeneous complex system. Hence the visualization of all the simulated sensor data is desirable and an intuitive interaction capability to change the parameters and spatial position of the devices would be helpful to optimize the system.

Because of these requirements, we propose a three-dimensional (3D) virtual environment for the simulation, testing and evaluation of sensor-based systems. Besides extensive research in virtual reality, nowadays even game engines and multi-user online worlds provide convincing 3D environments. So, instead of creating a new 3D-engine, we decided to use the 3D environment of Second Life [14]. In Second Life (SL), 3D content including buildings and props can be created easily, and anyone can interact with the environment in the form of an 'avatar' (a human-controlled graphical representation of the user).

The rest of the paper is structured as follows. We start with a brief review of related work. To motivate the merit of our simulation framework, we then report on the experience with an existing sensor-based system. After that, we explain two different approaches to simulation. First, we describe a rapid-prototyping approach for SL, and discuss its benefits and shortcomings. Second, we describe our own simulator framework [3, 16], and explain its functionality with respect to evaluation of sensor-based systems. We give an example where our system is used to evaluate the performance of an indoor-positioning system. The paper concludes with a discussion and summary.

### RELATED WORK
Currently, the development, testing and evaluation of new systems is realized in different ways, ranging from real-world testing and evaluation [4] and miniature mock-ups for prototyping, to software-based simulators [1, 11]. Recent testbeds are MoteLab [17] for wireless sensors, eHomeSimulator [1] for smart environments, and ubiBuilding Simulator [11] for large scale context-aware systems. While these software-based testbeds are far more practical than physical models, all of them are limited to testing in two-dimensional space.

Ubireal [10] is a 3D simulator for smart environments. Yet, its focus lies on systematic testing to verify rules and user-specified programming between different smart devices and sensors. There is no support for interactive exploration and testing. Another simulator, called TATUS [12], is based on the Half-Life game engine. The system focuses on human interaction with ubiquitous computing environments rather than the setup of such environments.

While all these approaches demonstrate promising features, they either (1) do not work as testbeds for simulation, or (2) provide specialized (non-generic) solutions, or (3) lack 3D interaction with the simulated virtual environment.

Let us now take a closer look at solutions that feed real-world data from sensors into SL and/or SL data into the real world (e. g. to control a device). In [8] data from a specialized power-plug based sensor network are fed into the virtual world by means of a (latency restricted) SL script-based implementation of a XML-RPC protocol. The data is used for visualization but there is no support for interaction with it. [9] is a work where sensors embedded in commercial mobile phones are used to infer real-world activities (whether the user is idle, walking or running), that in turn are mapped to visual metaphors in the virtual environment. [5] reports about a real-world control panel that can both control objects in the virtual world of SL and in turn be controlled by them. Changes to the knobs or pushbuttons in the real world are translated to their virtual counterparts in SL, and pushing the virtual buttons controls the LEDs on the real world control panel.

Although these approaches demonstrate interesting results, (1) they are not generic, (2) they don't provide a direct bi-directional feedback loop (e. g. if we control a real device via the virtual counterpart from inside SL and the status of the real device changes this change is immediately fed into and represented in SL again and vice versa.) and (3) they don't take into account the context of the devices in the environment (e. g. the position and the orientation of a sensor can be crucial for the system behavior like a indoor positioning system).

Because of the lack of interactive and generic solutions, we have created a bi-directional simulation framework for SL [3]. This system has been extended from a scripted simulation within SL to a more flexible interface and will be described by an example application.

## EXAMPLE APPLICATION

Positioning systems are often used in ubiquitous computing environments. As a simple motivating example for our simulation framework, we chose an existing indoor positioning system [2]. Sensor placement for such a system is a non-trivial task as it depends on several factors such as the infrastructure, the amount and type of available sensors, and interferences.

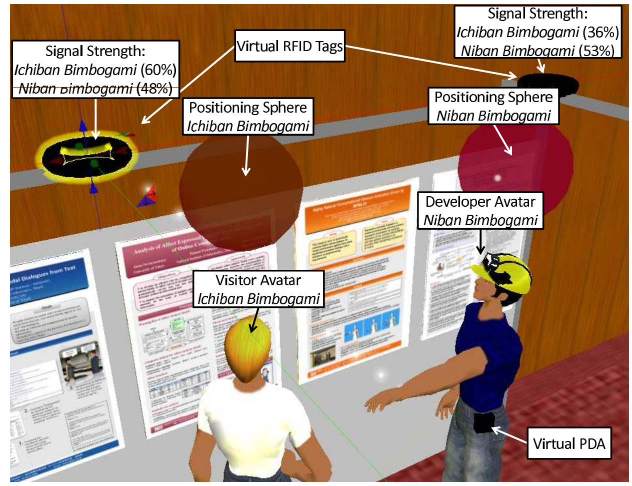


**Figure 1. Example of the simulated positioning system in Second Life with a Visitor Avatar experiencing the system and a Developer Avatar who is interactively adjusting the properties of a virtual RFID tag.**

The system described in [2] features different kinds of sensors and emitters: infrared beacons and radio-frequency identification (RFID) tags. The accuracy of the positioning system depends on the good placement of these sensors and emitters in the environment. The user carries a mobile device, which is equipped with the corresponding sensors. On this device the position of the user is computed based on the received sender data and afterwards displayed on a 2D map on the device.

When the system was installed in the environment, initial trials to improve accuracy by adding additional emitters failed. Furthermore, in boundary regions of the emitter field some unexplainable artifacts appeared in the position calculation. These open issues could be resolved easily in our SL based simulation system, as described in the following sections.

## RAPID PROTOTYPING IN SECOND LIFE

Our first approach was to investigate the simulation capabilities of SL. Therefore we used the official API of SL that is called "Linden Scripting Language" (LSL). This programming language allows one to assign scripts to in-world objects. With over 300 library functions and different data and message types, scripts can control the behavior of virtual objects and communicate with other objects and avatars (users of SL). Limitations of LSL include time delays for movement of objects (0.2 sec) and memory constraints for scripts (16 KB). These constraints have a high impact on the achievable simulation accuracy, response times, and achievable simulation complexity within SL.

To simulate the previously discussed positioning system we created virtual objects in SL that represent RFID tags and can be positioned within the virtual environment interactively (see Fig. 1). Visitors who wish to be

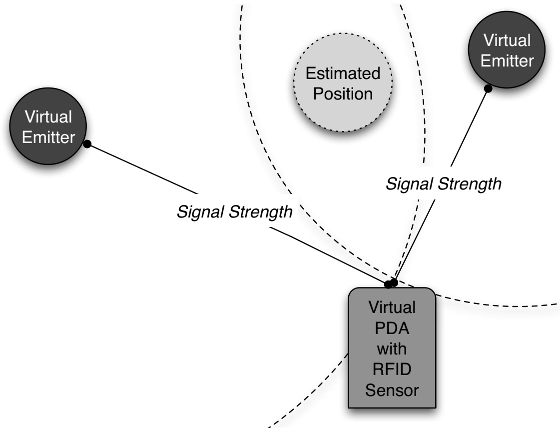


**Figure 2. Conceptual overview of the example application: the virtual PDA reads the signal strengths of the virtual emitters and calculates an estimated position.**

positioned by the system in SL have their avatar take a copy of a PDA object. The virtual PDA embeds a LSL script that is the core of the simulated positioning system and performs the calculation of the position. The PDA communicates with the virtual emitters and takes the signal strength to estimate the position, just as the real system (see Fig. 2). In the real world application, the result is shown on a 2D map on the PDA. In SL the calculated position is visualized in three dimensions, as a floating sphere in the virtual environment (see Fig. 1). If a user logs in to SL as a "visitor avatar", he or she can experience and interactively test and evaluate the sensor-based system. As a "developer avatar" the user can additionally adjust the virtual sensors and devices in the virtual environment.

The artifacts in the example application could be experienced in the simulation in SL. In both cases the signal range of the RFID tags has been too high compared to the distance of each RFID tag to another. This explanation was found after interactive testing (repositioning the sensors and adjusting their sender range). Consequently, the best results were achieved with just a small overlapping of the RFID signals.

Benefits of this approach include the ability of rapid prototyping of coarse simulations with reduced complexity and no need for additional software or servers: the scripts in SL reside within the objects. Shortcomings of this approach are the aforementioned limitations of the scripting language. Additionally, it can be very tedious or even impossible to map the functionality of an existing system into LSL. A better solution is to provide an interface to reuse existing systems, this approach is described in the following section.

## SIMULATION FRAMEWORK WITH TWIN-WORLD MEDIATOR

Our architecture (Fig. 3) consists of three components: (1) the Twin-World Mediator, (2) a sensor-based system, and (3) the SL 3D environment. The main task of the Simulation Framework is to provide an interface to existing systems, sensors and simulators and to mediate the exchange of data with SL for visualization and interaction.

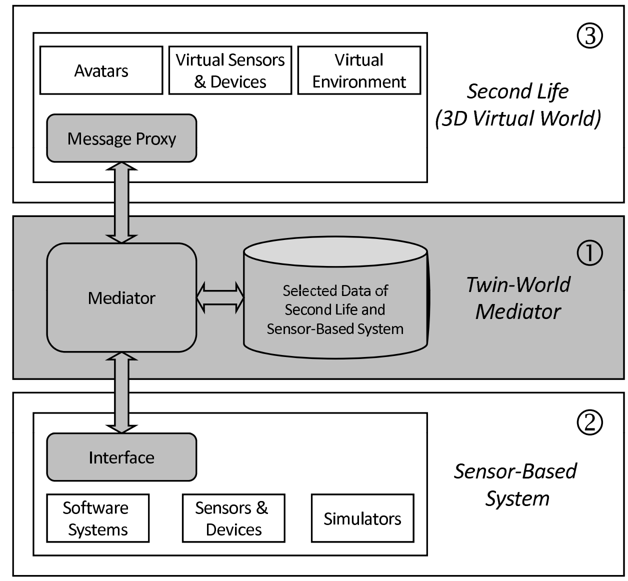


**Figure 3. Architecture that embeds existing sensor-based systems (2) with Second Life (3) through the Twin-World Mediator (1).**

In the following we first describe the architecture in more detail. To illustrate the usage of the system, we show how we embedded our example application.

### Components of the Architecture

The *Twin-World Mediator* (1) consists of the Mediator, the Message Proxy, the Interface and a database. The key component of the simulation framework is the Mediator which handles the data exchange between Message Proxy, Interface and the database of the simulation framework. It ensures the data exchange of the components of the sensor-based system with their virtual counterparts in SL.

A *sensor-based system*(2) typically consists of software systems and sensors & devices. Simulators are used for unavailable sensors and devices. The components of the sensor-based system register as listeners through the interface for the desired data.

The Message Proxy connects to *Second Life*(3) and gathers data about the components in SL and sends them to the Mediator. We are especially interested in the state of the avatars, the virtual sensors & devices, and the virtual environment because they represent the virtual counterparts of the sensor-based system which is to be tested based on their data. Obstacles in the virtual environment such as walls and other objects can influence the simulation.

```
float refresh_rate = 20; // 20 times per second
rotation old_rotation;
rotation new_rotation;
vector old_position;
vector new_position;

default
{
    state_entry()
    {
        // Activate the timer listener every
        // 'refresh_rate' times per second
        llSetTimerEvent(1 / refresh_rate);
    }

    timer()
    {
        new_rotation = llGetRot();
        new_position = llGetPos();

        // Rotation changed?
        if (new_rotation != old_rotation)
        {
            // Position changed?
            if (new_position != old_position)
            {
                llSay(0, "<Rotation " + (string)new_rotation + "> " +
                         "<Position " + (string)new_position +">");
                old_rotation = new_rotation;
                old_position = new_position;
            }
            else
            {
                llSay(0, "<Rotation " + (string)new_rotation + ">");
                old_rotation = new_rotation;
            }
        }
        else
        {
            // Position changed?
            if (new_position != old_position)
            {
                llSay(0, "<Position " + (string)new_position + ">");
                old_position = new_position;
            }
        }
    }
}
```

**Figure 4. Example of an update script for virtual objects, which informs about changes of position and/or rotation and is implemented in the Linden Scripting Language.**

### System Setup

In the following we explain how to integrate an existing system to our architecture. As an initial step the simulation framework has to be prepared for the specific simulation task. The developer has to register the existing sensor-based system with its hard- and software, in order to inform the simulation framework which data (from SL or other components) are required for the simulation task. This is done by registration as listener through the interface for the desired data.

In our example the sensor-based system consists of the PDA positioning software, and a simulator for the behavior of the RFID tags. The required data from SL comprises the coordinates and the orientation of the emitters, sensors, and avatars.

The Twin-World Mediator configures the message proxy according to the registered listeners. Then, the message proxy connects to SL and continuously listens (in SL) for the requested data and communicates it to the database of the Twin-World Mediator. Some objects are static and their data will be gathered only in the initial step (e. g. parts of the virtual environment like walls), whereas other objects are potentially moving; so they have to report about their changes (e. g., avatars, virtual sensors and devices). In those objects we have embedded specific LSL scripts to send the updates to the message proxy (see below).

### Update Scripts for Virtual Objects

The example LSL script (shown in Fig. 4) continuously sends updates about position changes and/or rotation with a predefined refresh rate (here 20 times per second). During each refresh cycle first the rotation and the position of the object are determined by the functions llGetRot and llGetPos. The new values are then compared with the previous values in order to determine whether the rotation and/or the position of the object has changed. Only the changes are transmitted (function llSay) to keep the traffic low. It depends on the object which refresh_rate is necessary and which object's changes (e. g. rotation, position, size or color) has to be transmitted. For example, for a RFID tag only the position is important and a refresh rate of 4 times per second is sufficient. The scripts are rather easy to understand and therefore quite easy to adapt for their specific task.

One of the most important differences to previous and related work is that the message proxy uses communication methods of both the scripting language LSL, and the libsecondlife API [7]. (Libsecondlife is an unofficial API that interfaces SL as a client and enables access to data of the virtual environment.) Thus the performance can be improved, technical limitations like the time limitations of the XML-RPC method of the LSL are circumvented, and SL can be interfaced more effectively.

### Simulation Update

After the system has been initialized, the Twin-World Mediator synchronizes the update loops of the sensor-based system and of SL to allow for development and testing with 3D interaction and visualization. As said before, the static data is collected only once (to save bandwidth) and sent to the database of the Twin-World Mediator.

In the second step the message proxy continuously collects (in an infinite loop) all the subscribed dynamic data and sends it to the mediator. The Twin-World Mediator notifies data changes to the listeners of the components of the sensor-based system. Then the components process this data and send the results back to the Twin-World Mediator. Data which is meant to be visualized in SL is sent via the message proxy to SL.

In the case of our example (the indoor positioning system), the coordinates of the virtual RFID tags in SL are sent to the RFID-simulator. The coordinates and orientations of avatars are also sent to the simulator. The simulator computes the results and sends them back to the Twin-World Mediator, which in turn delivers the data to the positioning system. In our case the PDA positioning system has been slightly modified in order

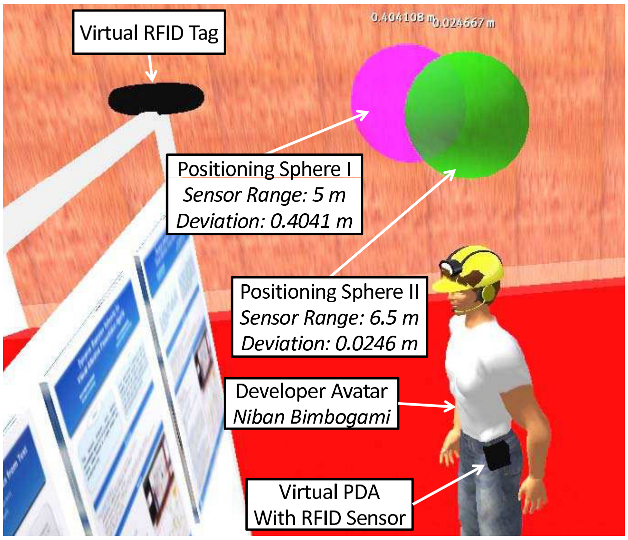


**Figure 5. Basic evaluation of an indoor positioning system by comparing different sensor ranges and measuring the accuracy/deviation (i) sensor range 5 meters and (ii) sensor range 6.5 meters.**

to be able (i) to receive the simulated sensor data of the virtual RFID tags, and (ii) to provide the estimated user position for the Twin-World Mediator.

The positioning system sends its results (the estimated position of the avatar) to the Twin-World Mediator. The message proxy takes this data and visualizes it in SL. We use a sphere to indicate the estimated position of the avatar in SL. In this way, the developer can inspect the results of the positioning system in SL (see Fig. 1).

In the following section we show how this can be extended for the evaluation of a sensor-based system.

## EXAMPLE EVALUATION OF SENSOR-BASED SYSTEM

[4] reports about the evaluation of the accuracy of a installed tag-based location system (Ubisense [15]) and the influence of the human body on it based on the fact that many tag-based systems use communication frequencies that cannot pass easily through the human body. To measure the accuracy of the system, they use a combination of definitions suggested by [6].

As a simple example how our approach could be used for the evaluation of a sensor-based system we compare the accuracy with different system settings. To measure the accuracy of the estimated position the deviation is computed by calculating the distance between the real position of the avatar and the estimated position. The measured deviation of the estimated position is displayed on the top of the positioning sphere (see Fig. 5). Obviously, the evaluation of a sensor-based system with our approach heavily depends on the quality of the used simulators. If the simulator takes into account obstacles for the sensors (like walls or human bodies) then our approach would facilitate the evaluation of a sensor-based system and it even would enable to compare two different sensor-based systems with the same data under different conditions.

In Fig. 5, the aforementioned indoor positioning system is tested with two different sensor ranges of the RFID sensor. RFID tags are placed on a uniform grid with 6 meter spacing. The Positioning Sphere I indicates the estimated position for a RFID sensor with a sensor range of 5 meters and shows a deviation of 0.4041 meters. Positioning Sphere II, which indicates the estimated position for a RFID sensor with a sensor range of 6.5 meters, shows a better accuracy (deviation 0.0246 meters) than Positioning Sphere I. Thus the issues that have been encountered with the real system (as mentioned before in Example Application), could be evaluated in a virtual setup and lead to the conclusion that the best results are achieved with a small overlapping of the RFID signals. With the current RFID tag placement in the environment Positioning Sphere II matches this condition better than Positioning Sphere I.

So far, we compared the system behavior of the same indoor positioning system with different sensor ranges and placements of the RFID tags in the environment. But obviously, modified versions of the current underlying algorithm or completely distinct algorithms could be compared with each other (using their best sensor range and RFID tag placement in the environment). For the evaluation of systems other metrics than the deviation could be desirable. The values of these parameters can be fed into the system via the Twin-World Mediator and displayed on the top of the positioning sphere as well (by a short LSL script). In addition to text-display, color-coding and resizing can also be realized with LSL.

## DISCUSSION AND CONCLUSIONS

The paper proposes a novel simulation framework based on the 3D virtual environment of SL, which can be used as an evaluation testbed for sensor-based systems. A core feature of our approach is the bi-directional interaction with our Twin-World Mediator. Events from the real world are reflected to the virtual world and vice versa.

With the example of a positioning system we have illustrated how our simulation framework can be used and how the virtual environment can be utilized for evaluation and optimization purposes.

Furthermore, the architecture is flexible and *extensible* and thus ensures that new sensor types, such as temperature sensors, accelerometers, or light sensors, can be included. Spatial characteristics of devices can be modeled and visualized to easily identify problems and interferences, e. g. when walls or other objects in the virtual environment influence the characteristics of the devices. Sophisticated simulators can also be adapted and connected to the system. Metrics for evaluation purposes can be updated via the Twin-World Mediator and visualized in SL.

The *3D interaction* capability of SL combined with the embedded simulators offers many advantages and opportunities. Virtual sensors and devices can be moved intuitively by 'direct' (avatar-mediated) manipulation (Fig. 1) and their parameters can also be changed easily by editing the object properties through the user interface of SL. Most importantly, these changes can also be fed back in real-time via the Twin-World Mediator and affect the connected system.

In our future work, we plan to implement a user-friendly interface and toolbox for developers of ubiquitous computing systems. To reach a broader audience and ensure higher flexibility, the Twin-World Mediator will be adapted to the emerging and open-source virtual worlds system OpenSimulator [13]. Furthermore, we intend to use the simulation framework for running systematic experiments of sensor-based systems. Specifically, computer-controlled agents, i.e. SL "bots", will populate the environment, and the behavior of the sensor-based system will be evaluated in the multi-agent setting.

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# Design and Integration Principles for Smart Objects

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Jin Nakazawa, Susanna Pirttikangas, Tsutomu Terada

## WORKSHOP GOALS AND TOPICS

Tagging everyday objects with sensors, actuators and building an instrumented environment are recent practices in industry and academia. In fact, the smart object domain has matured over the years. The combination of Internet and technologies like near field communications, real time localization, sensor networking etc. are bringing smart objects into commercial use. Several successful prototypes and applications have already demonstrated and deployed. However, the lack of commonality among the design principles and the underlying infrastructures of these projects is hindering the exciting future of smart object systems. We believe the primary reason behind this phenomenon is one missing rationale for the design and integration of smart objects. Now it is the time to focus on current practices and align on some key issues to continue the rapid progress of smart objects. The intention of DIPSO 2008 is to bring together researchers and practitioners from a wide variety of disciplines with the goal to discuss, identify, share experiences and formalize key issues surrounding the challenge of building scalable, interoperable smart objects and associated systems. Instead of narrowly focusing on new technologies, we are more interested in extracting practices from existing systems and in refining them through collaborative discussions. The immediate goal will be to investigate the key issues from a variety of angles influenced by the experience and the background of the participants. The ultimate goal will be to formalize the design and integration rationale of smart objects and to define research challenges to stimulate further research. Some key challenges that will be addressed in the workshop include:

1. *Design, Development and Representation of Smart Objects:* What are the design principles for smart objects? How to describe smart objects, what information do they carry, where does this information come from, what quality attributes does this information need to have? What is the relationship between the physical nature and the digital functionality of smart objects ? What kind of framework is suitable for selecting sensors and actuators? What kind of smart objects are suitable for a specific application domain and why? What are the difficulties in building economically feasible smart objects?

2. *Integration and Co-operation Models of Smart Objects:* What is the best approach to integrate smart objects into pervasive applications? Do we need an external dedicated infrastructure or should objects be built with communication capabilities? How to remonstrate the resource constraints of embedded platforms? How to represent the ecological relationship of smart objects? How to deploy smart object systems? How to enable end users to entail a smart space?

3. *Interaction Paradigm:* What is the appropriate interaction paradigm of smart objects? How to incorporate the smart features to an object while keeping its interaction metaphor intact? What novel enabling technologies are required to support the interactions ?

4. *Application Scenarios with Smart Objects:* What kinds of application scenarios will be benefited from what kind of smart objects? What kinds of services are expected from smart objects by applications? What are the driving economical factors that will influence smart object based application developments?

5. *Critical Success Factors:* What are the critical factors for the success of smart objects and how are they addressed? This may include, e.g. usability, security and energy efficiency.

We need a much better understanding of smart objects to approach the above mentioned challenges. In order to improve our understanding of these topics and to facilitate discussions, the workshop will be structured around the following three agendas :

1. Identifying the modalities of smart objects and smart object systems?

2. Identifying the primary design principles of smart objects. This can be decomposed into two questions: How to map an objects digital functions into it's physical appearance and how to select the augmentation role considering their potentiality and affordability in applications?

3. Identifying the appropriate way of integrating and deploying smart objects in existing or new environment. Identifying the role of end users in deployment tasks?

### Expected Outcome

We hope, the workshop will contribute in establishing a multifaceted research community in the smart object domain area. The expected outcomes are:

1. Survey of state-of-the-art work on smart object systems including the overview of existing prototypes and application scenarios.

2. Design and integration rationale of smart objects focusing on the existing practices that will provide a solid base for the rapid progress of smart object systems and stimulating further research in this area by identifying future directions.

# Advanced Middleware Support on Wireless Sensor Nodes

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## ABSTRACT
State of the art solutions employ gateways for protocol translation between wireless sensor networks (WSNs) and IT systems, which results in significant management overhead for WSN deployments. In this paper, we investigate the feasibility of IT middleware support on the sensor node itself to eliminate the need for gateways. A major challenge in this respect is the storage of relatively large network messages inside a sensor node, which might easily exceed the available resources. This turns the efficient utilization of memory into the key requirement for middleware support on sensor nodes. In order to cope with this, we derive and analyze a generic layer model for protocol processing and inspect implications on the memory requirements for each layer. Cross layer optimization is employed to gradually develop an architecture in which application relevant information is directly extracted from network packets, which drastically minimizes the overall memory consumption. We finally present the first implementation of a Universal Plug and Play (UPnP) protocol stack for sensor nodes. Measurements confirm the feasibility of UPnP support for even highly restricted nodes and suggest that support for more complex protocols is possible.

### Author Keywords
WSN, Middleware, SOA, UPnP

### ACM Classification Keywords
D2.11 Software Architectures: Domain-specific architectures, C2.4 Distributed Systems: Distributed applications

## INTRODUCTION
Motivated by the vision of ubiquitous computing, research on wireless sensor networks (WSNs) aims at the development of small, intelligent, networked sensors and actuators. These are used to create added value in diverse application domains like home automation, habitat monitoring, military, industrial automation or safety. Advancements in this area have already brought forth solutions in form of hardware and software [3] that are mature enough to be adopted in real world applications [10]. Having mature technology as a basis, the question on how to leverage the potential of WSNs becomes more and more important. Some researchers envision autonomous WSNs which use in-network processing to solve a certain task [7, 8]. For this purpose, new programming approaches and communication protocols have been developed. In other areas, like e.g. industrial automation, the WSNs are envisioned to extend the reach of IT systems into the physical world [4, 9], thus calling for the convergence of WSNs and IT. To this end, communication between WSNs and IT systems has to be facilitated.

In IT systems, the interoperability of basically arbitrary systems is desired. This motivated the vast adoption of the Service Oriented Architectures (SOA) paradigm and its implementation in form of the Web Services suite, which facilitates interaction on a high abstraction level. For the purpose of interoperability, programming and platform independent technologies like e.g. XML and HTTP are used. These technologies are usually considered to impose high requirements on computing power and memory. For WSNs, the communication mechanisms are dominated by the resource constraints (energy, computational capabilities, memory) of the nodes, so that typically efficiency is prioritized over interoperability.

State of the art solutions overcome this conflict by the use of so called gateways [6, 9]. The gateways, which are powerful nodes at the edge of a WSN, map the WSN traffic to IT compliant communication and thus preserve the freedom to use efficient communication means inside the WSN. However, the introduction of gateways leads to a dependency on an infrastructure for the use of the WSN. This restricts desirable features of WSNs like ad-hoc connectivity as a gateway needs to be installed before any interaction with the WSN. Moreover, the gateways themselves need to be maintained and therefore require additional management effort. Further, errors inside the gateway will make the WSN unaccessible. This turns the gateway into a single point of failure.

The next evolutionary step is the support of IT communication protocols directly on a sensor node, thus eliminating the need for gateways. A first step has already been made in this direction with the creation of the IETF working group on IPv6 over lower-power wireless network [2]. Support of the IP protocol allows WSNs to homogeneously blend into the IT landscape, as already shown by state-of-the-art sensor applications [4]. However, these approaches leave the support of higher level protocols (above IP) inside the sensor node an open research issue. While IP provides a general


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basis for interaction, it focuses on the delivery of data rather than on semantic interaction. In contrast to that, IT middlewares define means to explicitly model and share the services provided by the participants. This allows the easy creation of complex, distributed applications without detailed knowledge about the underlying technologies. Due to the lack of middleware support on sensor nodes, these advantages are only available for WSNs to a limited extend.

In this paper we will present an approach to facilitate middleware support directly on sensor nodes to overcome these shortcomings. To this end, we investigate the bottlenecks of middleware support using the Universal Plug and Play (UPnP) as an example. Following architectural considerations, we will propose an optimization for protocol stacks on senor nodes to reduce the consumption of memory. Finally, our results are used to build a prototype implementation of UPnP for the Sindrion [5] sensor node platform. Measurements show that UPnP support is feasible even on restricted senor nodes.

## UNIVERSAL PLUG AND PLAY

Universal Plug and Play (UPnP) is a widely used and commercially accepted middleware that allows devices to be described and controlled over the network. A peer-to-peer philosophy is inherent to UPnP, so that no central component is needed to facilitate interaction among the participants of a UPnP network. As we are interested in the realization of UPnP on a sensor node, we need to understand the requirements imposed by UPnP.

### Functional Features and Protocols

The main features incorporated in UPnP [11] are *Addressing*, *Discovery*, *Description*, *Control* and *Eventing*. The hierarchical view of the protocol stack is shown in Fig. 1.

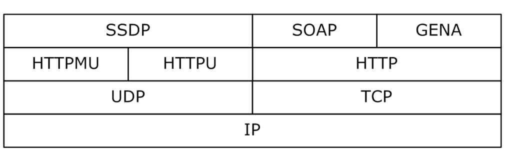


**Figure 1. Layer Model for UPnP Protocol Suite**

For *Addressing*, UPnP requires each participant to obtain an IP address via DHCP or Auto-IP. Support for this mechanism is trivial and can be expected to be provided by any IP enabled device. In order to facilitate *Discovery*, which is the dynamic look up of devices and services in the network, the Simple Service Discovery Protocol (SSDP) is used. SSDP messages are communicated via UDP unicast (HTTPU) or multicast (HTTPMU). The relevant information is encoded as plain text in specific HTTP header fields. Thus, SSDP requires a node to receive and transmit HTTP messages in the magnitude of 100 bytes as well as to conduct text parsing. Via *Description*, devices provide a description of their capabilities to the network. The description is given in XML format and transferred via HTTP. A node has to support the transmission of the descriptions, whose size is in the order of kilobytes. *Control* is the mechanism of invoking the so called actions using the Simple Object Access Protocol (SOAP), which relies on XML message exchange via HTTP. A sensor node has to support reception and parsing of the SOAP/XML messages as well as the transmission of the responses. The size of all these messages are in the order of kilobytes. For *Eventing*, UPnP employs the General Event Notification Architecture (GENA), which specifies means for (un-)subscription of observers and asynchronous event notifications. Similar to SSDP, GENA uses specific HTTP headers to transport the information for (un-)subscriptions. The event notifications consist of an XML message that is transferred via HTTP. To this end, a node needs to support HTTP message parsing and the transmission of the event notifications with similar size as SOAP responses.

Summing up, in order to make WSNs natively UPnP compliant the sensor nodes have to support parsing of incoming HTTP headers (for SSPD, GENA) and XML messages (for SOAP). Further, the reception and transmission of messages in the order of kilobytes has to supported.

## MIDDLEWARE STACK ARCHITECTURE

Let us now consider the implementation of the UPnP protocol suite on a sensor node. As UPnP uses layered protocols, the implementation will naturally follow these layers. In order to support generic statements on the issue of middleware support, we will not investigate the implementation of all UPnP protocols in particular but rather define a generic, coarse-grained layered stack architecture. We will use this architecture to identify and solve bottlenecks of middleware support on sensor nodes.

### Layer Definition

- Application layer: This is the highest layer of our model and realizes the application logic. It uses the features of a middleware to implement its functionalities. For UPnP, the application layer contains the implementation of UPnP device and service logic using the features of UPnP, as described earlier.

- Middleware layer: The middleware layer provides the middleware features like *Discovery*, *Control*, *Eventing*, etc. to the application. To this end, it translates between the semantics of the middleware protocols and their representation in a message. For UPnP, handling of the protocols SSDP, SOAP and GENA is located in this layer. These protocols specify how the UPnP semantics for e.g. eventing subscription are encapsulated in messages, i.e. which HTTP headers carry relevant information and in which format.

- Messaging layer: The messaging layer is responsible for the delivery and reception of complete middleware messages, using the underlying transport protocols. For UPnP, the support of HTTP over TCP and UDP (HTTPU/MU) is provided in this layer.

- Transport layer: The transport layer is responsible for the end to end delivery of packets over the network. To this end, it covers issues like fragmentation, routing and physical transmission. With regards to the UPnP protocol, the transport layer supports TCP, UDP and IP. Note that we ignore the lower layer communication layers in this study since we assume them to be given.

### Information Flow

Let us now investigate the information flow through the generic middleware stack architecture, depicted in Fig. 2, in order to understand the implications of the architecture on memory consumption.

*Incoming Message*

The transport layer receives and handles incoming packets and therefore needs at least one buffer to store such a packet. The size of the buffer depends on the physical packet size, which is normally defined in the MAC protocol. For the IEEE 802.15.4 protocol, the maximum packet size is 127 bytes. The Sindrion MAC protocol supports 512 bytes per packet. The messaging layer composes the incoming packets to a message, which is then provided to the middleware layer. As discussed earlier, the message size can be relatively big (in the case of XML messages) and thus will require a bigger buffer than for the MAC layer. Further, it is possible to receive multiple messages at a given point in time. Therefore, parallel reception of messages has to be accounted for. This means that, in a straight-forward layer-based implementation, multiple message buffers need to be realized.

The middleware layer extracts the middleware relevant information from the messages. The information handled inside the middleware layer requires less storage size than in the message layer (discussed in the next Section). Finally, the application layer receives the information from the middleware layer and extracts the relevant information.

*Outgoing Message*

The transmission of an outgoing message is initialized by the application. To this end, information about the type of the message and possible parameters is prepared and passed to the middleware layer. The middleware layer encapsulates this information into the middleware compliant format (e.g. HTTP header fields and XML tags). The message layer creates the complete message as required for transportation over the network. Similar as above, it is possible that multiple messages are transferred at the same time, e.g. event notification are sent to multiple observers in parallel. Thus, a buffer for multiple messages is required. The transport layer handles the transmission of single packets and therefore requires a single packet buffer.

### Memory Bottlenecks

Considering the memory requirements discussed above, we conclude that the queuing of incoming and outgoing messages consumes a considerable part of the overall memory. If we consider an exemplary UPnP stack, which e.g. should be capable of queuing five incoming and five outgoing messages with a maximum message size of 1,5 kilobyte, we need 15 kilobyte of RAM only to store the messages. This requirement can hardly be covered by existing sensor nodes, like the Mica2 (4 kB of RAM) or the Tmote Sky (10 kB of RAM) [3]. Therefore, we need a way to minimize the memory consumption.

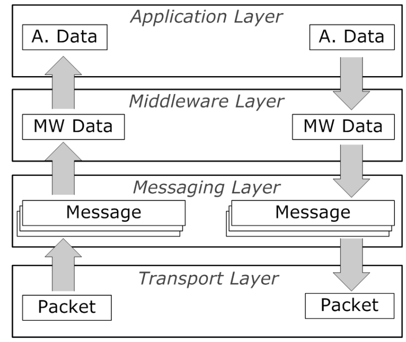


**Figure 2. Four Layered Stack Architecture**

## OPTIMIZATION CONSIDERATIONS

In the previous section we have inspected an architecture for layered protocol handling in which the storage of incoming and outgoing messages have been identified as a memory bottleneck. In order to cope with that, we will investigate a more compact storage of information.

### Messaging Layer

The messaging layer usually requires large buffers to store the messages communicated over the network. As these messages serve the purpose to realize middleware features, we leverage middleware knowledge to optimize their storage. The middleware provides side information about message types, message structures, possible parameters, etc. which allows for a compressed storage of information. To this end, different compression approaches can be folowed. For example, instead of storing the parameters of an UPnP action invocation as an XML structure (e.g. *<newStatus>0</newStatus>*), they can be stored as a key value pair of parameter name and parameter value (e.g. *newStatus,0*). Additionally, parameter values can be stored considering their data types, thus allowing for a more compact binary encoding instead of ASCII encoding like used inside a message. This shows that queuing on the middleware layer is more favorable than straight-forward message queuing.

In order to leverage this for our stack architecture, we merge the messaging and the middleware layer (see Fig. 3). Instead of assembling messages from incoming packets, we extract and store information relevant to the middleware on-the-fly. The same principle is applied to the outgoing communication, for which packets are created directly from the compressed data. The benefit of this approach is that the relatively large message buffers are replaced by smaller buffers containing only the compressed information. In order to realize this, we require a protocol handler that supports messaging and middleware protocols simultaneously. At the same time, we can also leverage the cross layer idea for protocol handling, as only the features of the messaging layer need to be supported that are actually required by the middleware. E.g. , in UPnP the HTTP support can be restricted to support POST and GET messages as only these are used by SSDP, GENA and SOAP. In summary, this means that by merging the messaging and middleware layer, we minimize the memory consumption as well as the complexity of the stack. This brings us one step closer towards realizing middlewares on sensor nodes.

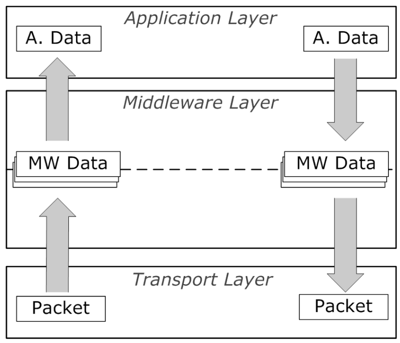


**Figure 3. Three Layered Stack Architecture**

**Middleware Layer**

In the previous discussion we have used middleware specific side-information to store a message in a more compact form. We now apply the same concept to reach even higher compression as we use application specific side-information. When we optimize the stack for a specific application, only information relevant for the application needs to be stored. This information is likely to require even less memory. While the middleware compression has to reflect the full feature set of the middleware, the application layer does not. For example, in UPnP and also other protocols (DPWS, Web services) resources are identified using URIs (Universal Resource Identifiers) or UUIDs (Universal Unique Indentifers). While these identifiers are suggested to be long in order to guarantee their global uniqueness, a practical application will only support a limited amount of resources. As a result, URIs and UUIDs can be represented in an application specific way using only a few bits rather then a few dozen ASCII characters. Further, application knowledge can also be used to store parameters of actions in a more efficient way. While the middleware layer uses information about data types (e.g. '*int*') for compression, the application knowledge allows the consideration of value ranges (e.g. '*0 - 9*') which leads to higher compression.

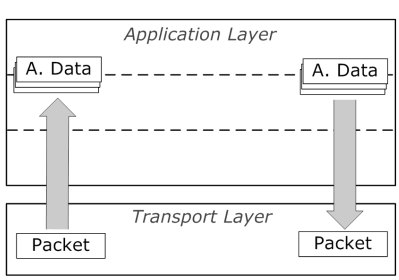


**Figure 4. Two Layered Stack Architecture**

For the stack architecture, this means that the extraction and storage of application information is beneficial for the memory consumption. To this end, messaging, middleware and application layer are merged and only application specific buffers are implemented (see Fig. 4). As a result, the protocol handling inside the stack considers application knowledge and is therefore optimized per application. However, the manual optimization of protocol handling is a tedious and error prone task. Thus, the automatic generation of a stack is recommended. To this end, a generator for UPnP stacks has been developed. It is presented in the next Section.

**Transport Layer**

Until now, we have subsequently minimized the memory consumption of the stack, leaving buffers only on the application layer and the transport layer. The transport layer contains a buffer for incoming and outgoing messages which has the size of a maximum MAC packet. As sensor nodes only provide half duplex communication, a single buffer should be sufficient. In order to realize a single buffer solution we merge application and transport layer, resulting in the architecture depicted in Fig. 5. Incoming packets are parsed directly on arrival in order to free the buffer as soon as possible. For the same reason, outgoing packets are written into the buffer only directly before transmission. The result is that even features like retransmission, used in reliable transport protocols like TCP, can be supported efficiently. In our approach, every transmitted packet is stored in memory in its compressed form. When a retransmission is required, the packet is decompressed into the buffer and transmitted. Therefore a packet only occupies the buffer when absolutely needed.

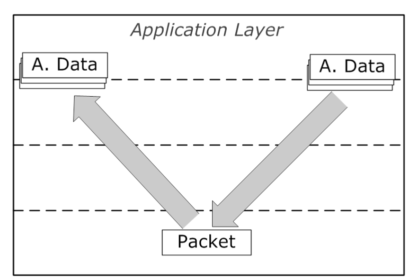


**Figure 5. One Layered Stack Architecture**

**Summary**

In this section we have discussed the optimization of the memory consumption of middleware stacks for sensor nodes in general. Application specific compression of data has been identified as the most efficient means to capture the information necessary to represent the global state of the stack. Therefore, aggressive cross layer optimization has been applied, which aims at the direct conversion of a packet into application information (and vice versa). In order to achieve this, an application specific protocol handler, that supports multiple protocols at the same time, is required. As a result, a stack has to be created per application and is therefore ideally generated.

In the following we will present an implementation of a UPnP stack that follows these design considerations. As we will see, our optimization approach results in a significantly reduced memory footprint. This finally allows the execution of the stack directly on a sensor node, thus underlining the benefit of our findings.

## PROTOTYPE IMPLEMENTATION OF EMBEDDED UPNP STACK

As underlying basis for our investigations, we use the Sindrion prototyping platform [5]. The Sindrion node is composed of a 16 bit controller @ 11 MHz, 128 kB RAM and 2 MB ROM. Its RF unit allows communication in the 868 MHz band with approximately 50 kbps transmission rate. A proprietary operating system as well as IP protocol support are available. A so called network adapter allows access to the nodes on IP level from a PC, which is the basis for direct node to PC interaction.

The UPnP stack is written in plain C and it consists of a small static core which is extended by a set of generated, application specific modules. These modules are created via a Java based code generator that uses the UPnP device and service descriptions as input and creates the C modules and header files as an output. The developer customizes the generator by specifying, among other parameters, how many connections are served in parallel (queue size) and how many event subscribers are supported in parallel. The protocol handling inside the stack is build around a Boyer-Moore type of text searching algorithm for SOAP and HTTP parsing. The necessary preprocessing of application specific search strings is conducted by the code generator at compile time. For the outgoing messages, application specific message templates are created by the code generator. The templates are compressed using an ASCII encoded dictionary. This allows the decompression to be implemented using only little dynamic memory. When a packet is transmitted, the relevant part of the message is decompressed directly into the transmission buffer.

In order to evaluate the memory consumption, we have generated various stacks which differ in the supported UPnP services, message queue size and number of eventing subscribers. The presented measurements show the RAM consumption of the modules of the UPnP stack (not including the packet buffer, which imposes a fixed offset of one MTU size depending on the underlying communication protocol). The values have been directly extracted from the linker MAP file, thus representing actual and not hypothetical values.

Table 1 shows measurements for a simple service, where the message queue size and the number of eventing subscribers are varied. In a first step, the service consists of a single 'GetStatus' action that delivers a boolean value and does not support eventing. In its minimal form, the stack only requires 154 bytes. Even when we increase the number of messages that are served in parallel to five, the memory consumption only increases moderately to 230 bytes. In a second step, we have modified the simple service to support eventing of a boolean value. The 'GetStatus' action remains the same. In its minimal form, the stack, including eventing functionalities, consumes 390 bytes. Although the absolute memory consumption is still quite low, we can see an increase of over 100% in comparison to the stack without eventing. This is partially due to the fact that eventing requires exchange and storage of a URL and hostname, to identify an event subscriber. These are lengthy strings and bare no potential for applicaiton specific compression, as they can be defined freely at runtime by the subscriber. As a result, the stack requires 1106 bytes in order to implement the service with five parallel subscribers. In summary, the overall memory consumption of the stack is still low enough to fit into current sensor nodes (like Mica, Tmote Sky, Sindrion). However, we also see that eventing is a relatively costly feature with regard to memory consumption.

| **Scenario** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **#Messages** | 1 | 5 | 1 | 3 | 5 |
| **#Subscribers** | - | - | 1 | 3 | 5 |
| **RAM in bytes** | 154 | 230 | 390 | 726 | 1106 |

**Table 1. Measurements for a simple Service**

In a second step, we analyze the influence of the device and service complexity on the memory consumption. To this end, we have generated stacks for the standardized UPnP devices Binary Light and Dimmable Light, and a standardized temperature sensor service out of the HVAC specification. The corresponding measurements shown in Table 2 reveal that the complexity in terms of number of services and actions does not have a dominant influence on the memory consumption of the stack. Although the Dimmable Light device provides twice as many services and actions as the Binary Light, the memory consumption is merely the same. The difference of a few bytes originates from using an integer parameter instead of a boolean. Further, the HVAC device consumes more memory although hosting fewer services and actions. The reason for this is that a string based variable with arbitrary content needs to be supported to represent the application context of the service. This variable has a similar effect on the memory consumption as the URL used for eventing.

| **Device Type** | **Binary Light** | **Dimmable Light** | **HVAC** |
|---|---|---|---|
| **#Services** | 1 | 2 | 1 |
| **#Actions** | 3 | 6 | 3 |
| | **RAM in bytes** | | |
| **#Msg. = 1**<br>**#Subscr. = 1** | 390 | 394 | 468 |
| **#Msg. = 5**<br>**#Subscr. = 5** | 1110 | 1122 | 1388 |

**Table 2. Measurements for Standardized UPnP Devices/Services**

In summary, we conclude that we have realized a UPnP stack with a low enough memory profile to be suitable for sensor nodes. Furthermore, we have seen that the UPnP device complexity does not have direct influence on the memory consumption. Therefore, an elaborate representation of a senor node's functionalities in a UPnP network is possible without resulting in higher memory requirements. However, parameter types and values should be chosen carefully in order to allow efficient storage. For example, restricting a string parameter to an enumeration that only consists of a few distinct values instead of defining it as a generic string results in smaller memory requirements. In UPnP, this can be done by defining so called 'allowed value lists' for the parameters inside the service description.

## RELATED WORK

Different approaches to support IT protocols on embedded systems can already be found in literature. The most prominent approach to facilitate Web services on embedded systems is the gSOAP toolkit [12]. Its unique feature is a binding between C/C++ code and SOAP elements, which allows implementation of Web Services on strongly typed C structures. To this end, the code for de-/serialization is created per application, using the WSDL description of the web service. As a result, programming of applications is simplified and the speed of parsing and generating messages is increased. However, the cross layer optimization idea, presented in this paper, is only partially reflected in gSOAP. Although application specific code is generated, it only accounts for the data type translation between C and SOAP. The core functionalities are wrapped inside a static module, which does not use application information for optimization. Further, gSOAP stores the complete incoming and outgoing messages in a buffer, which we have seen as a burden for the memory consumption. Intel [1] provides a toolkit for the development of UPnP applications. Code generation is used to create an application specific UPnP stack as well as skeleton methods, in which a developer can add the application logic. We witness a stronger employment of the cross layer optimization here, as even code for message parsing is specifically generated for the application. However, information about the application is not used to reduce the memory consumption. Similar to gSOAP, outgoing messages are generated via generic functions which create the complete message inside a buffer.

In summary, we see that the generation of application specific stacks is a common technique. The discussed toolkits however do not leverage the available information to the full extend to optimize the memory consumption.

## CONCLUSION

In this paper we have discussed the challenges of IT middleware support on sensor nodes. We have seen that middleware support requires the handling of multiple, large messages in parallel, which easily requires more dynamic memory than available on a sensor node. To this end, the reduction of memory consumption of the middleware stacks is a crucial issue. Analyzing the layer model of a generic middleware stack, we have seen that higher layers tend to have more side information about messages and therefore allow for a more compact representation of the message content. In order to leverage this, we have proposed an architecture in which messages are not stored in their on-wire format but in a compressed, application specific form. In order to achieve the highest compression, the stack implements application specific protocol handling. This calls for code generation techniques to create application specific middleware stacks. Finally, a prototype implementation proved that support of UPnP on sensor nodes is actually possible, which is a finding that exceeds the state-of-the-art. In its minimal form, the stack requires 154 bytes of dynamic memory, which is suitable for even highly restricted nodes.

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# Using the Connected Home Platform to support user tasks as orchestrations of smart objects services

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**ABSTRACT**

The ATRACO project uses the ambient ecology metaphor to conceptualize a space populated by connected smart objects and services that are interrelated with each other, the environment and the people. User activities are supported by the implementation of ubiquitous computing applications deployed over this ambient intelligence space. In this paper we present a possible realization of the ATRACO vision using the Connected Home Platform, a commercially available system adopted and evolved by ATRACO in order to provide network adaptation and context-aware services. A flexible and distributed context-aware service model is introduced using the OSGi and UPnP frameworks. UPnP is used to unify the existing network infrastructure comprising of heterogeneous technologies and protocols at the IP level. Furthermore, we introduce a context-aware service model and provide an example of orchestrating context aware services with the support of the platform.

**Author keywords**

Ubiquitous computing, smart objects, service oriented architecture

**INTRODUCTION**

Context-aware systems are an emerging genre of computer systems that help add some forms of intelligence to our surroundings. It is well-established that context-aware (sentient) systems should address three basic requirements, i.e. sensing, inference and actuation [3]. In the ATRACO project [2] we use the *Ambient Ecology* metaphor to conceptualize a space (Ambient Intelligence – AmI – space) populated by appliances, devices, and context aware artefacts and services that are interrelated with each other and the environment [5]. Adding context awareness to artefacts can increase their usability and enable new user interaction and experiences.



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Ubiquitous context-aware computing has been around for several years. Several projects have produced a host of different applications. Research in these projects is mainly driven by scenarios of AmI introduction into people's activities, which can be classified into six main activity domains: home, office, health, shopping, learning and mobility. Research issues can be clustered in those concerning computing, communications, interfaces, embedded intelligence, sensors and actuators [7].

In the context of Disappearing Computer initiative [4], the concepts of smart tags and smart objects were developed; these were used to compose distributed ubiquitous computing systems. The research that was initiated with Disappearing Computer, and other related initiatives (Presence, Global Computing) continued into FP6 in the context of several IPs. Among these, the Amigo project [1] focused on the usability of a networked home system by developing open, standardized, interoperable middleware, which will guarantee automatic dynamic configuration of the devices and services within this home system thus supporting interoperable intelligent user services and application prototypes. Along the same lines, TEAHA (The European Application Home Alliance) is proposing a method of secure service usage and discovery using a common proposed interface and set of methods that ensure the ease of use, privacy and interaction between clusters that implement different communication protocols [8].

In this paper we present the application of the Connected Home Platform (CHP) in supporting the realization of ambient ecologies. CHP uses a flexible and distributed context-aware service model based on the OSGi and UPnP frameworks. Furthermore, we introduce the context-aware service model and provide paradigms of context aware services that build upon perceptual and context aware components of the platform.

## ACTIVITY SPHERES

Nowadays, people achieve their goals by decomposing them into tasks (that is, by forming plans) and them by realizing these tasks with the help of objects or services in their surroundings. Goal achievement depends on the availability of the appropriate objects or services (henceforth called resources); people adapt their plans according to the available resources or the special characteristics of the environment. Thus there is a tight coupling between plans and resources that determines the degree of goal achievement.

One of the research goals of the ATRACO project is to decouple plans from resources. The basic concept we use is the "Ambient Intelligence sphere" or "activity sphere". An activity sphere is intentionally created in order to support the realization of a person's specific goal, which is described as a set of interrelated abstract tasks. This plan is abstract and contains only descriptions of the resources it requires; thus, it is independent from any particular configuration. The sphere is deployed over a particular AmI space and uses its resources to help its owner realize the tasks that lead to the achievement of the goal.

The ATRACO system supports this context-based transition from abstract to concrete. For each sphere, an ATRACO system is realized by the respective Control Agent, which can run on a PDA or a home server and contains the user goals and associated plans. Based on these, it discovers the available resources which could be used for task realization. When such resources are discovered, abstract tasks become concrete and each is assigned to a Task Agent; the realization of each concrete task can be thought of as a ubiquitous computing application. Thus, the AmI space becomes the platform on which ubiquitous computing applications that are part of an ATRACO sphere are realized.

The explicit configuration of a sphere requires the discovery of the resources in the ecology and their orchestration based on virtualized descriptions of their properties, capabilities and services. One could assume that these descriptions are made available through standardized protocols (i.e. as UPnP headers) or not (i.e. using proprietary meta-data).

In the former case, the approach adopted in ATRACO is to use the services of the Connected Home Platform, which provides the Control Agent and the Task Agents with descriptions of resources and protocols. In the latter case, we first construct a local ontology for each resource and then we apply ontology alignment in order to merge local ontologies into a global sphere ontology which contains all data and knowledge necessary to realize an activity sphere [6]. In the rest of the paper, we shall focus on the former case.

## CONNECTED HOME PLATFORM

The Connected Home Platform (CHP) is a commercially available platform that offers a complete set of smart home services running on top of existing broadband service bundles, thus implementing a connected home environment. It is based on the flexible MRG-110-6 Home Controller (referred also as Domotic Controller) of inAccess Networks, which can be easily integrated into wireless or wired LAN and provides access over LonWorks and KNX/EIB control nodes.

The main platform module is the home gateway, which coordinates all the individual smart objects and provides add-on functionality. Figure 1 depicts the home gateway software architecture. We assume that smart objects can be found in the AmI space, which offer a variety of services. The communication between the artifacts and the home gateway is based on the Lonworks and wireless Z-Wave and Zigbee protocols. Moreover, a Service Node is hosted at the operator premises. It is responsible for service provision and management, as well as for providing secure remote access to the home. The service node contains all necessary elements for service lifecycle management, introduction of new services, remote monitoring, watchdog timers, handling of user subscriptions per service package, ratter & charger, plus the ability to render the graphical or audio content depending on the user terminal capabilities for home remote access.

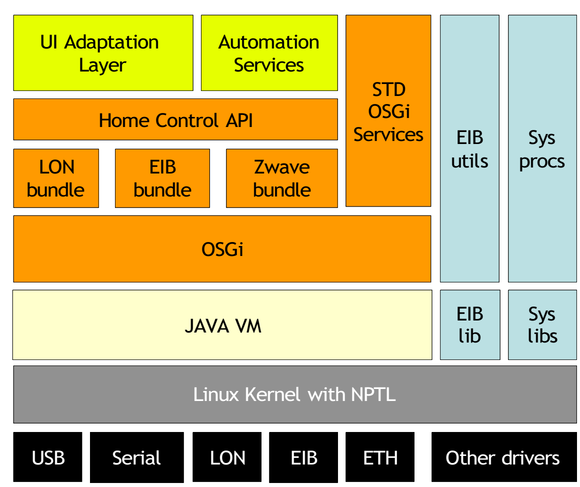


**Figure 1. Home controller software architecture**

## CONTEXT AWARE SERVICE MODEL

The CHP endorses the development, deployment and management of advanced, human-centric, context-aware services. Applications can exploit the context-aware services, the advanced user interfaces, and the virtualization of the home network infrastructure, through high-level mechanisms offered by the platform. CHP adopts OSGi as the defacto standard framework for the creation, composition and deployment of services. The CHP provides a registry for the services and an orchestration engine taking care of the service interaction. CHP further adopts UPnP as the control and management plane to deliver its services. The CHP enables a flexible model for home application/service development and deployment, which distinguishes between the following roles:

*AmI space infrastructure*: The infrastructure consists of the full range of smart objects (including sensors, devices, actuators, residential gateways, computing and network equipment) used to provide sensing, networking and basic services in the home environment. All these UPnP compatible components, during bootstrapping, will send presence announcements advertising their supported services. On the other hand, every device or service will listen for discovery requests. Upon reception of a search request, the device will examine the search criteria and will respond if a match occurs. Each smart object or service provides, according to UPnP specification, information regarding service resources and how to use them.

*Perceptual Components*: The perceptual components process sensorial input based on the range of sensors installed. By using the UPnP model, each perceptual component will discover easily network resources, such as sensors, actuators, cameras, microphones, speakers etc. With the use of a control point entity a perceptual component can be fed with appropriate type of information. The perceptual components will provide services responsible for dispatching events to registered control points. These services will also accept actions for configuration and initiation of raw information processing.

*Context Model*: Having UPnP descriptions of perceptual components and infrastructure elements at hand, it is possible to calculate context states. Based on the plan, these states can be combined towards identifying higher level contextual states (i.e. extracting more sophisticated context).

*Activity spheres*: Activity spheres are considered as applications that use plans and context models to realize their tasks. In the current implementation, the application logic will be specified in terms of service actions to be executed over a UPnP object. UPnP objects exist in all levels of the functional chain and range from simple sensors to complicated software modules. The applications will have access: (i) At the infrastructure level, to control, tune or configure sensors, actuators, devices etc. (e.g. towards regulating the environment, or adapting a device to context). (ii) At the perceptual component level, to configure the perceptual component for optimal performance or to control it (e.g. start/stop it) through the application. (iii) At the context modeling level to dynamically adapt (e.g. augment or restrict) the context model. (iv) At the application level, to leverage any other computing service that might be available within the UPnP network (e.g. invocation of a software component or application).

## UPNP VIRTUALIZATION OF HOME NETWORK INFRASTRUCTURE

CHP provides resource virtualization functionality, which adheres to the UPnP paradigm, for all the devices and networking technologies in the domestic environment. Home applications/services, and components for context awareness and advanced user interfaces regard resource virtualization components as a set of UPnP services, which can interact by invoking actions and receiving events. UPnP virtualizes all network resources from various heterogeneous networks into a common communication meta-medium. UPnP being agnostic for the origin (Zwave, Zigbee, Lonworks, IP, etc.), implementation (C, C++, Java, Python) and nature (software, hardware) of resources, unifies them as peer objects in the same abstraction layer.

The CHP will manage a complete, pervasive, unobtrusive and networked infrastructure. Figure 2 presents in general terms the infrastructure. There are various types of devices interconnected, using different wired or wireless network technologies:

*Home network infrastructure*. The CHP assumes that a modern home can have many devices that can be networked and controlled remotely. Devices can be computing, intelligent appliances (white/brown goods, cameras, microphones), sensors and actuators. The networking technologies may be wireline, relying on Ethernet, Firewire, Lonworks, KNX/EIB, or wireless, relying on WiFi, Bluetooth and ZigBee. Inside the home devices can communicate in ad-hoc mode. Such an option is imposed by the capabilities of many small devices, like wireless sensors.

*UPnP proxies to non IP networks*. The CHP will deliver high level context-aware services making use of a wide range of devices and appliances. These devices will eventually belong to heterogeneous networks and for that reason their virtualization as UPnP devices in the IP network is required. Special devices called UPnP proxies undertake this responsibility. UPnP proxies bridge IP networks with non IP networks representing at the same time devices belonging to non IP networks as UPnP entities. A UPnP proxy can interface more than one non IP networks.

*Service gateway*. The interconnection of the home network with the Internet is usually offered through a residential gateway (referred also as Home Controller), which is also manageable through UPnP regarding various network services like firewalling, routing, NAT, DNS and DHCP. The service gateway from its nature is provider-neutral and is empowered with OSGi. This enables the dynamic installation, update or removal of the software components (OSGi bundles), which finally will compose complex or simple services.

Virtualization of resources will facilitate infrastructure exploitation from context-aware components, advanced user interaction mechanisms and home applications/services. The platform will use UPnP mechanisms for the acquisition of signals from the network infrastructure (e.g. cameras, microphones). These signals will be the basis for the creation of (simple and advanced) contextual information that will trigger the home applications and services. Additionally, the CHP functionality will enable the home applications/services, perceptual and context-aware components to invoke actions, upon the underlying home network infrastructure.

The rationale for resource virtualization is that the abstraction and integration under a common umbrella (management/control interface) will provide to home application/service developers a platform that hides the details and the complexity of the underlying home network infrastructure.

Even when a smart object is connected to a non IP network, the system must make it available in the pool of available resources. Since it cannot join the IP network and advertise themselves as UPnP devices, the UPnP proxy undertakes the responsibility to do it on their behalf. A UPnP proxy performs all the necessary steps so as to ensure IP connectivity for all devices behind it. Acting as an inter-working unit between a non IP network and an IP one, the proxy starts a new IP session where the device is advertised as a UPnP device sending a multicast announcement. The proxy holds deferent profiles for each type of device it represents. For each new device type, the proxy updates its profile repository. The UPnP proxy is the key element of the infrastructure resource virtualization. Each device behind a proxy has the same IP address but a different UPnP address (a UPnP address is a URL pointing to device associated information). That way the proxy is able to accept remote procedure calls for many devices.

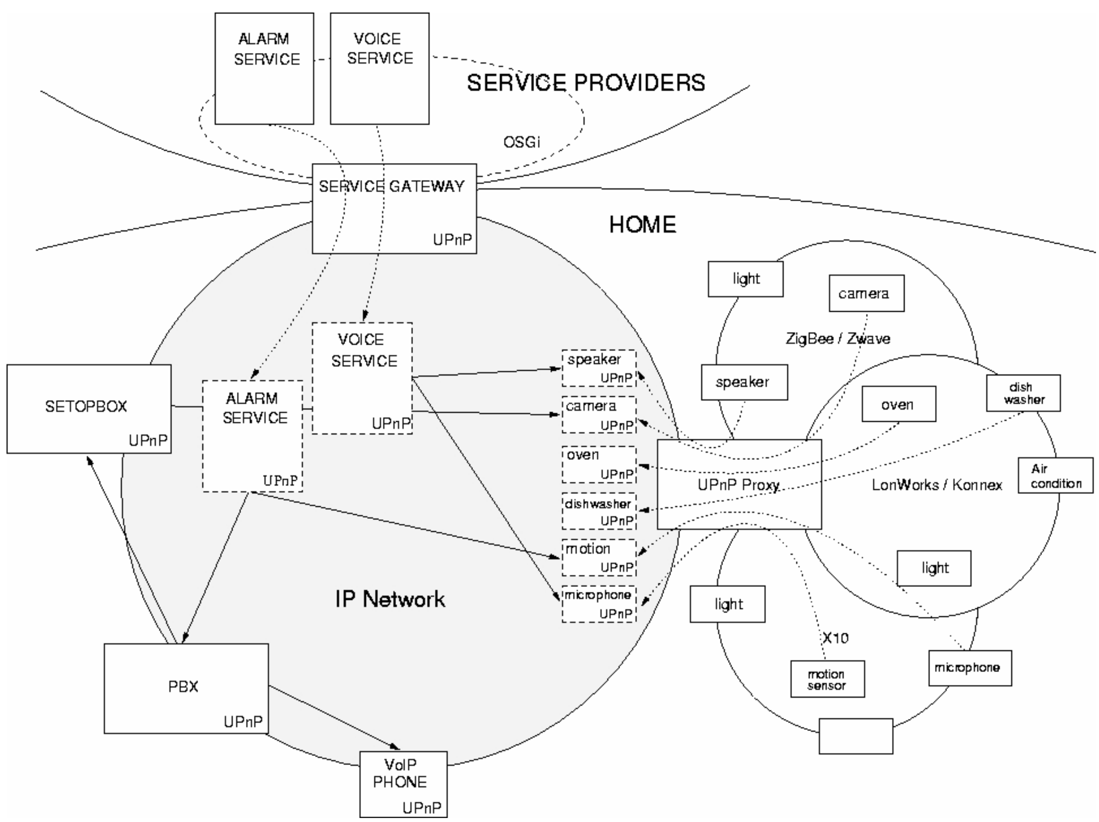


**Figure 2. General structure of the home network infrastructure**

The services, the context events and the actions that can be supported by a device are made known through the virtualization function performed by the UPnP proxies. Through the virtualization function, the user applications, the perceptual and the context-aware components can manage and use the infrastructure. Resource virtualization can be thought of as an abstraction of some defined device functionality and its public exposure as a service through the CHP platform.

## EXAMPLE APPLICATION SCENARIO

Consider the following scenario:

Suki's living room has embedded in the walls and ceiling a number of sensors reading inside temperature and brightness. He uses an air-conditioning as the main heating / cooling device. The windows are equipped with automated blinds, which can be turned in order to dim or brighten the room. For the same purpose, Suki can use the two lamps hanging from the ceiling. Suki's goal is to feel comfortable in his living room.

The Control Agent that manages the house contains an abstract plan, which states that, in order to achieve this goal, temperature and brightness have to be adjusted to a comfortable level. These tasks are "assigned" to two Task Agents. These retrieve abstract descriptions of the two tasks involved in this plan from the local database. Then it accesses the protocol independent Connected Home Platform installed in the house in order to discover the resources available in the living room and make the task description concrete (i.e. set air-conditioning temperature to 22 degrees C). With the help of CHP, each of these agents can access all devices in the house that relate to one concrete task.

A touch screen with voice recognition ability that is mounted near the room entrance is used as the main control point. Suki can use the mike in the screen to give voice commands to his home. All interaction between Suki and his home is managed by the interaction agent. This agent can receive Suki's commands and interpret them with the help of CHP. Then, this agent interacts with the various devices in order to provide output to Suki using their actuators.

Parts of this ambitious scenario will be realized in the context of ATRACO project. For example, Figure 3 shows how control of heating and lighting conditions can be achieved with the help of CHP in order to realize Suki's "feeling comfortable" sphere. The service can be triggered by two sources. The first is related to the identification of a user. This identification is done by components that offer context awareness. Alternatively, the second trigger is a command issued by a user. In the figure this is represented by the voice interaction agent. Having identified the user, and having at hand additional contextual information, the home application/service can decide on appropriate commands towards the networking infrastructure. In the example, there will be commands towards the lighting and the heating agents, in the context of a power and climate control services.

## CONCLUSIONS

The ATRACO project uses the ambient ecology metaphor to conceptualize a space populated by connected smart objects and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way. Everyday appliances, devices, and context aware artefacts are part of ambient ecologies. A context-aware artefact uses sensors to perceive the context of humans or other artefacts and sensibly respond to it. Adding context awareness to artefacts can increase their usability and enable new user interaction and experiences. Given this fundamental capability single artefacts have the opportunity to participate in artefact-based service orchestration ranging from simple co-operation to developing smart behavior. Smart behaviour, then, either in individual or collective levels, is possible because of the artefacts' abilities to perceive and interpret their environment.

In this paper, we presented one of possible implementations of ATRACO activity spheres, which uses the Connected Home Platform. The CHP enables network adaptation and supports context awareness for artefacts that participate in the ambient ecologies using a flexible and distributed service model based on the OSGi and UPnP frameworks. UPnP virtualizes the home network environment into a common communication meta-medium.

Nevertheless, the vision of ATRACO is to enable the bottom-up composition of services and capabilities of smart objects, in order to support user task realization in unknown AmI spaces. To achieve this, a semantically rich layer will be developed on top of the CHP, which will contain ontologies and agents. The former will describe heterogeneous services and the latter will use CHP resources to adapt the implementation of user tasks.


## ACKNOWLEDGEMENT

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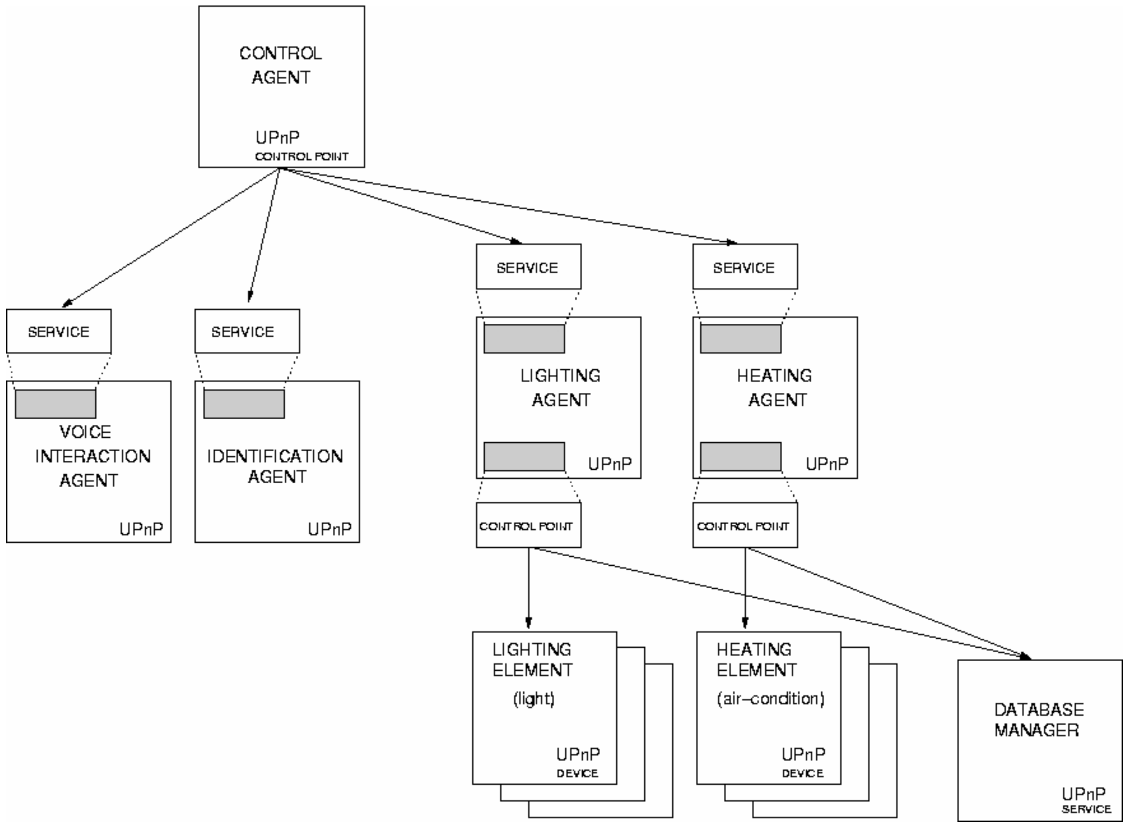


**Figure 3. Heating and lighting control using CHP services**

# SOEML: A Smart Object Event Markup Language using Temporal Intervals

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## ABSTRACT
This paper proposes a smart object event markup language. By attaching sensor nodes to everyday objects, users can augment the objects digitally and apply the objects into various services. When creating such smart object services, users should define events, such as bevarage of a cup turns cold or someone sits down on a chair, using physical values from sensors. The most common event definition for end-users is simply describing threshold of sensor values and boolean operation. When they want to define more complex events, such as multiple people sit down on chairs or a user starts to study using a pen and notebook, they need to use a programming language. To define such complex event easily without complex programming language, we present a new event description language called SOEML based on temporal intervals among simple events. We also provide users a visual interface to support users defining events intuitively.

## Author Keywords
Event Definition, Toolkit, Smart Object, Deployment

## INTRODUCTION
To realize ubiquitous computing environment, technologies such as computer, sensor, and network has been improving. Especially, small sensor nodes equipped with various types of sensors such as thermometer, accelerator, or illuminometer have enormous potential to create context-aware services that assist a variety of human activities. Our life is filled with everyday objects, and we often have trouble with them (e.g. lost property ). It is important to achieve the ubiquitous computing environment to apply everyday objects into ubiquitous services. Sensor nodes, when attached to everyday objects, enable us to gather real-world information as context. Recently, many researchers have been focusing on the ubiquitous services with these "smart objects" [5, 11]. With smart objects, users will be able to enjoy the privilege of ubiquitous technology anytime anywhere in their lives.


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To realize the smart object services in the home environment, the following two questions must be answered. The first is how to make our belongings smart. We already have a number of everyday objects. Therefore, providing an easy way to make them smart is important. We have addressed this with uAssociator [13], an easy assoication method between sensor nodes and objects. The second question, that this paper focuses on, is how to create smart object services which reflect users' requirements. It is not practical to build all the services that users may want to use. Therefore an environment for users to create services themselves is necessary.

The most common smart object applications are described naturally as a collection of rule-based conditions. MediaCup [5] is a common example: "when a MediaCup recognizes that the beverage in the cup is getting cold, MediaCup notifies a user to drink it quickly." To create such services, users must define an event by using physical sensor values and an action such as sending an e-mail or beeping a sound. Because these definitions are unfamiliar tasks for users, there has been an increasing effort and interest in developing infrastructures or toolkits which enables users to create context-aware application by themselves. From the point of view of context definition, these tools can be classified by the following two: low-level toolkits [3, 6] and high-level toolkits [7]. While low-level toolkits provide the needed support for acquiring context, a large amount of codes must still be written to develop simple sensor-rich applications. On the contrary, while high-level toolkits enables end-users to create simple context-aware applications for their instrumented environment, it is impossible to define more complex or flexible context. This is because only setting thresholds of sensor values or using boolean operation is not a sufficient way for defining complex events. For example, "bevarage turned cold" cannot be defined simply as "if the cup's temperature <= 40 degrees." This is because "bevarage turned cold" implicitly means "the bevarage which was hot turned cold." Therefore, the event shold be defined as "if the cup's temperature > 40 degrees and then <= 40." This means that it is important for context definitions to describe temporal relation between simple events. Let us present another example. An event "Multiple people sat down at the same time" can be useful for recognizing a "meeting" context. In this case, the event can be defined such as "if more than 3 chairs detect a person's weight at least once in 30 sec." This type of event is so complex that users need to write highly complex program.

Our purpose is to create a mid-level toolkit which enables users who have basic information skills to create both simple and complex smart object services. To realize the purpose, this paper focuses on a way to define events which are trigger of smart object services. As shown above examples, it is important to make consideration of temporal relation between simple events for defining more complex events. However, it is difficult task for users to define complex events which concerns temporal concept. For solving this problem, we presents a smart object event markup language called SOEML. SOEML is an XML-format language, and it enables users to define events by using interval-based temporal operation. Allen argues that all events have duration and considers intervals to be the basic time concept [2]. We extended the interval-based temporal operation to define smart objects events flexibly. SOEML has following three features; 1) it enables users to define complex event by combining simple events considering temporal relationship, 2) it enhances reusability of events by separating logic of events and target smart objects, and 3) it supports defining flexible events which are composed of multiple smart objects as "if more than 3 chairs detect a person's weight at least once in 30 sec".

The rest of this paper is organized as follows. In next Section, we present details of SOEML and its implementation. In Section 3, we discuss features of SOEML. Then, we survey on related work in Section 4. Finally, we conclude the paper describing foresight in Section 5.

## SOEML: SMART OBJECT EVENT MARKUP LANGUAGE

In this Section, we present details of a smart object event description method using temporal relation, called SOEML. With SOEML, users can define both simple event and complex event easily.

### Structure

SOEML is composed of 5 main elements: <event_template>, <temporal_relation>, <time_duration>, <smart_object> and <event>. Figure 1 shows an overview of these 5 elements. Details of each element is shown below in order.

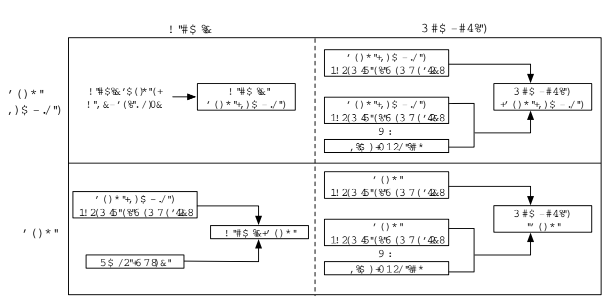

Figure 1. Overview of elements in SOEML

```
<event_template type="atomic" name="SomethingCold">
 <node_condition>
   <type>uPart</type>
   <sensor>temperature</sensor>
   <value exp="less">30</value>
  </node_condition>
</event_template>
```

Figure 2. An Example of Atomic Event Template

### Event Template and Temporal Relation

Event Template is a basic event model in SOEML. Smart object events can be detected by adapting the Event Template to target smart objects. There are two types of the Event Template: Atomic and Composite.

- Atomic Event Template

Atomic Event Template is used for defining primitive events, using a threshold of a sensor value. Figure 2 illustrates an exmaple of Atomic Event Template which defines "temperature is less than 30 degrees." For describing both Atomic and Composite Event Template, <event_template> element is used. The "type" in <event_template> is used for specifying whether the event template is Atomic or Composite. In element <event_template type="atomic">, users describe concrete sensor information. An element <node_condition> contains 3 elements: <type>, <sensor> and <value>. <type> is used for specifying sensor node types such as uPart [4] or Mote. <sensor> specifies which sensor on the node should be monitored. In case of using uPart sensor node, there are 3 types of sensors; temperature, movement and illuminance. <value> is used for setting a certain threshold of sensor values. An attribute "exp" in <value> governs types of thresholds. We prepared the following 7 types of thresholds; greater, greater-equal, equal, less, less-equal, between and except.

- Composite Event Template

Composite Event Template is a complex event which is defined by the correction of two event templates. For combining multiple event templates, we use temporal interval logic (see Figure3). In reference [2], a set of 13 relations between intervals are defined, and rules governing the composition of such relations controls temporal reasoning. Additionally, we defined a new relation "any" to the set to improve SOEML's flexibility. We present detail of "any" relation later in this Section.

Figure 4 shows an example of the Composite Event Template. This template relates two Atomic Event Templates by "meets" relation. Element <temporal_relation>, which has two or more <event_template> elements, is used for defining temporal relationship between event templates. It has a "type" attribute which defines a temporal relation from 14 types of relation shown in Figure 3. In this case, "type" is set to "meets" relation. Atomic Event Template "Some-

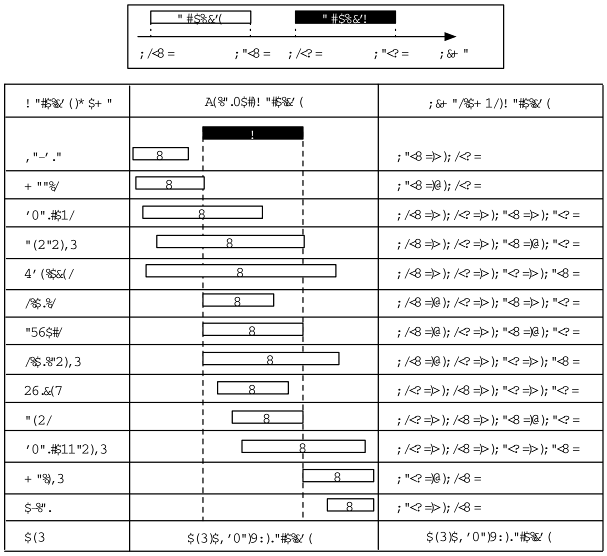

Figure 3. A set of 14 temporal relations for defining composite event

```
<event_template type="composite"
name="SomethingTurnsCold">
 <temporal_relation type="meets">
   <event_template ref="SomethingHot"/>
   <event_template ref="SomethingCold"/>
 </temporal_relation>
</event_template>
```

Figure 4. An Example of Composite Event Template

thingHot" in <temporal_relation> is defined as "temperature >= 30." The Atomic Event Template named "SomethingCold" is, as shown in Figure 4, defined as "temperature < 30." Therefore, this Composite Event Template means that the temperature of something went down from over 30 degrees to below 30.

### Time Duration

The element <time_duration> is used for defining certain time interval. Take the event "the temperature of a target is below 30 degrees for 10 seconds" for an example. In this case, users can define the event as shown in Figure 5. The element <time_duration> can contain time intervals such as <hour>, <min>, <sec> and <millisec>. The event above fires when "SomethingCold" event contiusly occur for 10 seconds. If the "type" attribute of <temporal_relation> is set to "contains" relation, the event fires when "SomethingCold" event starts and finishes within 10 seconds.

### Smart Object and Event

An Event Template turns to a concrete Event when it is paired with a smart object. Figure 6 shows an example of an event named "CupTurnsCold." The element <smart_object> contains two kinds of information; sensor information such as

```
<event_template type="composite"
name="SomethingColdOver10Sec">
 <temporal_relation type="during">
   <time_duration>
      <sec>10</sec>
   </time_duration>
   <event_template ref="SomethingCold"/>
 </temporal_relation>
</event_template>
```

Figure 5. An Example of Composite Event Template with Time Duration

```
<event type="atomic" name="CupTurnsCold">
 <smart_object ref="Cup"/>
 <event_template ref="SomethingTurnsCold"/>
</event>

<smart_object>
  <sensor_info>
     <type>uPart</type>
     <id>1.2.3.4.0.1.0.12</id>
  </sensor_info>
  <object_info>
     <name>Cup</name>
     <owner>Takuro Yonezawa</owner>
  </object_info>
</smart_object>
```

Figure 6. An Example of Atomic Event

node types and node ID, and object information such as object names and owner of the object. Applications, which provide smart objects services, need to know what object each sensor node is monitoring. This, in turn, requires association, or making a semantic relationship between the sensor node ID and its object information. uAssociator which we developed in [13] provides an easy association method and the associating information is stored into a JPEG file in an XML format (see Figure 7). The element <smart_object> contains the associating information. By copying this information to SOEML or selecting the JPEG file through a user interface shown in latter in this Section, users can define and use <smart_object> easily.

Alike Event Template, an Event has both atomic and composite types. Atomic Event is used for defining events of a

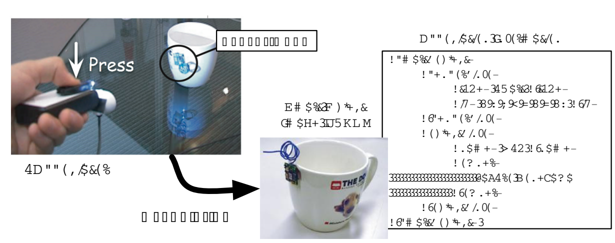


Figure 7. Association between an object and a sensor node

```
<event type="composite" name="Studying">
 <temporal_relation type="during">
  <event type="composite" name="PenAndNotebookMoved">
   <temporal_relation type="any">
    <event ref="PenMoved"/>
    <event ref="NotebookMoved"/>
   </temporal_relation>
  </event>
  <time_duration>
   <sec>10</sec>
  </time_duration>
 </temporal_relation>
</event>
```

Figure 8. An Example of Composite Event

smart object. On the contrary, Composite Event is used for defining events which involves multiple smart objects. Figure 8 is a Composite Event which defines "If both a pen and a notebook are moved at least once within certain 10 second." A Composite Event named "Studying" has a nested construction. First, it relates a Composite Event named "PenAndNotebookMoved" and time duration "10 seconds" with a "during" relation. This means that when the event "PenAndNotebookMoved" occurs within 10 seconds, the event "Studying" fires. The event "PenAndNotebookMoved" is also a Composite Event: it relates the event "PenMoved" and "NotebookMoved" by a relation "any". The relation "any" is a special temporal relation that fires an event when all inner events fires in any relation. Moreover, when "any" is used, additional attributes "firedCondition" and "firedNumber" can be set to the element <temporal_relation> for defining flexible conditions. For example, the code <temporal_relation type="any" firedCondition="more-equal" firedNumber="1"> means that when one or more inner events fire, the condition is fullfilled. There are 5 types of "firedCondition" - more, more-qeual, equal, less-equal and less. By using "firedCondition" and "firedNumber", logical addition or exclusive disjunction can be defined.

### Implementation

In this Section, we describe the implementation of the SOEML system. First, we will present the event detection mechanism. Then, we will show the user interface for creating the SOEML. We implemented these system with Java and JAXB [1] for XML parser. For defining schema for SOEML, we used XML Schema.

### Event detection

We assume that the users will use smart object services in the home environment where there is one or more computers which operates applications, coorperating with sensor nodes mounted on objects. Events which can be detected are highly influenced by temporal intervals which sensor nodes send packets to a computer. If the intervals of the packets being sent are different, it is impossible to evaluate whether the composite event occured or not. Therefore, we use sensor nodes which send a packet at an equal interval (500 milliseconds). The current detection mechanism for temporal evaluation is based on an event-driven algorithm. When an

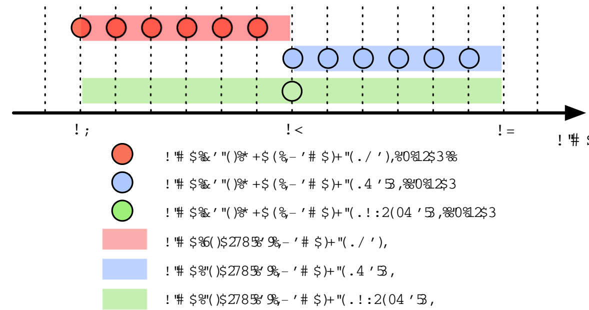

Figure 9. Time chart of Event Template "SomethingTurnsCold"

event constructing a Composite Event is recognized, a temporal evaluation is executed in every interval (500 milliseconds). Each event stores both the start time and the end time, and the system computes every past events or time duration which users have defined. Note that the start time and the end time of Composite Event or Atomic Event which contain Composite Event Templates are dependent to inner events which construct the Composite Event/Event Template. Figure 9 shows the time chart of the Composite Event Template "SomethingTurnsCold" shown in Section 2. The Event Template "SomethingHot" started from T1 until T2, while "SomethingCold" started from T2 until T3. This temporal order matches "meets" relation, and so the Composite EventTemplate "SomethingTurnsCold" fires. In this case, while the Atomic Event Template "SomethingHot" and "SomethingCold" fires every time when the sensor data matches the event, "SomethingTurnsCold" fires at T2 when "SomethingHot" and "SomethingCold" matches "meets" relation. If "SomethingTurnsCold" is a part of upper Composite Event Template, "SomethingTurnsCold" is treated as an event which has time interval from T1 to T2.

### User Interface

We also implemented a prototype of user interface for describing SOEML. By using the interface, users can load SOEML, visualize its structure and save as XML code. The interface provides a structure of the elements visually with animation (see Figure 10). Users only need to define thresholds or select applicable elements from comboBox for defining SOEML. This enables users to configure SOEML intuitivelly. For deciding thresholds, users can refer concrete sensor data illustrated in chart. The interface also supports associating sensor nodes and objects by uAssociator [13]. This means the interface supports users to install smart objects and define its event.

## DISCUSSION

We discuss features of SOEML in terms of descriptive capability and reusability.

### Descriptive Capability

SOEML enables users to define complex events by correlating simple events which is based on thresholds of sensor nodes. Because the correlation of events can be defined by 14 temporal interval logics including Allen's 13 relations

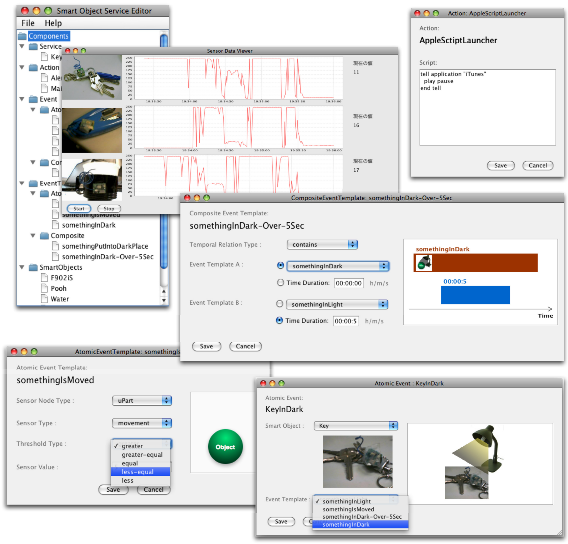

Figure 10. User interface for editing SOEML

and the "any" relation that we propose, users can create various smart object events without using complex programming language. Let us get back to the example "if more than 3 chairs detect a person's weight at least once in 30 sec" in Section 1. Though this event is difficult to define with programming language, users can model the events by SOEML simply as Figure 11. Figure 12 shows a visualized image of SOEML which defines a Composite Event "Meeting". The event "Meeting" correlates "MoreThan3ChairsUsed" event and time duration "30 seconds" by a "during" relation. "MoreThan3ChairsUsed" event is also a Composite Event which uses the temporal relation "any". In this case, "firedCondition" and "firedNumber" is set for defining the condition of "more than 3 chairs being used." With "any" relation, users can define flexible events. However, there are limitations in SOEML compared by programming language. For example, it is impossible to define events which requires an average of sensor values. Alternatively, it is burden task to define composite events which includes repetition of an event. As future work, we will focus to improve flexibility of SOEML for defining these events.

### Reusability

In SOEML, an event is expressed as a pair of Event Template and Smart Object. In other words, when users want to adapt the same event recognition logic to an object, the only thing users need to do is to change the Smart Object paired to the Event Template. This feature boosts up the reusability of SOEML. Additionally, all events are based on simple thresholds of sensor values. This reduces difficulty for users to modify SOEML defined by other people. We basically do not assume that the users can use the same event that they have modelled in a different environment. This is because the sensor values that the object detects differs when the environment of user changes. Therefore, the feature that a user can use or easily change an event which another person has made is very important.

```
<event type="composite" name="Meeting">
 <temporal_relation type="during">
  <event type="composite"
  name="MoreThan3ChairsUsed">
   <temporal_relation type="any"
   firedCondition="more" firedNumber="3">
    <event ref="Chair1Used"/>
    <event ref="Chair2Used"/>
    <event ref="Chair3Used"/>
    <event ref="Chair4Used"/>
    <event ref="Chair5Used"/>
   </temporal_relation>
  </event>
  <time_duration>
   <sec>30</sec>
  </time_duration>
 </temporal_relation>
</event>
```

Figure 11. Composite Event of "InMeeting"

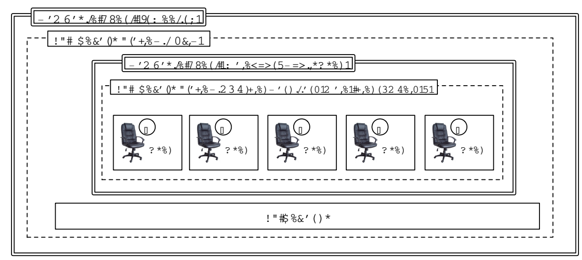

Figure 12. Visualized SOEML "InMeeting"

## RELATED WORK

Dey et. el. interviewed 20 people without programming skills about favorable application for ubiquitous computing environment [7] . As a result, 80% out of 371 proposed applications can be described with if-then rules. This indicates the efficiency of the if-then rule as an end user programming in the ubiqitous computing environment. Following these results, Dey et.el. has built a visual programming environment which enables users to write the if-then rule. However, the definable rules are limited to events possesing a simple operation such as boolean logic. Similarly, there have been many approaches to define services using the ECA(Event-Condition-Action) rule. Shankar et. el. quoted that the ECA rule could not assign conditions before and after firing which was a fault for ECA [10]. Shankar adopted the ECPAP rule which adds the befor and after rule, and built petri net for plural rules, increasing the number of rules able to change. However, their target users who defines the ECPAP rule is an owner of the room, not the non-expert users. Jung focused on the users' mental model, proposing an event definition method using 5W1H [8]. However, to write in a 5W1H method, there must be an environment where the sensor data is able to be understood as context, therefore it is insufficient to use at home or non-instrumented environment.

Composite event detection research has been done in active database research. Yoneki et. el. proposed to introduce interval-based temporal operation to describe events in the sensor network system [12]. They defined 10 types of composite event operators such as conjunction, disjunction or concatenation. Though their semantics covers various types of composite events (e.g. including location information), high level language for defining the events is unconsidered. On the contrary, the Tag and Think [9] is a research using temporal relationship to detect events alike ours. In Tag and Think, in order to estimate what the object is from the values from the sensor nodes attached to the object, developer defines the relation of the object's status and the possible status considering the temporal relationship, and evaluates from the state transition diagram and the status obtained by the experimented data. Tag and Think defines the object's status with the amount of change of a sensor at a certain time, therefore it enables estimation with high accuracy to various environment. On the contrary, we have focused on not just the same object, but on an environment where users can define events containing multiple objects using the threshold of sensor nodes. Additionally, the statement of a "any" relation enables users to define events flexibily.

## CONCLUSION

To enable context-aware services to fit user's life or respond to users' request, the importance of toolkit will be increased in the decade ahead. To raelize toolkit for smart object services, this paper presents a smart object event markup language called SOEML. Defining events is an unfamiliar task for users, so easy description way without complex programming is necessary. SOEML enables users to define both simple and complex event based on threasholds of sensor values by using XML format. To define complex event, users can use various temporal logic. Additionally, we presented new relation "any" to improve flexibility of events. SOEML also provides a reusability of event because it splits off logic and its target by using the Event Template.

Finally we describe future work. First is an evaluation of our system. We have plan to execute users study. Second is cooperating with other sensors such as location sensors or RFID. By introducing various sensors to SOEML, more complex event can be defined. Third is connecting events to various actuators. With cooperating information appliances, a toolkit which supports to bootstrap and create smart object services can be realized.

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# Configuration Method of Wireless Smart Objects

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## ABSTRACT

This paper states that it is possible to reconfigure smart objects over a wireless network. Smart objects can transfer processor configurations, memory and other hardware blocks through a network to other objects. Smart objects can carry several different configuration files and apply suitable configurations for specified tasks. Smart objects can also download configuration files over the wireless network. With a swarm of these FPGA-based objects, it is possible to specify a new data processing paradigm: Cognitive Computing. A calculation platform can easily adapt to the demands of a specific task. Some of the objects can be configured to function as memory blocks, while others can function as processors or other functional parts.

An experimental prototype of the smart object has been made and tested. The smart object can send and receive different configuration files and reconfigure itself for new configurations.

### Author Keywords

Smart Object, Cognitive Computing, wireless configuration

### ACM Classification Keywords

H.5.3 Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces

## INTRODUCTION

CMOS (Complementary Metal-Oxide Semiconductor) technology is at a state where line widths cannot get much smaller. Soon line widths will be the size of a few atom diameters. Simultaneously, digital designs are getting more complex as processors and other system architectures evolve. This will lead to a situation where it is not economically profitable to produce silicon wafers that are big enough. This sets certain limitations for the development of modern ICs (Integrated Circuit) and for the current, most applied computing platform: the single-chip processor.

We have few choices. Either to find a new technology that allows us to keep following Moore's Law and to add more and more gates into logic designs that allow more complex systems to be built, or we can start researching different ways of adding complexity into systems. And that process has already begun. Processor companies like Intel and AMD are bringing out new processors that have a new property: several processors next to each other in one silicon chip. This new way of thinking has made possible less power consuming, more efficient data processors. Still, there is the limit of how many processors or logic gates can be fitted into one piece of silicon until it is not more profitable anymore. Finally, technology will meet its limit when there simply is not any more space available in one piece of silicon. At this point, at the latest, new technologies, such as the use of wireless communication to contact several silicon chips, will have to be introduced..

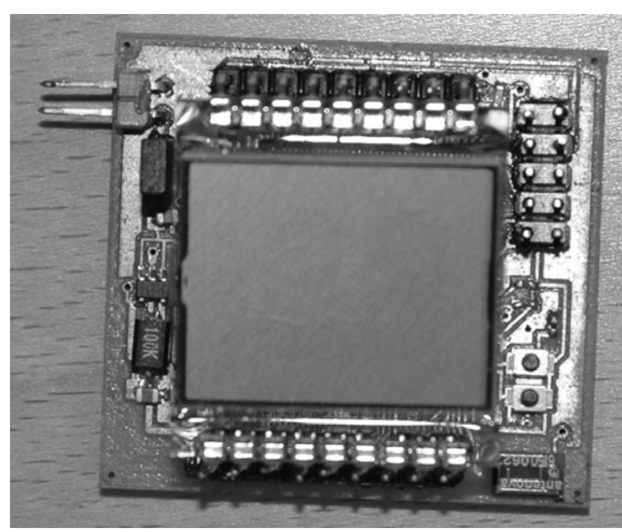

**Figure 1. Prototype of Smart Object with display.**

What if the demands of computing platform would be divided among several – even millions of small smart


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objects? If these particles were small enough, they would neither use a lot of power, nor heat up excessively. With small size they could be also independent of external power [1]. A swarm of these objects would be impossible to configure one by one, but rather through a wireless network.

## REQUIREMENTS OF THE SMART OBJECTS

Before a smart object is capable of functioning as a solid, single member of any swarm, a lot of problems have to be solved.

When dealing with a real swarm of smart objects, one concern is simultaneous possible configuration processes and any other exchange of data. There are plenty of options on how to configure numerous objects, and they will be discussed later. Communication standards must be applied to ensure the transmission of the correct data packets. Also, the possibility to add more smart objects to any swarm, without any restrictions, will be vital. Every smart object will be named with an individual ID. The possible use of soft-core processor requires extra attention. Attention has to be paid to the design of the processor, because there are numerous similar processors running simultaneously. Research for this will be done later.

### Size

The ultimate aim is to create smart objects the size of a tip of a needle, or smaller. This means that the human eye cannot distinguish an object of this size. Such objects could be spread like powder, wherever a swarm of smart objects was needed. This means that eventually physical manipulation of a single object is almost impossible, considering their small size. Thus, all the commands, data and configurations would have to be sent over the network.

### Power Feed

Thinking of smart objects in swarms makes you realize that it would be almost impossible to feed power to all the objects, especially with wires. The objects must carry some kind of power production and storage within them, in order to achieve functionality in big numbers. The most probable means of producing energy for a smart object would be solar power or inductive feed of electric power. A very small battery must be integrated into the smart object to ensure continuous power feed.

### Communication

The smart objects must have a communication device that enables them to communicate with each other. Communication must be robust enough to ensure a secure transmission. The objects must share the same communication standard. The transmission of a configuration file is the most critical part of transmitting data. The radio used in this work [6] is capable of sending 32 bytes of data in one data packet. It is used through an SPI (Serial Peripheral Interface) and it uses 2.4 GHz base band GFSK (Gaussian Frequency-Shift Keying) modulated frequencies.

It is vital for the system to be able to send configuration files unharmed. This determines the importance of the transmission in the configuration sequence. The corruption of bits will reflect on the appearance of the hardware of the smart object which might even result physical damage to the device.

### Configuration

Prototypes are configured through Active Serial configuration mode [4]. First, a configuration is loaded from a computer to an external serial configuration device [5]. The device used in this prototype is Altera EPCS4. A smart object always reconfigures itself from a configuration device. A basic configuration contains logic to operate the radio circuit through the SPI interface and a standard to communicate with other objects. This enables the reconfiguration of the smart object. The Basic configuration has to follow all the extensions of the smart object configuration files, because every time an FPGA is reconfigured, it loses its previous configuration, including the abilities to use the SPI interface and to communicate. If the basic configuration is corrupted, it can be assumed that the smart object is not working properly and it cannot be restored without physical manipulation.

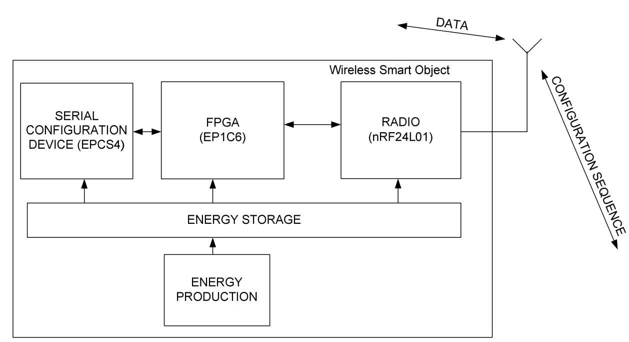


**Figure 2. Block diagram of a Smart Object.**

## FPGA ON SMART OBJECT

Nowadays, FPGAs provide the only known technology to enable reconfigurable, efficient calculation platforms. The FPGA is the brain of a smart object. It can learn by reconfiguring itself with new configurations. This offers unlimited possibilities for the objects, because a swarm of smart objects can be reused for different purposes. A single object can be configured to have a soft-core processor, DSP properties, or anything that fits into the limited hardware space. On the other hand, several smart objects can form e.g. a large amount of non-volatile memory.

There are two types of configuration memory technologies existing in FPGAs. Configuration information of an SRAM-based FPGA is lost after power has been switched off. A flash-based FPGA has non-volatile memory, which ensures that no configuration is lost after a power shortage. An SRAM-based FPGA can be configured directly from the computer, but it can also use flash-memory as a source of a configuration file. A flash-based FPGA is more integrated than an SRAM-based FPGA with an external configuration device. If some of the memory is left unused from the configuration device, it can be used freely as an application memory to store information in both technologies. This allows objects to send generic codes to objects during the configuration process. After the configuration, the smart object can use generic codes, e.g. for setting a radio channel.

A smart object could also be implemented with a microcontroller. Software that runs the microcontroller could also be sent over the network and stored into a flash-memory. The microcontroller would be more energy efficient than an FPGA on modern technology, because of the leakage current of the FPGA. But because the microcontroller is software controlled, it means dramatically slow data processing speed. Although a microcontroller might contain desired properties such as an analog-to-digital-converter, in the final implementation of a smart object, everything should be integrated in one chip.

**CONFIGURATION OVER THE NETWORK**

In the case of an EP1C6 FPGA device, the size of a raw configuration file is 1167216 bits. The size of the Serial Configuration Device, EPCS4, which is used in the prototype, is 4194304 bits. If compressed, the configuration file takes up less space than 1048576 bits, which is one fourth of the total size of the memory. The radio used in this project, capable of transmitting 32 byte packages, needs to transmit exactly 4096 packages to transfer one configuration file from one smart object to another. Altera provides an IP mega function that makes the implementation of a serial configuration device easier [7]. This mega-function can also be added to the design, if a NIOS II processor is used.

In this prototype, transmission of a configuration file is implemented as follows: the object that is the receiver sets the radio to function as a receiver and starts listening to the channel. The transmitting object sets the radio to transmit and begins to read the configuration memory from the beginning of the memory, 32 bytes at a time. Then, these 32 bytes of data are moved to a payload buffer of the radio. Then radio then transmits the data over the channel to the target object. The transmitting object has to know the address of the receiving object and both objects should have the same channel set.

The radio has built-in automation that ensures that the data is sent successfully. After the radio has sent one data packet, it immediately starts listening to the channel. If the receiver receives a data packet, it sends an acknowledgement to the transmitter immediately. If the transmitter receives the acknowledgement, the transmitting object knows that the data has been sent successfully. If the transmitter does not get the acknowledgement within a certain timeframe, it resends the current data packet over the channel. Limitations can be set, how many times transmitter tries to resend one data packet before it flags an error. Data packets have PIDs (packet ID) to ensure that the same packet is not received twice or more as a new packet.

When transmitting a configuration file, the configuration process iterates itself as long as the whole configuration is read from the original location and sent and stored to the target memory of the target object. When everything is done, the FPGA starts an automated reconfiguration process, during which it reads the new configuration file from the beginning of the memory and then reboots itself with a new configuration.

Radio control requires only 4 pins. All the data is guided through serial lines; MOSI and MISO (Master out Serial In, Master In Serial Out). The radio functions as a slave, the FPGA as a master. The device also has an input SCK, which provides clock feed for the SPI logic. The SCK is generated by the logic in the FPGA. A CE is a chip enable input, which enables the usage of a chip. All the commands start by setting the CE to logic low. First, a one-byte command word is written to the radio, and depending on the command, the data is read or written to the radio. All the logic is done on the rising edge of the *SCK*. Figure 3 represents the radio control and the connections required.

An IRQ (Interrupt Request) pin works as a flag to point when something has happened in the radio that requires attention: When a new packet arrives, data is sent successfully, or an attempt to send data has occurred too many times, the IRQ pin activates. In this project the IRQ has its own FSM (Finite State Machine) that produces information for the smart object every time the IRQ is activated.

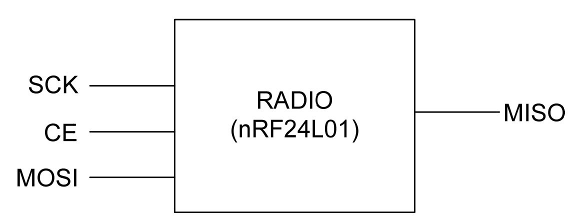


**Figure 3. Radio SPI: inputs and outputs**

The transmission and the receiving of a configuration have their own FSMs, and the SPI has its own FSM. The main-FSM, the transmission FSM and the IRQ-FSM use the SPI-FSM. Control of the SPI can also be implemented as a ready-made IP-block if NIOS II architecture is used.

### Over-the-air-programming

OTAP (Over-the-Air-Programming) is a common term in sensor network platforms. They have some similar characteristics with smart objects. Both are configured over a network and both are designed to work with small energy consumption. There are two major approaches for the sensor nodes, the work based on microcontrollers [9, 10] and FPGAs [11, 12]. Efficient ways of transmitting a configuration code to nodes is discussed in [10]. The function of these wireless nodes is to gather information from the environment, and possibly to process the information in the node before transmitting the data to the computer that assembles gathered data. Intention of this project is to get a swarm of smart objects to function as a solid system.

## ASSEMBLY OF THE PROTOTYPE

A photograph of the prototype of a smart object developed in this project can be seen in Figure 1. The dimensions of this first prototype are approximately 4 cm per side. The height is approximately 1 cm. The smart object can nowadays be made much smaller, but the developed first version required some extra properties to be debugged to achieve the desired functionality. Currently, the dominating component of the object is the FPGA device itself, which measures 22 by 22 mm. [2]. Two step-down regulators [8], the serial configuration device and the radio circuit are approximately 4 by 4 mm, each.

Considering the possibly quite minimal size of a smart object, the most significant problem is power production. If the smallest existing Flash-based FPGA is used, a smart object without power blocks could be fitted into the volume of 1 $cm^3$. Professional integration of the components, when the whole smart object is designed into a mixed-signal silicon chip, will result, in a decade or more, in a smaller smart object.

| | |
|---|---|
| $P_{idle}$ | 58,5mW |
| $P_{RX}$ | 101,4mW |
| $P_{TX}$ | 81,9mW |

**Table 1. Average Power consumption of smart object**

Collecting solar power from this area, when thinking smart object the size of 1 $cm^3$ covered with solar panel, produces an insufficient amount of energy to run or charge a smart object. This would require a bigger panel than the object itself. Solar panel technology of today cannot meet the requirements of this project yet. Use of inductive Power is not researched in this paper.

Table 1 represents power consumption of smart object on different circumstances. Idle Power consumption presents a state when FPGA has configured itself and is working normally. Power consumption of receiver is bigger than transmitter because receiver has to listen to the channel continuously when transmitter operates in bursts. Radio can be easily turned off after transmission to save energy.

If a soft-core processor is to be used in a smart object, more space is needed in the reconfigurable logic. This means a bigger FPGA. A soft-core NIOS II-processor requires in its smallest version approximately 700 FPGA LEs (Logic Elements) [3]. This means that the smallest versions of the processor cores can be implemented several times on an FPGA, which is used in this project. An EP1C6, used in the prototype, has 5980 LEs [2]. The simplest soft-core processor contains only basic peripherals, and the IP mega function that enables the manipulation of the external flash memory cannot be fitted into the EP1C6. Adding a mandatory memory manipulation property for the NIOS II processor requires a bigger FPGA.

In this project, the transmission of the configuration file and the functionality of the transmitted configuration file has been tested and proved to be working. The testing has been made so that the first smart object has been configured to have no outputs. Then, another smart object with a more complex configuration has sent its configuration file to the first object. As a result, both smart objects have the same more complex configuration working, and it has proved to be working correctly with same usage of outputs on both objects.

Configuration files with different purposes can also be transferred. Smart objects can carry several configuration files depending on the size of the external Serial Configuration Device. The device used in this project can hold up to 4 different configurations. A configuration that is going to be driven into the FPGA must always be at a "zero" location in the external serial configuration device. If an old configuration file that is located in "zero"-location is to be saved, it has to be moved before the new reconfiguration process. If an NIOS II processor is used, it is important to be aware of the fact that the program that runs the soft-core processor is stored in the external Serial Configuration Device. This limits the number of possible configuration files. Furthermore, if a configuration device contains some non-configuration data that needs to be saved, the whole memory cannot be formatted during reconfiguration.

## CONCLUSION

The development of future computing platforms might require some changes to the trends of modern technology. If no new technologies appear, this will mean certain limitations for the development of modern computing platforms.

Implementation presented in this paper is the most suitable method when beginning to research techniques for making a swarm of wireless, reconfigurable smart objects to work together. An FPGA is a more efficient platform for complex calculations than a microcontroller, as possible processor architecture might have to be designed specifically for the smart objects.

This paper introduces a way to connect small smart objects wirelessly. Configuration files can be sent and stored into smart objects. The objects can receive different configurations from other objects and reconfigure themselves according to the needs of the system, without any physical contact. A swarm of smart objects offer a solution to the rising demand for computing platform efficiency. With some more research, the calculation complexity of the computing platform can be increased, simply by adding more objects into the system. A swarm of smart objects create a new trend of computing – Cognitive Computing.


### ACKNOWLEDGEMENT

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# Randomised Collaborative Transmission of Smart Objects

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### ABSTRACT
We propose a randomised approach to time and frequency synchronisation of superimposed received signals from collaboratively transmitting smart objects. The technique is feasible without communication between nodes and entirely relies on the receiver feedback. It is practical for an arbitrary number of received signals and transmitter nodes. The superimposed received signal has its maximum constructive interference focused on an arbitrary location of a remote receiver. In both, analytic considerations and in a simulation environment we demonstrate that synchronisation of several hundred received signals is possible within milliseconds.

### Author Keywords
Collaborative transmission, Sensor networks, Optimisation, $(1+1)$-EA, Smart Objects

### ACM Classification Keywords
C2.7.c Sensor networks, I2.m.c Evolutionary computing and genetic algorithms.

### INTRODUCTION
In recent years, computing devices of diminishing size that embed sensing capabilities, communication and actuation have become reality [1, 2, 3]. In [4], nodes of 1-4$mm^2$ size are discussed so that a paintable or even sprayable network of smart objects may be envisioned that seamlessly integrates into everyday artefacts, cloths or buildings. Consequently, a scenario in which a huge number of communication devices pervasively resides in one or several smart objects is possible. However, at such extreme sizes, energy consumption and lifetime become major concerns for the design of sensing, communication and computing hardware that is integrated in these smart objects. An ambitious solution to power supply at these sizes are parasitically operating nodes that obtain energy, for instance, from solar, environmental movement, temperature change or chemical reactions in living organisms [5, 6]. The energy consumption of parasitic nodes is restricted to several ten microwatts. This greatly impacts the transmission range of parasitic sensor nodes so that information can only be obtained from the network, when the receiver is in direct proximity with the transmitting nodes which is not feasible in many application scenarios [7]. One solution to this problem is to cooperatively transmit information by distinct nodes of a network by utilising constructive interference of the transmitted signals at the receiver. When signal components are simultaneously received, they add up to a sum signal. If they are not synchronised, the interference is destructive, which leads to a distorted signal at the receiver. When, however, identical signal components arrive at a receiver in phase, the interference is constructive and the signal strength is improved. Cooperation can increase the capacity and robustness of a network of transmitters [8, 1] as well as the maximum transmission range [9] and decreases the average energy consumption per node [10, 11].

The use of constructive interference in sensor networks was studied by various groups in the last decade [12, 13, 8, 14, 15, 16, 17]. These approaches utilise neighbouring nodes as relays [18, 19, 20] as originally proposed by Cover and El Gamal in [21]. Neighbouring nodes repeat a recently received signal to achieve a sufficient synchronisation of signals at a receiver. The major drawback of this approach is that the nodes are not synchronised wherefore the location at which a maximum constructive interference of signal components is observed is also a random parameter that depends on several aspects as the placement of nodes, the synchronisation between nodes or the environmental reflection of signal components. For practical applications this means that the receiver has to relocate to find sufficiently synchronised signal components, if there are any.

Cooperative transmission is accomplished in the literature by three distinct approaches: Multi-hop, Data flooding and cluster based.

Multi-hop relaying relies on the physical channel. The multi-hop scenario is interpreted as multi-dimensional relay channel, where communication between all nodes is allowed [22]. It has been shown that this approach optimally divides the network resources in terms of information theoretic metrics [23]. With increasing scenario sizes, this approach is, however, not well suited since the number of transmitted bits per square meter decreases quadratically with the size of the network [24, 25].

An alternative approach that bases on flooding the network with a message that shall be transmitted is presented in [26, 27]. The opportunistic large array (OLA) method utilises the constructive interference of spatially related transmission signals of nodes in a sensor network. Neighbouring transmitters function as relay nodes that retransmit a received signal various times. In this approach the network is flooded with nodes that transmit the desired signal whereby constructive interference is created. A related approach is presented in [16, 15, 28], where the signal is overlaid with white noise to increase the probability of constructive interference. However, for all these strategies the maximum constructive interference occurs at a random point in the transmission range since nodes are not synchronised and also no receiver feedback is utilised.

The third, cluster based approach was first proposed in [29]. The basic idea is to build up clusters of collaboratively transmitting nodes that cooperate when sending or receiving messages [23]. In [30] the optimal cluster design is derived. This approach has the benefit that standard routing algorithms as well as multi-hop theory can be applied with little modification. However, the capacity of a network that follows this topology is lower than for the previously detailed approaches [25, 31].

In contrast to these cooperative approaches we propose to utilise the receiver feedback in order to guide the synchronisation of transmitted signals. By doing this we are able to synchronise a virtually unlimited number of received signals at any concrete target location of a receiver without the need of cooperation between nodes and at a very fast pace. With respect to the fact that no cooperation between nodes is required we refer to this approach as collaborative transmission. In the following sections we demonstrate that it is possible with collaborative transmission to increase the strength of a received signal by a factor that is easily larger than 100 in a fraction of a second.

## COLLABORATIVELY TRANSMITTING SMART OBJECTS

We are especially interested in the communication between and with smart objects. The focus of this work is on the sensing, computation and communication components of intercommunicating smart objects. For ease of presentation we refer to such a network of smart objects as a wireless sensor network (WSN), since not the types of smart objects but the number of nodes that contribute in communication is relevant for our approach.

We consider the following scenario. A sensor network of $n$ tiny, square millimetre sized, parasitic sensor nodes is deployed with a high density of sensors per square meter. The information sensed by the sensor nodes is to be transmitted to a stationary remote receiver that is located far off the transmission range of each single sensor node. The receiver can, however transmit a feedback regarding the measured channel quality back to the sensor network. It is possible to measure the channel quality in terms of impulse response of a potentially superimposed channel and to estimate the future channel state by long-term prediction at the transmitter side. This approach is, for example, investigated by the group of Lajos Hanzo at the University of Southampton with focus on the improvement of MISO and MIMO techniques [32, 33, 34]. It requires, however, ambitious capabilities at the transmitter and receiver side and is for that reason currently not feasible for parasitic sensor nodes.

We therefore propose an initialisation phase triggered by the remote receiver. In this phase all nodes simultaneously transmit a predefined signal for synchronisation purposes. The remote receiver compares the received superimposed signal with the expected sequence and transmits the sum difference between both signals as feedback. This feedback guides the synchronisation process at the sensor nodes. When nodes are sufficiently synchronised, the receiver ends the initialisation phase and requests data. Synchronisation between transmitted signals is obtained by phase shifting the baseband signal at the sensor nodes. This can be accomplished for sensor nodes either by utilisation of VCO-elements or by even simpler L/RC-transmitter types. These transmitters enable the easy time/phase shift of a signal by short time alteration of the baseband frequency. In spite of this, these transmitter types are highly error prone so that frequency as well as phase shift are subject to errors. Since the more exact VCO-elements are, however, way more expensive and are not likely to decrease in cost due to manufacturing conditions, we believe that L/RC-transmitters are the only feasible way of implementing parasitic sensor nodes that collaboratively transmit their data.

We investigate the synchronisation process and model the scenario as black-box optimisation problem. The search space of the problem is given by the combined frequency and phase shifted received signals. One point in the search space is given by one configuration of transmitted signals:

$$\sum signal_i(t) \tag{1}$$

W.l.o.g. we assume that a sinus signal at $f_{base}$ =2.4 GHz is transmitted by the nodes so that

$$signal_i(t) = A \cdot \sin(2\pi \cdot (f_{base} + f_i) \cdot t + \varphi_i) \tag{2}$$

with phase shift $\varphi_i$ and frequency shift $f_i$ defines one configuration of signal $i$. At time interval $t$ a search point $C(t)$ is given by the set of configurations for all received signals.

$$C(t) = \sum_{i=1}^{n} signal_i(t) \tag{3}$$

The fitness function $f_{fitness} : C \rightarrow \mathbb{R}$ is provided by the receiver feedback. W.l.o.g. we assume that the optimisation aim is minimisation. We apply a $(\mu + \lambda)$ evolutionary algorithm to this problem with $\mu = \lambda = 1$, which means that population size as well as offspring population size are 1 and the offspring is chosen as the best (in terms of fitness value) individual of these two. Since population size is 1, no crossover is applied and mutation is the only search operator. The $(1 + 1)$-EA is a natural choice in this problem domain since a population directly refers to one configuration $C$ of the sensor network.

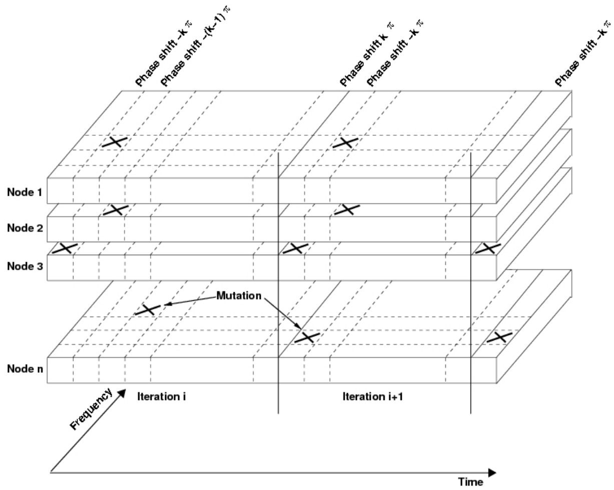


**Figure 1. Illustration of the basic scenario. From iteration $i$ to iteration $i+1$ a mutation is applied to sensor node $n$.**

Mutation in the sensor network is obtained without cooperation between sensor nodes. Every node decides randomly after each period of the transmitted signal whether a mutation is applied. In positive case the phase of the signal is altered by a random process. As detailed above, this might also result in frequency alteration. The alteration is maintained in future iterations when the receiver feedback is improved and is reversed otherwise. This principle is illustrated in figure 1. In the figure, node $n$ alters the phase of the transmission signal. Because the fitness value observed in iteration $i+1$ is improved, this alteration is maintained also in iteration $i+2$

In the following sections we present analytic results on the optimisation speed as well as on the performance the approach achieved in simulations.

## ANALYTIC CONSIDERATION

In the analytic consideration we aim to estimate the expected optimisation time for a $(1+1)$-EA on the optimisation problem. We assume that the optimisation aim is to obtain perfect synchronisation between all $n$ received signals. This means that all $n$ signals at the receiver have identical phase and frequency.

As discussed above, due to the utilisation of L/RC-elements frequency and phase are potentially distinct between signals. Consequently the periods of the signals are of distinct length as depicted in figure 2. We assume that the actual frequency of the signals is centred around a base frequency while the deviation is guided by a random process. We assume a Gaussian distributed process with a standard deviation of $\sigma$. For the analytic consideration, we assume that the fitness value is given by the maximum count of received signals that are in phase:

$$f_{fitness} = \max_i\{|S^i_{\kappa\omega}|\} \tag{4}$$

where $S^i_{\kappa\omega} = \{signal_i(t)|\varphi_i = \kappa, f_i = \omega\}$. We assume that a total of $k$ different phase shifts are possible and consider a maximum of $l$ discrete frequencies.

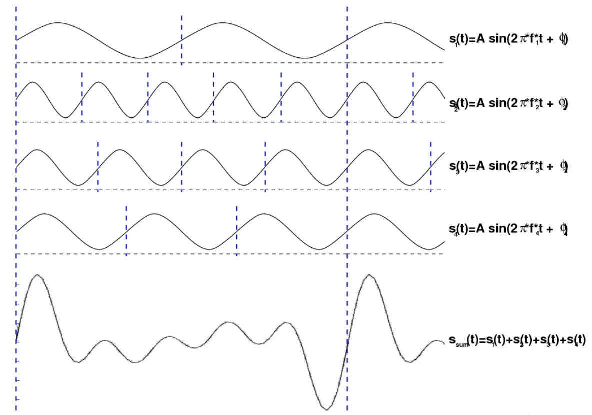

**Figure 2. Illustration of periodic relative phase shifts between several signals at various frequencies.**

As depicted in figure 2, the relative phase shift between signals of distinct frequencies is not constant over time. However, given any two signals $s_i(t)$ and $s_j(t)$, the same sequence of relative phase shifts occurs repeatedly, and the repentance-frequency is given by the lowest common multiple of the period lengths of the signals. The same mutation of one signal can therefore have different impact on the received sum signal, because the time of mutation also matters. Since, however, the mutation time as well as the mutation itself are guided by random processes, this property does not impact the analytic consideration. We assume a uniformly distributed mutation probability of $p_m = \frac{1}{n}$ for each of the $n$ sensor nodes and uniform distribution of all possible mutation outcomes. Since $k$ distinct phases and $l$ distinct frequencies are considered, a specific mutation occurs with probability $\frac{1}{k\cdot l-1}$.

In order to estimate the expected optimisation time, we have to understand the optimisation problem a bit better. According to the fitness function, the individuals with worst fitness value have distinct phase and frequency for all $signal_i(t)$ in $C(t)$. Basically, the fitness function is guided by the number of signals that are received synchronously in phase and frequency. The maximum fitness value is therefore given by the number of nodes ($n$) and it declines every time the largest set of synchronously received signals is increased. We consequently obtain a fitness based partition of the search space with $n$ partitions. The partition with fitness value $f_{fitness}$ is then labelled $L_{n-f_{fitness}}$. The probability to increase the fitness value by at least one is

$$\frac{1}{k\cdot l-1}\cdot\frac{n-f_{fitness}}{n} \tag{5}$$

since every one of the $n-f_{fitness}$ not synchronised signals is altered in phase and frequency with probability $\frac{1}{n}$ and achieves the specific mutation required with probability $\frac{1}{k\cdot l-1}$. The optimisation of the $(1+1)$-EA is guided by the fitness function which has the same value for all individuals in $L_i$ but differs for all individuals in $L_j$ with $i \neq j$.

Whenever the fitness value is increased due to a mutation, the current layer $L_i$ is left by the algorithm. In layer $i$, a total of

$$\left( \begin{array}{c} n-i \\ 1 \end{array} \right) = n - i \tag{6}$$

1-bit mutations with probability $\frac{1}{n} \cdot \frac{1}{k \cdot l - 1}$ each suffice to improve the fitness value. We therefore require that at least one of the not synchronised signals is correctly altered in phase or frequency while all other $n-1$ signals remain unchanged. This happens with probability

$$\begin{aligned} & \left( \begin{array}{c} n-i \\ 1 \end{array} \right) \cdot \frac{1}{n} \cdot \frac{1}{k \cdot l - 1} \cdot \left(1 - \frac{1}{n}\right)^{n-1} \\ = & \left(\frac{n-i}{n \cdot (k \cdot l - 1)}\right) \cdot \left(1 - \frac{1}{n}\right)^{n-1}. \end{aligned} \tag{7}$$

Since

$$\left(1 - \frac{1}{n}\right)^{n} < \frac{1}{e} < \left(1 - \frac{1}{n}\right)^{n-1} \tag{8}$$

We obtain for the probability $s_i$ that $L_i$ is left and a layer $j$ with $j < i$ is reached due to mutation as

$$s_i \geq \frac{n-i}{n \cdot e \cdot (k \cdot l - 1)}. \tag{9}$$

The expected number of mutations to change the layer is bounded from above by $s_i^{-1}$. We consequently obtain the overall expected optimisation time as

$$\begin{aligned} E[X] & \leq \sum_{i=0}^{n-1} \frac{e \cdot n(\cdot k \cdot l - 1)}{n-i} \\ & = e \cdot n \cdot (k \cdot l - 1) \cdot \sum_{i=1}^{n} \frac{1}{i} \\ & < e \cdot n \cdot (k \cdot l - 1) \cdot (\ln(n) + 1) \\ & = O\left(n \cdot k \cdot l \cdot \log n\right). \end{aligned} \tag{10}$$

Considering a transmission frequency of 2.4 GHz and $n = l = k = 1000$, this upper bound on the expected time for optimisation corresponds to an expected synchronisation speed of 1.25 seconds.

## SIMULATION

We implemented a matlab simulator for collaborative transmission in wireless sensor networks. For the simulations it is assumed that a sine signal of 2.4 GHz is utilised for the initialisation phase of the network. In the simulations a mutation probability of $p_m = \frac{1}{n}$ was assumed for each one sensor node. In a mutation, phase and frequency are randomly altered. We apply a uniformly random phase alteration in the range of $[-\pi, \pi]$ and with stepwidth $0.1 \cdot \pi$ . The frequency alteration is guided by a normal distribution with mean $\mu$ at 2.4 GHz and standard deviation $\sigma$ of 10 MHz.

At the receiver the superimposed signals are compared to the expected, perfectly synchronised $n$ received signals. Since both, frequency and phase are subject to alteration, the receiver compares several perfectly synchronised frequency and phase altered signals. In the simulation the received signal is compared to 441 distinct signals which constitute all possible combinations of phase alterations at stepwith $0.1 \cdot \pi$ in $[-\pi, \pi]$ and phase alterations of 1 MHz in $[-10$ MHz, 10 MHz$]$.

The simulation is simplified in that it does not consider multipath propagation and that pathloss for all signal components is considered identical.

Simulation results of a simulation with $n = 1000$ nodes are depicted in figure 3. As it can be observed from the figures, the initial, totally distorted superimposed signal at the receiver is already recognisable after a few hundred iterations. With further iterations the signal is nearly recovered and the main improvements regard signal strength. After 40000 iterations, the amplitude of the superimposed signal is approximately 800 times greater than the amplitude of each one of the received signal components. At a frequency of 2.4GHz, 40000 iterations translate to an optimisation speed of about 17 milliseconds.

## OUTLOOK

Despite these impressive results there are still several issues we want to address in future work. The most pressing of these include the consideration of receiver and transmitter movement. While the short synchronisation time should allow reasonable movement at the receiver, a set of moving transmitters might require more advanced synchronisation approaches.

Furthermore, since crossover might speed up the optimisation time significantly, we will consider populations of greater size. To achieve this, several transmit signals per node (distinct phase and frequency shifts) or the division of nodes into various, spatially interweaved, sets that transmit at distinct times are possible approaches to increase the population size.

Additionally, future simulations will also consider path-loss and multipath propagation of signals. Also, a demonstration environment consisting of real sensor nodes is to be implemented and analysed for this scenario.

## CONCLUSION

We have demonstrated that communication with smart objects that are equipped with tiny, square millimetre sized communication, sensing and computing components is feasible for ultra-low-power parasitic implementations. Although the transmission range of these smart objects is strictly limited due to power constraints, the transmission range can be greatly improved by collaborative transmission approaches.

We have shown that collaborative transmission in networks of wirelessly interconnected smart devices is feasible without communication between nodes. The problem scenario was modelled as black-box optimisation problem and solved by a $(\mu + \lambda)$ evolutionary algorithm with $\mu = \lambda = 1$. In an analytic consideration we derived an upper bound on the optimisation time of $O(n \cdot l \cdot k \cdot \log(n))$ where $n$ is the size

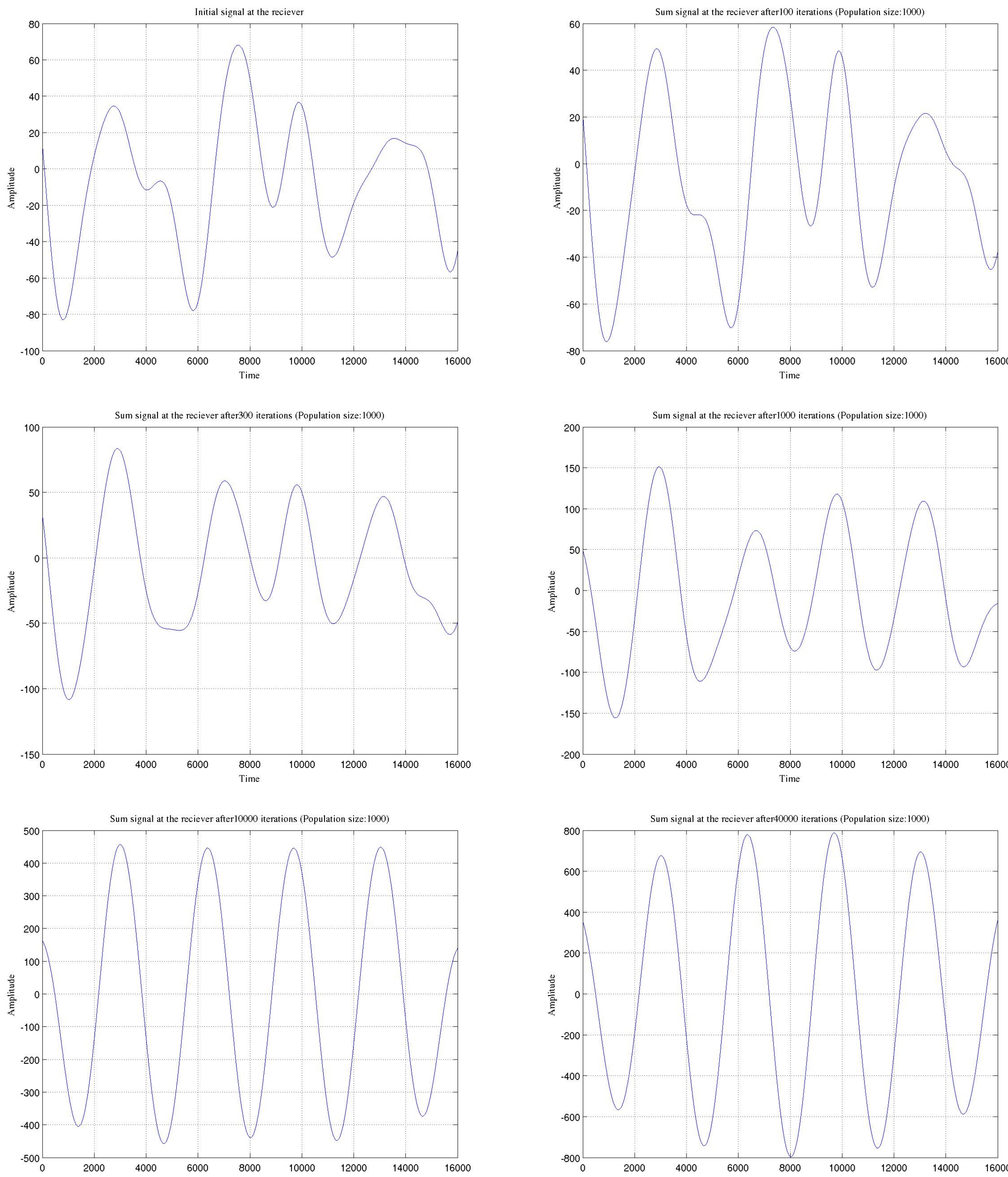


**Figure 3. Illustration of the received superimposed signal at various times in the optimisation run.**

of the sensor network and $l$ and $k$ describe the amount of variation in phase and frequency.

In a simulation environment we obtained a synchronisation time of about 17 milliseconds and an amplitude boost of the received signal of approximately factor 800 for a network of 1000 collaboratively transmitting nodes at $2.4$ GHz.

We conclude that reasonable movement of transmitting or sending nodes is also possible with such rapid initialisation speed.

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# Experimental Wired Co-operation Architecture of Reconfigurable Small Smart Objects

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**ABSTRACT**
This paper describes a preliminary study and experimental design of future small smart objects. Especially, reconfigurable small smart objects in a solid wired grid are considered. The most important property of future small smart objects will be their ability to communicate with each other and effectively co-operate. This can be done in many ways and one is described in this paper. A network of small smart objects is a network structure which enables objects to form a fabric like physical structure in which objects can communicate. Actually, building small smart objects and the entire network is not possible using present technology because of its physical size, but a technology independent structure and operation can be considered. The network structure is based on the idea that small smart objects are connected to each other and all objects supply data packets to each other in order to enable communication between all objects. Objects can also copy their configuration to adjacent objects which helps to set up and maintain the network.

**Author Keywords**
Transparent structure, FPGA, Packet Transmission.

**ACM Classification Keywords**
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

Development of integrated circuit's development has always been towards smaller and faster components and devices. During last decades, the development has been enabled mainly by continuous progress in IC fabrication technology. Almost every year, silicon chip manufacturers have moved to use smaller pitch width but the basic technology has remained almost the same. Switching elements on silicon chips are made smaller and more power efficient by decreasing the line width. The phase of moving to use narrower line width which leads to larger number of transistors on a chip has followed Moore's law [5]. Moore's law indicates exponential growth and it is clear that it can't go on indefinitely. When CMOS (Complementary Metal Oxide Semiconductor) line width comes to a point where it can't be reduced any more the overall progress in IC technology will most definitely continue with some other technology than CMOS.

Semiconductor technology has moved to use 65 nm line width in manufacturing ICs in 2007 and some 40 nm circuits have been introduced in 2008 [3]. According to ITRS Road Map for semiconductors, line width will narrow down to 14 nm by 2020 [6]. With 65 nm technology the area of one CMOS logic gate (4-transistors) is 1.3 $\mu m^2$. If human eye can distinguish objects that are bigger than 200 µm but not smaller it, is possible to implement approximately 30,000 logic gates on 40,000 $\mu m^2$ area that can't be seen by a human eye. Even if, all the chip area could be used to implement logic, only some basic functions could be realized with these chips. From now on, in this paper, these invisible chips are called small smart objects or just objects.

One solution for the problem that individual chips are too small to house the logic to perform any practical functions, is to use lots of these small objects to perform the overall function. The physical structure could still be invisible, if objects are not too close to each other. Small smart objects would communicate with each other and enable large design entities even though individual parts are small. One kind of transparent computing platform could be made connecting objects few millimeters apart from each other. Distance between objects depends on application but in order to maintain transparency objects can't lie right next to each other. Possible application for this kind of transparent fabric could be interactive display which could sense many kind of stimuli through its sensors and display the data it processes. E.g., objects in display-structure would contain light emitting device (LEDs) therefore one object could form a pixel on display. Display could also process all data it receives and display the processed data. Some quantities that display could measure are, e.g., temperature, air pressure, air pollution, humidity, light intensity and noise.

On the display, only objects that have LEDs on would be visible.

There are also possible future applications that need wireless communication between objects and so solid network is not a good solution for all kind of small smart objects communication. One of these future products is nanorobots that can be utilized in medical applications. In medical applications nanorobots size of a blood cell could follow blood vessel and reach almost any part of a human body internally. Specially, in cancer treatment there is two important factors that effect patient's odds on surviving cancer: the cancer has to be diagnosed as soon as possible in order to start treatment before it is too late. And drug delivery has to be well targeted to reduce side effects from chemotherapy. Both these tasks could be carried out with nanorobots that find tumor cells and kill the cells. [4]

Although, mass production of small smart objects is neither economically nor technologically possible today, it is worth considering beforehand how these objects would function and communicate with each other. In this paper a simple structure of solid communication network is introduced

## IMPLEMENTATION OF DIGITAL LOGIC

When designing digital logic there are in general two options available to implement the design: Application Specific Integrated Circuits (ASIC) and Field Programmable Gate Arrays (FPGA). Although same operations can be realized with both circuits there are some big differences. Differences between ASIC and FPGA implementations' area efficiency, power consumption and speed have been studied in [7]. Differences seem to be quite significant and don't really praise FPGA circuits. Area efficiency of FPGA compared to ASIC varies from 40 times worse when only logic elements are used to 21 times worse when FPGA's "hard" blocks, like multipliers and block memories, are used. Dynamic power consumption is approximately 12 times bigger with only logic elements in use and only little bit smaller when "hard" blocks are used. Critical path delay is 3 to 4 times longer with FPGA and figure is the same with and without "hard" blocks. These numbers illustrates the supremacy of ASIC over FPGA when considering only properties that are important in completed product that is not adaptable. FPGA's "hard" blocks mean fixed and optimized blocks that are supposed to function optimally.

Both circuits have their pros and cons. ASIC implementation is much better when considering power consumption, speed and area efficiency. Therefore ASIC is better if object has some specific function to fulfill and it will remain the same entire product life cycle. ASIC implementation requires substantially more design effort than FPGA. FPGA has advantage of being reconfigurable, which means, in the case of smart objects, that the hardware structure of the logic inside of one individual object can be configured to execute different functions at different times. In ASIC implementations, logic configuration has to be fixed during design phase and no changes to the hardware structure can me made after that. This also means, that even though the silicon area of FPGA implementation is approximately 40 times that of respective ASIC area, the difference doesn't matter that much if the following three conditions are met. First, the function that is used at once fits on FPGA-circuit. Second, there is lot of small functions that are totally independent from each other and only one function has to be executed at the same time. And last, the delay due to reconfiguration doesn't affect operation. These are the basic design conditions that have to be met if considering implementing such a big design on FPGA that it doesn't entirely fit on a FPGA-circuit.

Difference in area efficiency is still quite significant and means that the same silicon area of an ASIC implementation can contain up to 40 different variations of that one function a respective FPGA area contains. For example, implementation of 40 different variations of a certain digital decoder/encoder could be implemented to occupy on ASIC the same area as one version in an FPGA. On the other hand, some new coding methods could be introduced after the ASIC has been made. In this case ASIC can't be modified but FPGA can still get the job done. However, one commercial FPGA device can contain logic structure which is equivalent to more than one million 2-input NAND gates. If the digital logic implementation of a smart object's intelligence fit into a FPGA device containing logic structure equivalent to less than couple of millions of basic gates, then the ASIC implementation is not practical at all.

Even though ASIC's logic is fixed, it is not totally out of consideration when talking about adaptable function. There is a way to use ASIC and still maintain adaptability. When a processor is implemented on ASIC the logic design is fixed but the program code can be modified. This allows object's operation to be modified. On the other hand, we would still miss some FPGA's properties and if design entity of a small smart object is very small it is very wasteful to use processor that requires a lot more resources than simple control logic on FPGA. This paper concentrates on these very small smart objects and therefore processor implementations on ASIC is not considered here.

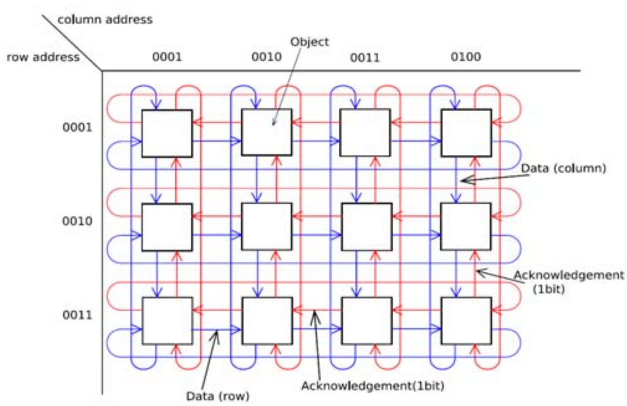
When designing small smart objects there is one more reason to use FPGA circuits instead of ASIC. Using FPGAs, all individual smart objects in a swarm can have the same digital hardware structure, because the specific functionality of an object can be configured separately to all objects. In case of sensor network or some other application that needs lot of different components on different objects, using the same hardware might be inefficient but could be done.

### COMMUNICATION NETWORK OF SMALL SMART OBJECTS

In this paper a model of a communication network that could be used in interactive display application is proposed.

The structure of network is matrix like network in which small smart objects are next to each other. Example of a communication network is shown in Figure 1. Blue arrows are data buses and red arrows acknowledgement bits that objects use to tell transmitting object that data is being received. As well as objects data is transmitted through these connections also power and configuration are supplied to objects using these connections.

**Figure 1. Structure of the communication network. (Only data**




**connections are shown)**

Objects are mainly connected to four adjacent objects and they are able to send data to two of those on the right and below and receive data from two on the left and above. Exceptions to connections can be made on the edge of network where objects can be connected to other side of network like it has been done in the Figure 1 or connectors can be left floating. If connectors are left floating, only one of sending and receiving connectors can be left floating in order to ensure individual object's proper function. These requirements enables individual objects to be operable but in order to maintain network operations other requirements have to be taken into account as well.

### Objects Addressing and Data Transmission

Each object has an individual address that also indicates object's position in the communication network. The address is divided into two parts: row address and column address. In Figure 1, rows are organized horizontally and columns vertically. Addresses are formed this way to help finding objects in rows and columns. Column and row addresses increase to right and downwards. The number of address bits depends on how many objects are needed in application and how objects are placed in the network. If there is much more columns than row or vice versa longer addresses are needed than total number of objects would require.

The data from one object to another is transferred in packets. All objects send packets to adjacent object in row or column. Objects can also supply packets in between sending object and receiving object therefore objects doesn't have to be right next to each other to be able to communicate. In every object that supplies packets to other objects the packet address is read and according to packet address object sends the packet to next object in column or in row. If packet's row address is the same as object's row address the object sends the packet in row. Same operation happens when column addresses are the same. If the packet address is totally different compared to object's address the packet will be sent to next object in row. This means that packet first finds the right column and when it is on the right column it finds the right row. Therefore it is important to make sure that packet can't end up circulating in a row that is shorter than other rows and therefore all the columns can't be found.

If one of the object's sending connectors is left floating object has only one alternative in which direction to send the packet therefore it doesn't matter what is the address in the packet. In order to ensure transmission to all objects it is inevitable to make sure that not too many connectors are left floating. Easiest way to confirm this is to connect all connectors or check that all objects can be reached by moving from one object to another right or downwards.

Packet consists three different parts: receiver's address, time-to-live bits and data. Time-to-live bits ensure that packet doesn't circulate in network indefinitely if none of the objects receive the packet. Every time a packet passes an object packet's time-to-live value is reduced by one. If value of time-to-live bits goes to zero transmission of the packet is terminated. The number of time-to-live bits depends on the number of objects because the initial value of time-to-live bits has to be larger than number of objects in longest transmission chain in network. The longest transmission chain is usually between objects that locate in opposite corners of network.

As object can receive packets from two directions and start data transmission itself at the same time there has to be buffer to make sure that packets would not get lost even if object can't send packets at the same phase as it receives them. All the packets that are received and will be supplied to next object goes to buffer to wait transmission. When the transmitting part has completed previous transmission next data packet goes to transmission and the object sends the packet to next object. Buffer size and means to avoid buffer overflows are highly application dependent and are therefore ignored in this paper.

### Adding New Objects to the Network

New objects can be added to network without any changes to overall structure. If the network remain square shaped after adding new objects connections between objects are like is demonstrated in Figure 1. To maintain square shape, full rows and columns should be added to network. In some cases, adding individual objects to network could be needed and shape of network will become other than square. In network that is not square shaped, special attention has to be paid on ensuring communication. In some cases, row or column connector has to be left floating. For example, if a row is shorter than other rows the last object in the row can't be connected to the first object in the same row because from this row it is impossible to reach all required columns. To get rid of this situation, row's last object's row connector is not connected. This forces a packet to change row to a longer row, where it can find all the columns.

After physical connection, new objects have to be configured. As required FPGAs are based on SRAM (Static Random Access Memory) technology, some kind of booting device is required. Booting device or configuration device basically contains configuration data and configures FPGA after power is turned on. Every reconfigurable smart object should contain at least one configuration device or non-volatile configuration memory inside the FPGA. If the configuration memory is inside the FPGA, accessing the memory outside the FPGA should, however, be possible. Copying configuration is being performed by copying configuration data from one configuration device to another. The copying is controlled by the object that has already been configured. So objects don't actually configure adjacent objects but give them the configuration data that is being used in configuration.

Although, objects that are not next to each other can communicate with each other, they can't copy their configuration to non-adjacent object. Configuration data is being transferred from one object to another serially, not in packets like other data. This is why there has to be direct wire between two objects when copying configuration. To maintain simple connections only adjacent objects are connected with these direct wires. This sets limitations, if there is different kind of configurations needed and adjacent object doesn't happen to have needed configuration. Some other means to transfer configuration data is needed. One possible way to do this is to include all configurations a part that enables objects to change their configuration data by them selves. After this is done, new configuration data can be sent in data packets to any object. On the other hand, transferring configuration data in packets requires that object must be configured to receive packets before it can receive configuration data from network.

After the new object has been configured it notifies that it has no address. It asks address from objects on the left and above and both these objects give address to new object. In practice, acknowledgement signals are used to inform adjacent objects that an address is needed. When an object notifies that its acknowledgement signal is asserted even though it is not sending data, it knows that an adjacent object needs an address. The new address is calculated based on their own addresses. If network is properly organized both objects give the same address. This is one of the reasons why address is separated in row and column addresses and why addresses are organized from lowest to highest.

### Spreading the Configuration Data over the Network

When new objects are attached to the network, adjacent objects copy their configuration data to new objects and so new objects become functional without external control. There might be also situations when configuration of all objects has to be modified and new configuration data has to spread around entire network. In this case, at least one object has to be configured externally of the network, because required configuration doesn't exist in the network. After the first object has been configured the copying of configuration data to adjacent objects can start. Spreading the configuration data efficiently and fast is important. If objects are configured one after the other it takes long time to configure all objects, because configuring even one object takes few seconds. At least, when using flash memory to store configuration data, even erasing content of flash takes few seconds.

Configuration time can be reduced by allowing one object to copy its configuration to more than one object. Since copying of configuration has to be carried out with same connections than communication one object has only two object that it can configure. This limits the total time of configuration but keeps the connections simple. Figure 2 shows in which order configurations have to be made in order to attain optimal total configuration time. The numbers in Figure 2 indicates simultaneous configurations. For example, all configurations that are marked with number 4 occur at the same time. As we can see configuring network which has 16 objects takes 6 times longer period of time than configuring one object.

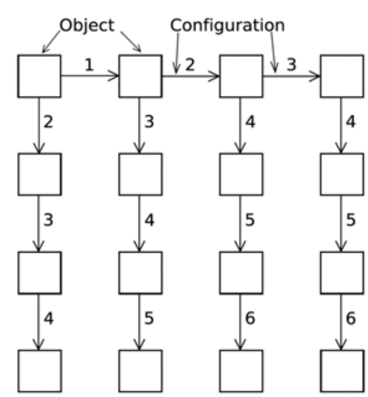



**Figure 2. Configuration of entire network.**

Time of configuration can be estimated by equation

$$T_{tot} = 2 \cdot T_{obj} \cdot \left(\sqrt{N_{obj}} - 1\right), \quad (1)$$

where $T_{tot}$ is time of configuring entire network, $T_{obj}$ time of configuring one object and $N_{obj}$ is the number of objects in the network.

## EXPERIMENTAL DESIGN ON FPGA

In order to verify proper function of a communication network an experimental implementation has been done. The

Altera Quartus II v7.2SP3 FPGA software was used to implement the logic design and configure FPGAs. Entire digital logic was coded in VHDL and one Altera's Intellectual Property (IP) function was used. At the first stage of design, two Altera DE2 Development and Education boards were used to verify design. Later, two macro models of objects were made.

**Properties of Experimental Design**

In the experimental design, all the required functions were designed and tested but the function had to be controlled by the user. In small smart objects, all functions have to be automated but at this point of development only separated functions were tested. For example, user has to give commands to one of the objects to start communication or to start copying configuration to another object. Objects have five basic functions: Object can receive its own address from user because first object in the network can't get address from other object. Object can give address to adjacent object when needed. It can send and receive data and copy its configuration to adjacent object. Besides these five functions objects also need to read the data it receives in order to decide whether the data is meant for this object or to some other object. If the data is meant for some other object the data has to be transferred to next object on the right or below. Supplying data to other objects have to be automated. All of these functions can be tested on development boards except copying configuration because of restrictions of HW implementation of the board. In order to test configuration transfer objects configuration device should be accessed directly via IO-pins which is not allowed in the development board. This developed experimental macro model of small smart object is used to test and verify the copy operation of configuration data from one object to another.

**FPGA Resource Usage**

The number of resources the object needs is important figure considering how small object could be. On both Altera's FPGA circuits (2C35 on development board and 1C6 on model object) that were used design used 1321 logic elements (LE) and 2048 Random Access Memory (RAM) bits. Although only 2048 bits were needed entire 4 Mb memory block had to be used. On this point of view using one bit of memory requires just as much resources as using 4 Mb of memory. In reality implementing memory using LEs instead of memory block is reasonable if required memory is very small. Cyclone FPGA's basic logic element consists of a 4-input LUT and a D-flip-flop register. The experimental design needed 1197 4-input LUTs and 780 registers. The used silicon area could be estimated by estimating the area that ASIC design would require and considering that FPGA's area is as much as 20 to 40 times that. On the other hand, commercial FPGA devices always comes in discrete sizes so there are always some left over resources on FPGA circuits and the final physical size of the implementation is determined by the dimensions of the selected FPGA device. [1, 2]

**Test bench**

The communication was tested using development boards and macro model of a small smart object. The network properties were tested on development board, which enabled implementing 16 objects on same board. On VHDL design object formed a component and, at top level entity, there were 16 components connected together. This testing structure helped testing the data packet routing because only one FPGA was needed. The entire testing structure included also one object on separate FPGA because testing objects that locate on same FPGA doesn't take in to account, that different objects should have asynchronous clock signals.

All communicational properties were tested on development boards so only thing that needed to be tested on objects macro model was copying of configuration. The object's models were build in a way that one object was directly connected to another objects configuration device so configuration could be copied from one object to another. Also communication was tested with model objects but using only two objects it was impossible to test data packet routing like it was done with development boards.

Both testing structures verified the design to work properly. Although test cases that contains thousands objects and lot of data transferring might reveal some things that need to be revised.

**CONCLUSION**

Small electronic devices that can be integrated to all kind of structures will draw lot of attention in the future. Devices that are available every where but don't need any attention from the user are easy to use. One of these applications is intelligent fabric which could be formed by making very dense network of these devices.

This paper introduces a network structure that allows small smart objects to co-operate. Objects are able to communicate with each other and copy their configuration to adjacent objects. Co-operation is probably the most important property of small smart object because objects are so small that instead of having all important properties on their own they co-operate and function together like bigger and well-equipped device. Ability to copy configuration to adjacent objects increases networks autonomy and decreases need of maintenance. Even if there is lot of objects only one has to be configured by the user and the rest is left for network. In the case, when multiple different configurations are needed, each one of these configurations has to be configured to network at least once.

Building an invisible device which in this paper is considered to be smaller than 200 μm in diameter is impossible with present technology. In the future it might be possible even with CMOS technology but considering even smaller devices; it is obvious that some different technology is needed.

**ACKNOWLWDGEMENT**

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# Using smart objects as the buildings blocks of pervasive awareness applications

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**ABSTRACT**
Awareness systems are a class of computer mediated communication systems that help individuals or groups build and maintain a peripheral awareness of each other. Traditionally awareness systems have been studied at the workplace, with awareness of co-workers being a useful by-product of rich media interconnections between them. Awareness systems for informal social use are still in their infancy as a technology and as a research area. Such systems promise to address pressing social problems: elderly living alone, families living apart for large parts of the working week, monitoring the well being of an ill relative, etc. The ASTRA platform, which is being developed in the context of the EU research project ASTRA, provides a generalized solution to the development of awareness applications that are based on the concept of pervasive awareness, i.e., where awareness information is automatically generated as a result of using personal and home devices and smart objects, which capture and exchange information about the user semi-autonomously. In this paper, we shall present how smart objects in a person's environment can be used to capture and convey awareness information under this person's control.

**Author keywords**
Ubiquitous computing, smart objects, awareness systems, service oriented architecture

**INTRODUCTION**
Pervasive awareness systems are a class of computer mediated communication systems that help individuals or groups build and maintain a peripheral awareness of each other. Traditionally awareness systems have been studied at the workplace [2], with awareness of co-workers being a useful by-product of rich media interconnections between them. Awareness systems for informal social use are still in their infancy as a technology and as a research area. Such systems promise to address pressing social problems: elderly living alone, families living apart for large parts of the working week, monitoring the well being of an ill relative, etc. [8]



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An approach for conceptualization of awareness systems in the current domain research proposes the description of the awareness in reference of the activities that a person is made aware of [13]. Based on this approach, Metaxas and Markopoulos [3] introduced an abstract formal model of awareness systems that incorporates related concepts and supports reasoning regarding social aspects of using awareness systems. Their model draws the basic notions of focus and nimbus by the work of Rodden et al. [12], who applied them in a spatial model of group interaction, in order to address mutual levels of awareness within a virtual environment. Early works in the domain of informal social communication like the concepts developed by the Presence project [6] or the Casablanca project [7] were created as installations that users could use as they were.

The ASTRA platform, which is being developed in the context of the EU research project ASTRA [1], provides a generalized solution to the development of awareness applications that are based on the concept of pervasive awareness, i.e., where awareness information is automatically generated as a result of using personal and home devices and smart objects, which capture and exchange information about the user semi-autonomously. The ASTRA platform and the assorted end-user tools implement the principles of Theory of Connectedness, an extension to the focus - nimbus model. Briefly, focus represents a sub-space within which a person focuses their attention, while nimbus represents a sub-space across which a person makes their activity available to others.

In this paper, we shall present how smart objects in a person's environment can be used to capture and convey awareness information under this person's control. In the next section, we shall give the basic approach and notions we use in order to represent the problem domain. Then, we shall describe how the solution to the problem is support with ubiquitous computing technology and provide an example scenario using the proposed technology.

## BASIC MODELLING FRAMEWORK

In order to support the development of awareness applications, we consider that people conduct their activities within an ambient intelligence space using smart objects and that it is possible to access and combine the services offered by these objects. Our approach is based on the following concepts (Figure 1):

- AmI space: An AmI space is to a physical space the same as to that what an artifact is to an object. To be more precise, an AmI space embeds sensing, actuating, processing and networking infrastructure in a physical (usually closed) space and offers a set of digital services.
- Artifacts: An artifact is a tangible object augmented with computation and communication capabilities. Its properties and services are digitally expressed.
- Services: These are offered by an artifact or the AmI space. They could be considered as virtual artifacts.
- Ambient Ecology: It is the set of artifacts contained in an AmI spaces and services offered therein; artifacts may be connected, thus offering more complex services.
- Plugs: They are the interface of an artifact and constitute an expression of its properties, capabilities and services recognizable by other artifacts or services.
- Synapses: They are associations between two compatible plugs. When a property of a source artifact changes, the new value is propagated through the synapse to the target artifact. The initial change of value caused by a state transition of the source artifact causes finally a state transition to the target artifact. In that way, synapses are a realization of the functional context of the artifact.
- Spheres: An activity sphere is deployed over the Ambient Ecology of an AmI space and uses its resources (artifacts, networks, services etc) to serve a specific goal of its owner. It usually consists of a set of interrelated tasks; the sphere contains models of these tasks and their interaction. The sphere instantiates the task models within the specific context composed by the capabilities and services of the container AmI space and its contained artifacts. In this way, it supports the realization of concrete tasks.

## AN EXAMPLE OF AMBIENT ECOLOGIES

Consider the following scenario:

Students of the Distance Education University (DEU) usually live in disparate locations all over the country. Each of them has his personal matters, but they all have in common their studies at DEU. Punch and Judy are two students of the "Software Design" Teaching Unit; in the past week they have been collaborating in order to study and submit a common project.

Punch is 33 years old, single, working hard and overcommitted. He lives in Athens and likes technology and is keen on using new gadgets he discovers in the shops. Judy is a 27-year old single woman, who lives in a small apartment in Santorini. She is a travel agent, likes natural products and dislikes technology. Both have installed in their smart homes an Ambient Ecology to support their study.

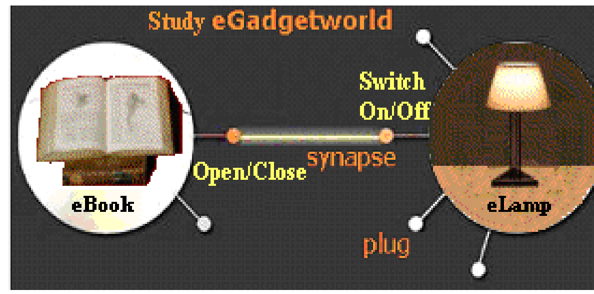



**Figure 1. The concepts of artifact, plug and synapse**

Punch's Study sphere consists of the following artifacts: eBook, eChair, eDeskLamp and eDesk. The eDesk can sense light intensity, temperature, weight on it, and proximity of a chair. The eChair can tell whether someone was sitting on it. The eDeskLamps can remotely be turned on and off. The eBook can tell whether it is open or closed and determine the amount of light that falls on it. Collective artifact operation is accomplished by establishing synapses between the constituent artifacts, in order to realize the following behavior:

When this CHAIR is NEAR the DESK
AND
ANY BOOK is ON the DESK,
AND
SOMEONE is sitting on the CHAIR
AND
The BOOK is OPEN
THEN
TURN the LAMP ON.

On the contrary, Judy's sphere is rather simple and only uses the services of an eClock, an eLamp and a PictureFrame. Whenever she starts her study, she sets the eClock timer to 90' and connects it to the eLamp; after 90', the eClock alarm goes off (without making any sound, of course) and forces the eLamp to flash two times, via their synapse.

## AWARENESS SYSTEM AND APPLICATIONS

The purpose of an awareness application is to convey a person's condition, need or want to a community of users who have subscribed to this application. Usually, an awareness application is developed by a person, who subsequently publishes it to a community, or invites people to subscribe to it.

To the ambient ecology concepts described above we add two basic concepts that originate from modeling of awareness:

- Focus: A person's focus is the set of conditions, situations or events that this person is interested in. A person's focus may include another person's nimbus. It is modeled as a set of events that happen in this person's AmI space.
- Nimbus: A person's nimbus is the set of conditions, situations or events that this person makes public, i.e. makes them available to become part of some other persons' focus. A person may interact with his nimbus by causing events in his AmI space.

Consider a very simple example. Suppose that Punch every now and then likes to go to the local pub, particularly when he doesn't feel like studying, but he hates going out alone. So he has created a simple awareness application that he calls "out to the pub" and he has invited his friends to join this application.

An awareness application can be considered as a set of conditions and events that convey specific meaning to a defined community of persons. So, regarding the "out to the pub" application. Punch has created some rules which signify when he wants to activate this application; for example, he wants to go out when he is not studying or not sleeping or not cooking, but he does not want to go out when he has company at home. His friends have done the same; of course, each person can create his own rules that activate this application.

So, in order to define an awareness application, a person has to:

- Provide a short textual description of the application and describe its various instances
- Define the conditions that trigger the application – this is his nimbus
- Define the other persons he wants to be aware of this application – they have to include this applications in their focus

So a community is the set of persons that a person allows to have access to his nimbus.

Note that a person may subscribe to an awareness application published by another person. In this case, he has to include this application to his focus.

Based on this framework, we then describe a ubiquitous computing awareness application as an activity sphere, which is instantiated on the ambient ecologies in the different AmI spaces of the various application users [14]. Each instantiation makes use of the different resources in each AmI space and of the artifacts in each ambient ecology and is realized as a set of synapses between the artifacts and the provided services into the AmI space. In order to manipulate their focus, nimbus and awareness applications, people use the artifacts in the AmI space.

## ASTRA SYSTEM

In order to support the realization of ubiquitous awareness applications, we have developed a two-tier architecture in which:

- A centralized remote server is used to store the awareness application descriptions and the community profiles, and
- Local (user) servers are used to support the instantiation of focus and nimbus.

### ASTRA server

The ASTRA server runs the ASTRA platform, which provides different end-user services and is responsible for integrating system services, such as ontology manager and service discovery. The platform adopts a Service Oriented Architecture (SOA) and makes its resources available as independent services that can be accessed without knowledge of their underlying platform implementation. The platform offers:

- Awareness services: These services provide awareness information and are built on the services at the lower level.
- Collaborative services: These services are providing abstractions that are relevant to the users when they are developing awareness applications, such as users, communities, and places.
- Technical services: These services are necessary to support, e.g. the discovery and composition of services, both at run time and during end user development.

The ASTRA platform uses TCP/IP networking and Web Service interfaces for the SOA components. A open-source OSGi implementation called Knopflerfish was chosen for ASTRA. OSGi was chosen due to its very elegant and easy way of deploying services.

The Awareness Manager supports users in controlling incoming and outgoing awareness information (i.e. their focus and nimbus). It is based on a realization of the publish/subscribe model [5]. People who subscribe to the same awareness application are regarded as a virtual community. When an event is published by a peer in the community, all the other subscribers are notified.

The Community Manager provides representation and management of communities of users of awareness applications. This module stores centrally information about the addresses and profiles of the community members, and directly cooperates with aAwareness Manager.

### Local subsystem

The local subsystem is built upon GAS and uses GAS-OS as the supporting middleware. We have designed the Gadgetware Architectural Style (GAS) as a generic architectural style for activity spheres [10]. GAS adopts the principles of software component technology and service oriented architectures and applies these to the domain of ubiquitous computing, in order to describe the process whereby people configure and use complex collections of interacting artifacts [8]. Thus, a component in the ubiquitous computing domain is an artifact, physical or digital, which is independently built and delivered as an autonomous functional unit that offers interfaces by which it can be connected with other components to compose a larger system, without compromising its shape or functionality. The above definition emphasizes the fact that any sphere component provides its functionality in the form of well-defined services; these are accessible via interfaces.

Each artifact in a person's AmI space runs the GAS-OS middleware [3]. This enables the discovery of artifact services by the end-user tools and their composition in the context of awareness applications. The GAS-OS middleware provides ubiquitous computing application designers and developers with a runtime environment that can execute the activity task models, as they are instantiated on the artifacts that exist in a specific AmI space. It provides the necessary communication layer as well as the abstraction layer (interaction model) that enables an artifact to collaborate with other artifacts and take part in activity spheres [4].

An ASTRA user has to define how his focus and nimbus will be realized within an AmI space. For example, Punch has to describe the rules that trigger the awareness application "out to the pub" and also those rules that help the local system deduce his current condition. These rules are defined using the services and states of artifacts in the AmI space. So, Punch could define a rule stating that "when I am not working and it is Sunday evening and I switch my TV set off, then I want to go to the pub". The information necessary for the system to evaluate this rule can be gathered as follows:

- Not working: this information describes Punch's current condition; it can be received from a central "point of intelligence" in the house, or deduced as a result of a different set of rules, the description of which lies outside the scope of this paper
- Sunday morning: this piece of context refers to time and can be received from a calendar service of the AmI space
- TV set off: this other piece of context can be directly retrieved from the artifact TV set, which is part of the ambient ecology in Punch's home

When this rule fires, then an event is sent by the local ASTRA subsystem to the ASTRA server. This event is associated with the "out to the pub" awareness application and is propagated to all of its subscribers by the Awareness Manager.

In a similar manner, Punch can define rules describing how he wants to be notified of events that are caused by the other subscribers in the "out to the pub" application. Examples of such rules are: "when I am in the living room, and the TV set is on display a message on the TV screen, otherwise flash the floor lamp twice", or "when I am in the kitchen, show message in the photo frame", etc.

Using the GAS approach, people can define their focus or nimbus using artifact combinations. In GAS terms, this means that the system or the user has to look for the artifacts that have properties matching the task requirements, select the most appropriate ones and combine the respective plugs into functioning synapses. In the above example, Punch has to create a synapse between the day plug of an artifact calendar and the on/off plug of the TV set.

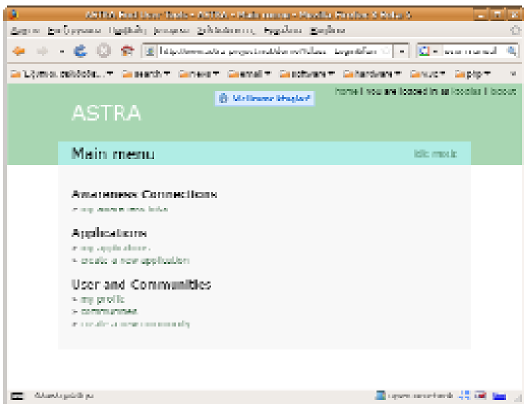
### ASTRA tools

The ASTRA end user tools use a web interface and connect to the ASTRA platform via a specific API. The tools support user management, rule editing, and application management, in a way that semantically relates to the focus / nimbus model, albeit using of a more familiar terminology for end users (Figure 2).

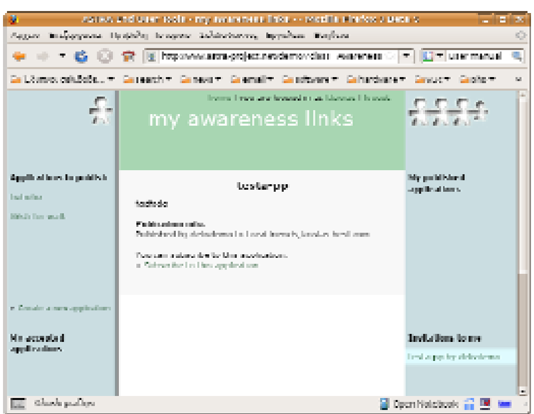
The SOAP protocol has been chosen for communication and data exchange between ASTRA tools and ASTRA platform. SOAP is a simple XML based protocol to let applications exchange information over HTTP. It is an open standard maintained by the World Wide Web Consortium – W3C. ASTRA tools implement a SOAP client using PHP SOAP extension. The ASTRA platform exports its methods as SOAP web services. The tools interface is written in XHTML 1.0 Strict, a W3C Recommendation that is compatible with HTML 4.01 and it is supported by all modern web browsers.

The tools contain the following interlinked modes: Awareness Connections manager (where the user can define their Focus or Nimbus), Pervasive Application manager (where the user can associate their awareness focus or nimbus to a ubiquitous awareness application), and User and Communities manager.

The approach taken in the ASTRA project, when scaled up, has the risk of imposing a heavy semantic load to the user, as he will have to be able to distinguish between various notifications that he will receive and interpret correctly the different events they represent. An obvious solution to this is to use the screens that are available in the ambient ecology (i.e. TV set, mobile, PDA etc) to display semantically rich textual messages, or to use voice synthesis to explain the meaning of the notification. Both these approaches, however, are intrusive, in the sense that they will require the person to shift his attention to the event. A more complicated approach that we are looking into in the project is to use ontologies to create semantically rich descriptions of events and services and then use user-defined policies to deal with conflicts of event interpretation. For example, when the notifications for two events from different awareness applications are similar, then more detailed information has to be conveyed, so as the person can distinguish between them.




Main menu




My Awareness Links (application selection)

**Figure 2. Sample ASTRA end user tools**

## AN EXAMPLE AMBIENT AWARENESS APPLICATION

Now we shall develop the previous example, so as to use the ambient ecology to convey awareness information:

DEU offers to its students a set of services in order to improve their communication and collaboration, but also aiming to create among them the sense of a community. These services include a forum for exchanging ideas, e-mail accounts and access to teleconferencing facilities. However, these services are hardly a match for the need of students to feel everyday that they are part of a community, that they are not alone in their endeavor. Recently, DEU is offering an awareness service based on the ASTRA platform for a trial period of one academic year to the student of one specific teaching unit. The ASTRA platform enables subscribed users to form communities and to exchange awareness information and applications between the members of a community.

Punch and Judy have taken advantage of the new DEU service (of course, it was Punch who had the idea; he managed to convince Judy by promising that he would configure her side of the application as well as his). So, Punch created a DEU Study awareness application and Judy subscribed to it. Punch included in his Nimbus the Now Reading state of his sphere and Focused his system on Judy's Reading state. On the other hand, Judy included in her Nimbus the state of her eClock and her PictureFrame; her Focus was set on Punch's Now Reading state.

In Punch's side, whenever he turns on his Study sphere, as his eLamp is switched on, his awareness system sets the value of his Now Reading state in his Nimbus. The ASTRA system communicates Punch's Nimbus to Judy. Judy has Focused on Punch's Now Reading state, and has connected it to her PictureFrame; whenever it changes, her eLamp flashes and Punch's picture appears. In parallel, as Punch has set his Focus on Judy's Reading state, whenever she takes a break (as a result of her eClock's timer reaching zero), his eLamp flashes. Figure 3 shows the awareness system described in the example.

## CONCLUSIONS

In this paper, we have presented a novel service oriented architecture that supports the composition and management of ubiquitous computing awareness applications. The aim of this class of applications is to support communication among people without interfering with their task-at-hand.

The architecture presented uses smart objects in the person's space as conveyors of this person's awareness condition or want. The person can configure these objects using special end user tools, which support the discovery of artifact services and their combination in a simple way, as well as the definition of awareness applications using first-order logic rules on these services.

A two tier system has been developed to support this service: in the person's local space, interaction among smart objects is achieved with the use of GAS principles; these allow the integration of artifacts running specialized middleware GAS-OS, or other commonly available systems, such as UPnP. In the server side, the specialized ASTRA platform was developed, which offers services for the management of applications and user communities.

Research on ASTRA project continues in order to evaluate and improve the concepts and tools presented in the paper.

## ACKNOWLEDGEMENT

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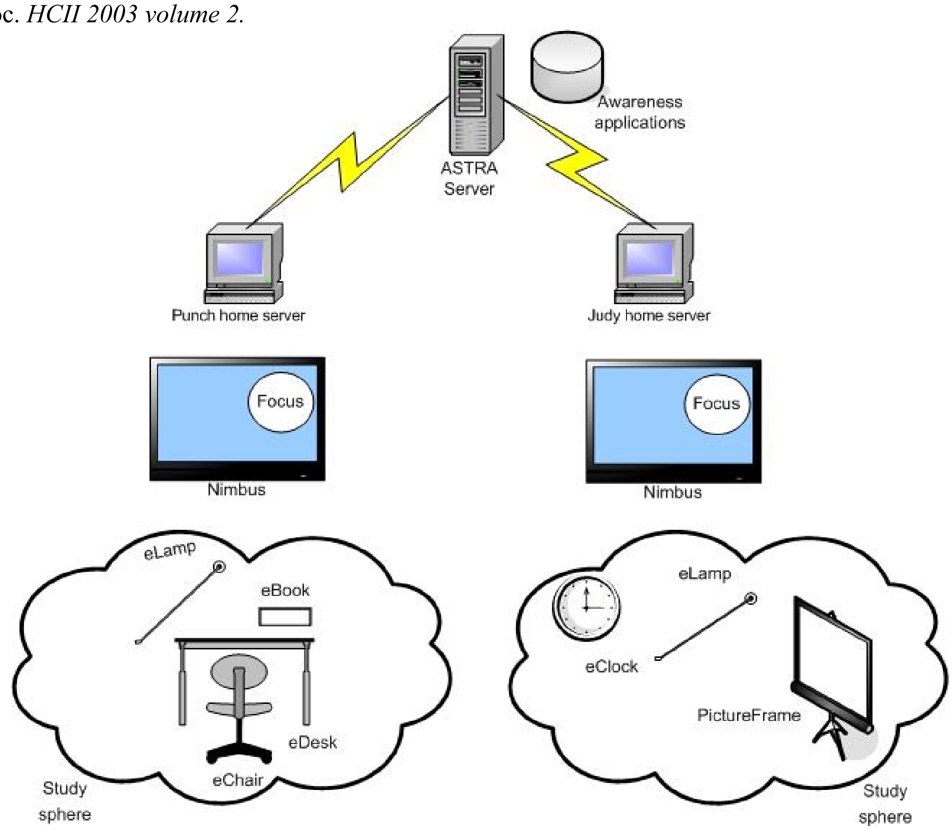


**Figure 3. The awareness system of the example**

# Multi-Tracker: Interactive Smart Object for Advanced Collaborative Environment

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**ABSTRACT**
This paper introduces a Multi-Tracker which is a nickname of multi-tracking system as a smart object for advanced collaborative environment. This Multi-Tracker improves functionalities of infrared laser pointers by embedding location tracking sensors. Whoever uses this pointer can be tracked his location and interfaces with a collaboration system in a room-based meeting space. The information from the Multi-Tracker is used to provide suitable services to each user. We show the usability of this Multi-Tracker by designing a few interaction services and adopting this to a collaboration prototype system.

**Author Keywords**
Multi-Tracker, Multi-tracking system, Smart object, SMeet Advanced Collaborative Environment, Location Tracking, Pointer Tracking, Context-aware based User Interaction, Interaction Manager.

**ACM Classification Keywords**
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

**INTRODUCTION**
As Mark Weiser first introduced the term "ubiquitous computing" [1], ubiquitous computing environment has been characterized by distributed device networks, human-centered multi-modal interaction, unobtrusive hardware such like smart devices, sensors and support of context-aware based services. For the realization of Mark Weiser's vision, we let everyday objects have embedded processors which can sense, monitor and track some environmental status and communicate among others. By doing this, these objects support people without their awareness of detail technologies and we call them as smart objects.


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Some successful prototypes of smart objects are Media Cup [2] and several Aware Objects in AwareOffice [3] such as chairs, windows and doors. In addition, there are some specific smart user interfaces as smart objects in iStuff [4] such as iButtons, iMike and iSytlus. All these things are attached some processors or sensors. With these smart objects, we have a new method to interface with a space. Accordingly, the interaction of ubiquitous computing environment can be changed to human-environment interaction from human-computer interaction. And finally interaction will be extended to among smart objects in an environment including human.

Especially, we considered advanced meeting environment with ubiquitous computing technologies. Meeting collaboration environment has evolved from the past. At the beginning, the environment requires just ability to communicate with many participants. And nowadays the remote participants can join collaboration by sharing their video/audio data at the same time. In this case, to connect with remote meeting nodes, computing facilities and user interfaces for them are required. Traditional keyboards and mice are commonly-used interfaces for this purpose. However, for advanced meeting environment, we ask it smarter and more realistic than ever; even all members are distributed over the world, we want to feel as if we are all at the same time and at the same place.

To design smart meeting environment, we have to satisfy users' expected quality of experience of collaboration. For example, even if we don't know the stored address and name of a displayed document, we expect to move this to a different display system or download it to our storage. Without knowing the exact control method of a camcorder, we simply hope to see the captured video stream at the corner of a meeting room. For these purposes, we need rather new interface tools different from traditional ones. Thus, multimodal interactions are adopted to allow users to operate in a natural manner like voice, hand or device-based gestures, eye-tracking, body-movement [5], as well as traditional text-based or graphic based ones called WIMP (Windows, Icons, Menus, and Pointing) [6].

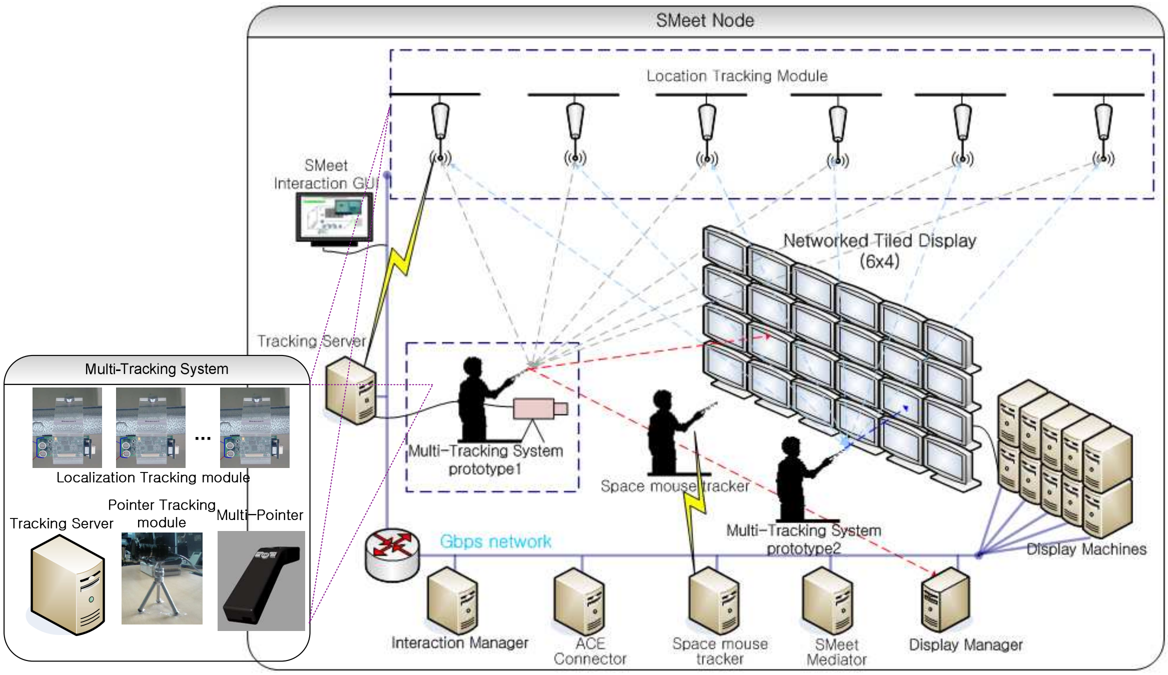


**Figure 1. An SMeet node with multi-tracking System.**

Therefore, these multimodal interactions help people free from computers during collaboration and increase efficiency of meeting. Especially for meeting collaboration, pointer-based interaction can be easily used to operate a meeting environment. So, we design a Multi-Tracker which has location and pointer tracking functionalities and adopt this smart object to interface with whole meeting environment.

Research related to multimodal interaction has been carried out as a part of Human Computer Interaction (HCI). For example, various outputs of Dynamic Graphics Project (DGP) Lab. at University of Toronto such as vision wand and the free-hand-gestures recognition has been produced [7, 8]. And for pointer tracking, Kirstein and Müller used a laser pointer as an interaction device [9]. Once laser pointer spot is detected by a camera, the coordinates of the spot in the display was calculated. They use gesture interactions with turning on or off the laser pointer. Their work stimulated a lot of research on laser pointer based interactions.

The rest of this paper is organized as follows. Before introducing the design and implementation of Multi-Tracker, we briefly describe the adopted prototype system targeting advanced collaborative environment, SMeet (Smart Meeting System). And then we present the Interaction Manager of SMeet which can control all user interactions and collects interaction information from a Multi-Tracker processed in an SMeet node and suggest a few interaction services supported in SMeet by using Multi-Tracker. The implementation and operation of these services are explained for feasibility of this Multi-Tracker. Finally, we conclude with evaluation and our future work.

## SMEET AND SMART OBJECTS

Our prototype, Smart Meeting System (SMeet) targets an environment which enables users to collaborate with remote participants by using a wide range of devices embedded in networked meeting rooms [10].

To construct one SMeet physical node, we use a set of devices such as media devices like microphones, speakers, and cameras, display devices such as plasma displays, projectors, or tiled displays, interaction devices like pointing devices, cyber gloves, location trackers and gyro mouse and a number of computing machines. All devices are connected to wired or wireless LAN, and SMeet nodes are again connected by high-performance WAN (Wide Area Network) [11]. Figure 1 shows an SMeet node with a Multi-Tracker and this Multi-Tracker is used as one interaction device. Especially, for provision of tasks or services to users, we have a few functional managers. These are Mediator, Display Manager, Interaction Manager, Media Manager, and ACE Connector. Among them, Interaction Manager (IM) manages and supports suitable tasks for users. For that purpose, IM equips several functionalities like supporting of multimodal and multi-users interaction and management of whole objects of a meeting environment such as several types of displays, storage machines or camcorder [12]. Among these objects, some of them can be smart, and others are not. To interface with them, SMeet uses a Multi-Tracker as an interaction device. Finally, we aim at interfacing with whole space, but currently, our implementation is limited to interface with a display system.

### MULTI-TRACKING SYSTEM

Main interaction services which SMeet provides are two. The first one is pointing service enables a user to point a certain object in a meeting environment and the second one is location tracking service tracing users' position in a space.

For provision of these services, we design multi-tracking system which is integrated with location and pointer tracking functionalities. This system is used to operate interaction between users and a meeting space.

Multi-tracking system has four modules which are Multi-Pointer module, location tracking module, pointer tracking module and a tracking server. The Figure 2 shows the structure of multi-tracking system and the real snapshot of each module except tracking server is in the Figure 3.

- The Multi-Pointer module: it is bar-type and movable device having four interaction buttons and it is the thing we want to estimate its location. It periodically broadcasts a message on the RF channel and an ultrasonic pulse at the same time.
- The location tracking module: they are attached to a ceiling and all of them measure the time difference of arrival between a RF message and an ultrasonic signal from the Multi-Pointer. Then, they report the time difference to the tracking server.
- Pointer tracking module: it is a camera with narrow band pass filter matched infrared pointer.
- Tracking server: it finally calculates the location and the coordinates of pointed spot with the Multi-Pointer and periodically updates it with collectively gathered time differences and communicates with interaction manager to deliver interaction information.

And, Table 1 depicts its specification for user interaction of SMeet.

In this multi-tracking system, there are two essential techniques. The first one is pointer tracking method and another one is location tracking method. Next following two subsections describe these techniques in detail.

#### Pointer Tracking

We used infrared laser pointers and narrow band-pass filters of corresponding wavelength. These narrow band-pass filters were installed on the cameras to process spots from specific laser pointers. In order to detect users' identification as well as the pointing locations, each user was given a unique wavelength laser pointer (for example, 808nm or 850nm).

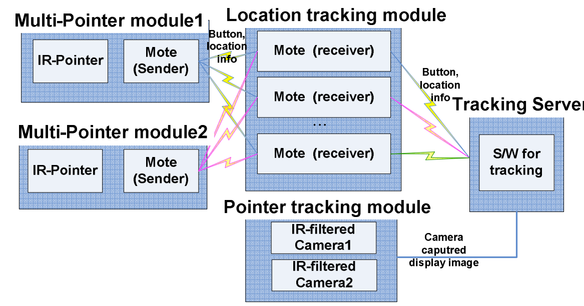


**Figure 2. Structure of multi-tracking system.**

(a) Multi-Pointer module (b) Location tracking module (c) Pointer tracking module

**Figure 3. Modules of multi-tracking system.**

Cameras for each laser were used for tracking laser pointer's pointing position. An alternative approach for distinguishing users with laser pointer may be using blinking patterns. However, synchronization between the camera and blinking system may be required. We used infrared lasers which are not observable by the users. In this case, static error between pointing location and detected location (this occurs due mainly to erroneous calibration) may not be perceived by the users.

To calculate the laser pointer's pointing location in a large display, coordinate transform is required. In order to calculate necessary parameters for coordinate transform, we measured the locations of each corner of the display by placing infrared LED beacons. These locations in camera space with given display's resolution were used to calculate Homography. The pointing coordinates of display are calculated with this Homography [13]. We used Zhang's method for calculating Homography.

In study of Myers and et al, they show the laser pointer's beam is too unsteady. Usually the spot of laser pointer is shaken rapidly and chaotic around of the position which a user wants to point while pointing. Some points which are shaken are made acute angles with the previous point. These make a cursor blink and give an incongruity to users. By ignoring the point which makes an acute angle with the previous one, the cursor can be moved smoothly and users feel less incongruous.

#### Location Tracking

For location estimation of a movable Multi-Pointer, an ultrasound-based localization is used. Figure 4 shows components for location tracking.

| | |
|---|---|
| **Infrared laser pointer** | - Infrared laser device for rather bright display<br>- wavelength: 808nm, 850nm |
| **Optical Filter** | - filters which pass only limited spectrum light for successful recognition of laser pointer |
| **Infrared camera** | - cameras which can track the pointed spot by laser in real time<br>- VGA level resolution<br>- frame rate : more than 29fps |
| **Ultrasound Sensor Node** | - A device for localization, it measures a distance from beacons to mobile nodes by using arrival difference between RF and ultra sound signals. |
| **Tracking Server** | - pointer tracking is with an error tolerance of 30 pixels<br>- location tracking is with an error tolerance of 0.5 m |

**Table 1. Specification of multi-tracking system.**

There are a Multi-Pointer, several location tracking motes, a calibration mote, and a tracking server. Especially, it has calibration mote which is placed on the ground, and it is used to measure the speed of ultrasound in the space for accurate location estimation.

The hardware of this system is a cricket mote [14] based on MICA2 and it transmits messages on RF channel or signals. The software is modified in order to be suitable for our system.

*Distance Estimation*

The distance from the Multi-Pointer to each location tracking module can be obtained by taking the time difference of arrival between a RF message and an ultrasonic pulse.

Although the Multi-Pointer simultaneously transmits both the RF message and the ultrasonic pulse, the time difference exists because the speed of RF is faster than that of ultrasound. For example, as shown in Figure 5, the RF message and the ultrasound reach the location tracking module at $t_0$ and $t_1$, respectively, and thus the time difference is $(t_1\text{-}t_0)$. The time difference of arrival is expressed as follows:

$$t = \frac{d}{v_1} - \frac{d}{v_0},$$

where $t$ is the time difference of arrival, $d$ is the distance, $v_1$ is the speed of ultrasound, and $v_0$ is the speed of RF. In that case, the speed of RF is very huge, thus the term can be negligible. Consequently, the distance is the time difference of arrival multiplied by the speed of ultrasound.

The speed of ultrasound is affected by the indoor environment such as temperature and humidity. The change

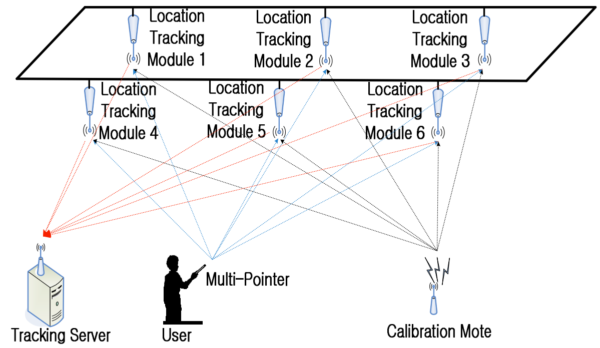


**Figure 4. Environment for Location tracking.**

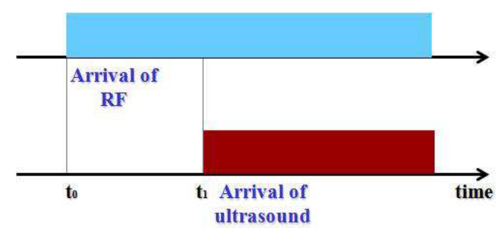


**Figure 5. The arrival time of an RF message and ultrasound to a location tracking module.**

of these factors causes inaccuracy of location estimates. In order to improve accuracy, we use an auto-calibration technique that automatically measures $v_1$ using the calibration mote depending on the indoor environment.

*Location Estimation*

The location of the Multi-Pointer is finally determined by a lateration algorithm. The distances between each location tracking module are calculated by Euclidean distance. In addition, we know the distances from the Multi-Pointer to each location tracking module. With these distances, we estimate the location using the lateration algorithm [15].

## INTERACTION MANAGER OF SMEET

Interaction Manager (IM) is a service manager which is charged with the controlling all user interactions in SMeet. IM manages all possible target objects of user interactions in a meeting environment as a "Space Object". Especially, provided interaction devices such as a Multi-Tracker are a smart object and they are also one of Space Objects in SMeet.

Like this, IM collects inputs from heterogeneous interaction devices, analyzes the contents and helps other output objects using this examined data to provide suitable applications to users. In this case, interaction devices like a Multi-Tracker are a mean to link among Space Objects. In addition, when users' information, such as name and role, can be delivered to IM, IM can provide filtered services based on each user's context. Most of all, it is important to operate interactions by many participants at the same time for meeting environment.

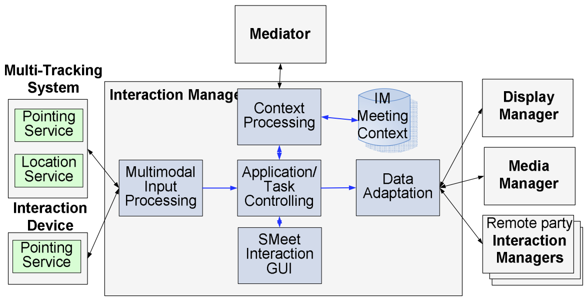


**Figure 6. SW architecture of Interaction Manager.**

For above functionalities, IM's software structure is like Figure 6. And this is composed of five parts.

- Application/Task Controlling Part: it is main module to decide suitable applications for requesting users and handles flow of applications by referring IM Meeting Context.
- Multimodal Input Processing Part: this part is in charge of the connection management of each interaction service. And input from different interaction devices is decoded in this part also.
- Context Processing Part & IM Meeting Context: this part maintains meeting context downloading from mediator's Space Repository. IM's Meeting Context is composed of general meeting context and Space Object context. It updates and gives this information when required.
- Data Adaptation Part: when an application or task for users is decided, this part is responsible for adaptation of output which is transferred to suitable service managers.
- SMeet Interaction GUI: it displays the current status of meeting environment, especially focusing on Space Objects such as users, interaction devices, and output devices. For example, it shows users' location when it is changed, and their current interactive objects. In later, this GUI will manage the relationship among Space Objects.

## IMPLEMENTATION OF COLLABORATION SERVICES

### Design of Services

The information from multi-tracking system is pointed coordinates and users' position information. By analyzing this, SMeet offers following three services. Each service has its own dependency template like $\{(s_{name}) – sm_{name} – sm_{name}\}$ , where

SM: set of service managers, S: set of interaction services,

$sm_{name} \in SM$, $s_{name} \in S$.

- Interactive-display service: This service is performed related to displays in SMeet. When several contents are displayed over a public display in SMeet, users can control the contents such as moving to other display systems, resizing the visually displayed contents' size, and showing the pointed spot with a personal pointer image. The relationship among service managers of this service is depicted like

  $\{(s_{\text{pointing service}}) – sm_{\text{interaction manager}} – sm_{\text{display manager}}\}$.

  When IM understands users' intention for this service, it can communicate with Display Manager to complete this service. This service also can be filtered depending on the recognized users' role.
- Follow-me-display service: This service makes selected contents to follow the authorized users with Multi-Pointer over displays in a space. In case there are several displays, the most suitable display can be selected for the contents. This service has relationship among service managers like

  $\{(s_{\text{location service}}) – sm_{\text{interaction manager}} – sm_{\text{display manager}}\}$. This service is provided for only authorized user such as presenter. So, the user identification should be recognized by IM.
- Contents-protection service: during a meeting session, when an unauthorized person enters a meeting node, some protected contents become inactivated. This service has relationship among service managers like

  $\{(s_{\text{location service}}) – sm_{\text{interaction manager}} – sm_{\text{display manager}}\}$.

### Implementation of Interaction Services

*Interactive-display service*

A user with a Multi-Pointer can point a specific spot over a public display, and this pointing action results in showing a personal arrow image allotted to each person. And moving operation supports users to locate the visualized media on a display to other position of display systems. In this scenario, these pointing and moving operations are allowed for all users. Lastly, resizing operation can change the displayed size of media. However, this operation is allowed only for specific authorized users, such as a presenter. Figure 7 (a) shows the pointing operation with multiple users, and Figure 7 (b) and (c) describe the resizing operation each.

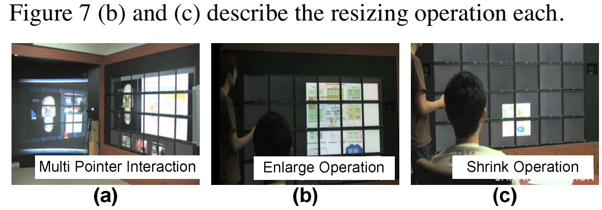


**Figure 7. Implementation of Interactive-display service.**

*Follow-me-display service*

Whenever an authorized Multi-Pointer user moves, the location information is delivered to IM. And then, IM decides whether the main displayed contents moves or not as the location of the user. In this scenario, one with a presenter role can be supported by the service. Figure 8 (a) shows the case of an authorized person, and the unauthorized person's case is in Figure 8 (b).

(a) (b)

**Figure 8. Implementation of Follow-me-display service.**

*Contents-protection service*

Each Space Object has its own allowed authorities. When unauthorized persons enter, some contents to be protected should be hidden. Figure 9 (a) captures the state before an unauthorized person enters, and we can notice the displayed contents was disappeared for security in Figure 9 (b).


(a) (b)

**Figure 9. Implementation of Contents-protection service.**

## CONCLUSION

In this paper, we have introduced the design of Multi-Tracker as a smart object to support advanced interaction for users and to fulfill the users expected QoE. The Multi-Tracker has localization and pointing functionalities together. For verification of this pointer's functionality, we adopted it to our prototype system, SMeet. Especially, Interaction Manager of SMeet has connection with this multi-tracking system, collects interaction data and finally offers suitable operation for users. Until now, this Multi-Tracker is used for limited applications. However, it can extend its usability to whole environment. In the future, as SMeet provides a framework for supporting extended interaction, Multi-Tracker can be used with more various services.

## ACKNOWLEDGMENTS

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# An Augmented Book and Its Application

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**ABSTRACT**
In this paper, we propose an augmentation of an ordinal book with page flipping event detection. Two types of add-on devices, i.e. a book cover and a bookmark version, have been investigated in combination with two accelerometers. The augmentation allows a system to provide a reader with value added experiences while keeping the original sense of utilization intact, e.g. a texture of paper. Since it utilizes a paper-based book, the complex copyright issues do not need to be addressed. We have also developed a prototype of an application: virtual illustration system. It automatically provides multimedia information based on the page that a reader is reading. Everyone can publish and share the contents like an HTML document. The performance of page flipping detection and the usability of the devices have been evaluated. The prototype application has also been tested using real contents.

## INTRODUCTION

Today, digitally enhanced *books* are getting available. A typical functionality includes providing multimedia information, e.g. a music clip, a picture, that matches with a scene that a user is reading [2][5]. This allows a reader to have more rich experiences than a traditional paper-based book reading. However, such a digital book is not so popular now, and some manufacturers have decided to withdraw from the market [9][11].

The difficulty in reading a text through Liquid Crystal Display (LCD) for a long period of time and the lack of the texture of paper might be technical reasons. Recent advancement of electronic paper and flexible display technologies would improve the readability and the sense of page flipping, respectively[6][12]. However, a very advanced Virtual Reality technology is still required to provide the sense of the weight of the remaining pages. When we read a class of a book like a mystery, we may implicitly predict the change of the suspect or the conclusion according to the current position in the book, which is obtained by the weight/thickness perception as well as a visual feedback. We consider this is very important and interesting perspective for the interaction with a book.


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More important and critical reason is the complexity of the right to publish an electronic version in Japan. It is not clear who owns the right: the author, the publisher, etc. In case of a book based on an animation film, the organization that holds the copyright of the characters owns the right. This prevents the digital version from being created and widely distributed in the market, which is a fundamental issue in a digital book.

To address these issues, we have decided to leverage an ordinal book. A sensor augmented book cover and a bookmark have been investigated to detect a page flipping event and thus to track the current page. This keeps the tactile sensation of a paper-based book intact while providing a reader with some services based on a page that he/she is reading. In this paper, we present the design of two add-on devices and the algorithm for page flipping event detection. Also, as an application, Virtual Illustration System has been developed, and the feasibility has been evaluated using real contents.

## RELATED WORK

In terms of the interaction with a paper-based document, the DigitalDesk [13] is a pioneering work. EnhancedDesk [7] also seeks the smooth integration of paper and digital information on a desk. They allow automatic retrieval and presentation of digital information by recognizing the contents [13] or the tag [7] printed on a page, and direct manipulation of digital information by gesture recognition. They are basically the augmentation of desk operation, and thus working area is exactly restricted to the place of the desk. On the contrary, our augmentation is done on the book side, which provides a user with a certain degree of freedom in working place.

Regarding contents identification, detecting the reading page is a relative approach [3, 10], where a content is linked to one or a range of pages. On the other hand, embedding contents into a page allows direct identification using an appropriate detector [4, 8]. Back et al. augmented a book with RFID tags and a receiver to provide additional information based on a page [3]. Also, a reader of the Magic Book [4] sees 3D characters related to the page through a head mounted display. The Interactive Textbook system [8], an application of EnhancedDesk, literally provides an interactive experience with the electronic contents linked to a page. They are realized by visual tags. Furthermore, a completely new material of a paper was investigated to detect the bending action by polymer conductive ink [10]. However, they need specially manufactured pages, i.e. *redesigning*, which makes the cost of a book high. It also prevents an existing book from adopting to an augmented service. An extra device is also required in case of the Magic Book, where a reader need to adapt to the new style of reading a book. In contrast, our system aims at realizing the page detection in a cost effective manner and providing a reader with almost the same way of reading an ordinal book. This is enabled by attaching a device to a common part of a book, i.e. book cover and bookmark, rather than utilizing special pages or requiring a reader to wear special glasses.

WikiTUI [14] is designed to provide bi-directional interaction with digital contents using Wiki infrastructure. A reader can add and obtain digital annotations based on the page he/she is reading. To determine the page, a reader must specify the number projected on the table by pointing gesture. This means he/she *flips* both the actual page and the virtual page. The page number is correct so far as a reader follows the flipping rule, however it requires a reader's attention. We consider it is inadequate for a book like a novel since a reader likes to concentrate more on reading a text.

## AUGMENTED BOOK

### Design Issues

Two models of providing multimedia information, i.e. push and pull, have been considered ahead of the augmentation design. We have taken the push based approach, where contents are provided automatically based on an event. The event includes the detection of a visual tag [4, 8], an RFID tag [3], keywords in a text, etc. In contrast, in the pull model, a reader explicitly retrieves contents by pointing gesture [14], for example. We consider that the push model is less interruptive to a reader due to such an automatic nature. Additionally, we have considered that multimedia information is absolutely supplemental one. So, it would be better to provide *silently*. A textual description added for detailed explanation might be appropriate for explicit acquisition, which we do not intend to support so far.

We aim at identifying contents in a cost effective manner, where neither special paper material nor preparation of tags is required. We have determined to detect the current page number that a reader is reading and to retrieve corresponding contents based on some mappings. It is utilized as a key for the contents identification. We have had two options regarding the page number detection. Recognizing the printed number by a camera is a direct approach, while counting the page flipping using some sensors is an indirect one. We have taken the latter approach due to its relatively simple nature. Reading a book at a specific place, e.g. a camera-mounted desk, might be able to recognize the page number accurately [13], and even automatic contents retrieval might be possible using frequent keyword detection, but a reader's posture is restricted at the same time. A wearable camera solution allow a reader to be free from such a constraint. But, the complexity of the system would get drastically larger.

### Designing Add-on Devices for Page Flipping Detection

Page flipping detection is realized in two ways: a book cover and a bookmark versions. An accelerometer has been utilized to detect the movements of a book cover and a bookmark every time a page is flipped. Two accelerometers have been attached for each device. One of them is utilized as a reference to avoid confusing the movement of a book itself. The flipping detection algorithm is described in next section. Figure 1 shows the devices and their usage scenes. Note that, in the figure, the page is flipped from left to right that is a traditional reading way of a Japanese book (reading in vertical way from top to bottom, and from the right side to the left).

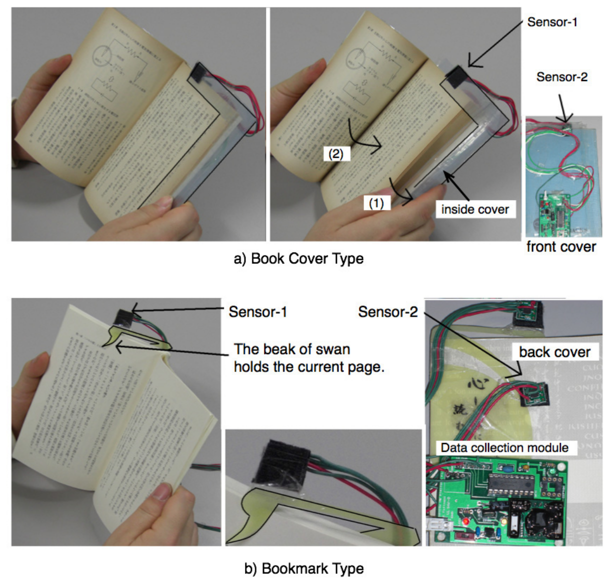



**Figure 1. Devices for Page Flipping Detection: a) Book Cover and b) Bookmark Type**

We have developed more than 20 prototypes of the two versions to find suitable design in the usability and the performance of the detection, where the size and the sensing position as well as the material are subject to test. As shown in a), the book cover type is utilized by (1) picking up the inside part partially covering the reading surface when a reader flips the finished page (2). The inside part of the cover is translucent so that it could avoid interrupting the reader's view. Every time a page is flipped, the part is flipped accordingly to hold the page. Thus, a 3-axes accelerometer is attached there to detect the movement of the inside cover (marked as Sensor-1). Also on the front cover side, the other 3-axes accelerometer (Sensor-2) is attached. The material of the cover is polyethylene terephthalate (PET) with 0.3 mm thickness, and the "reverse Γ shape" of the inside part was finally determined to balance the usability (the readability of a text and the ease of manipulation) and the detection performance.

The flipping detection by the bookmark type is realized by the movement of a withy prop that holds the pages to read. We have augmented a product called *SwanTouch* [1]. Whenever a reader flips a new page, the page pushes the *beak* of swan forward, and soon the beak goes behind the page due to its withy material. So, the movement of the beak represents flipping of a page. One accelerometer is attached on the beak (Sensor-1), while the other is on the back cover (Sensor-2). SwanTouch is made of polypropylene. We have also tested other materials, i.e. an acrylic sheet with 0.5 mm thickness and a 0.3 mm PET one. Among them, the polypropylene one performed best.

In the two implementations, the sensor readings are collected on a PIC microcontroller. Then, they are wirelessly transmitted every 50 msec to a controlling PC, where the detection is actually done. Our future implementation will detect the flipping locally (on PIC side), and only the event will be sent. Additionally, the accumulated number of page flipping events are maintained in a persistent storage. So, he/she can resume the reading without flipping the pages from the beginning.

### Page Flipping Detection Algorithm

We have applied the same flipping detection technique and configuration for the two versions, which utilizes the ratio of Sensor-1 to Sensor-2. Figure 2-(a) and (b) indicate the sensor readings from Sensor-1 and Sensor-2, respectively. Here, the page flipping with three styles of reading were recorded: horizontal, with a slope, and vertical. The average of the variances of the three axes ($x$, $y$, and $z$) within a certain window (20 samples, i.e. 1 second) is calculated (c) and then utilized to obtain the ratio (d). We have adopted the ratio since we found it difficult to distinguish the actual flipping from mere movement of a book itself when only one sensor (Sensor-1) is utilized. The two sensors show the same waveforms when a book is moved. However, only the inside and the beak parts are actually affected by page flipping in the book cover and bookmark versions, respectively (compare (a) and (b)). The body of a book moves independently. Therefore, we have considered the ratio performs well. Here, Sensor-2 acts as a baseline. To get the final answer, *the detection of flipping*, a threshold has been specified based on a preliminary experiment. Although the reading styles are changing continuously and they are apparent in the sensor readings (a), the ratio-graph becomes pretty clear (d). Note that the vertical axis of (d) is a log-scale. The performance and the usability of the two add-on devices will be evaluated in the later section.

## APPLICATION PROTOTYPE

### Virtual Illustration System: Concept

As an application of an augmented book, we have developed *Vistual Illustration System*. The system provides a reader with multimedia information according to the page that he/she is reading. There is an external mapping of one or a range of pages to the information. Anyone can participate to the process of producing an augmented reading experience like posting a review of a book onto his/her blog. The copyright issues do not need to be addressed so far as a contents creator follows the traditional copyright rules in a paper-based book. A reader can select his/her preferred one from multiple contents for a single book. This is the analogy to a *favorite blogger* from whom one likes to get information. Also, once he/she purchases the device, it is utilized

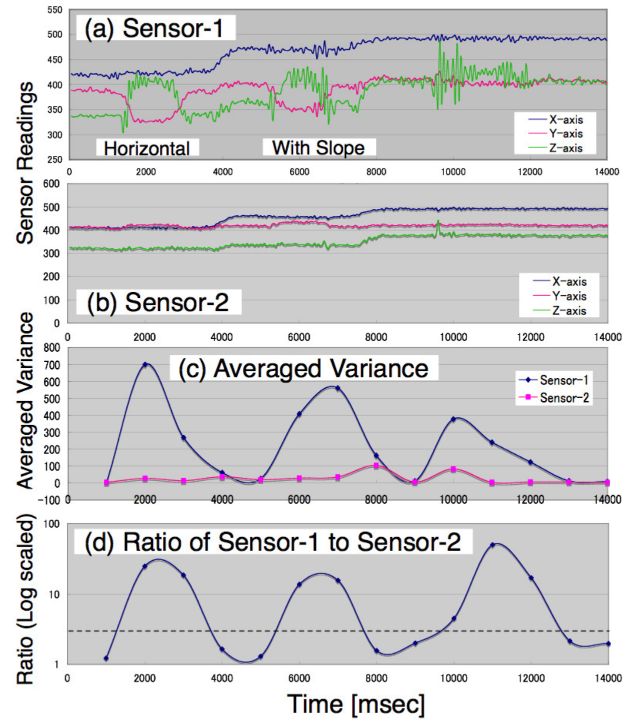



**Figure 2. Data Plotting of Sensor Readings (a) and (b), Averaged Variance (c), and Log-scaled Ratio of Sensor-1 to 2. “Th” in (d) indicates the threshold for flipping detection**

for any contents. We consider this is an evolutional form of a traditional web system. A web browser provides a user with an experience on a digital document, while our device is for a paper-based document, *book*.

### System Overview

The system consists of an augmented book with a page flipping detection capability, a book *contents* description, multimedia contents, ContentsServer, BookServer, and a multimedia system. The core of the system is the *contents description* that maps pages to corresponding multimedia information. Figure 3 illustrates the overall system architecture. They are created by anyone who wish to produce an enhanced book reading experience and uploaded to a ContentsServer (marked (1) and (2) in Figure 3, respectively). The contents, e.g. image and audio, can be stored anywhere. They are specified by unique URLs. We have developed an original contents markup language, *eBookML*. It contains a set of contents file locators and their controlling information for each number of the accumulated events. A controlling entity, *BookServer*, downloads the contents description that corresponds to a book when a person starts reading (3). BookServer interprets the description (5), and a multimedia system is controlled (6) when the condition is satisfied on the detection of page flipping (4). This is very similar to the web contents distribution system, where clicking a mouse is analogous to a page flipping. Here, the number of the page flipping event is counted so that it can approximate the current page. Exactly speaking, the number does not indicate the actual *page number*, but the number of the *page flipping*. So, the system does not identify whether a reader is reading on the left side or right side.

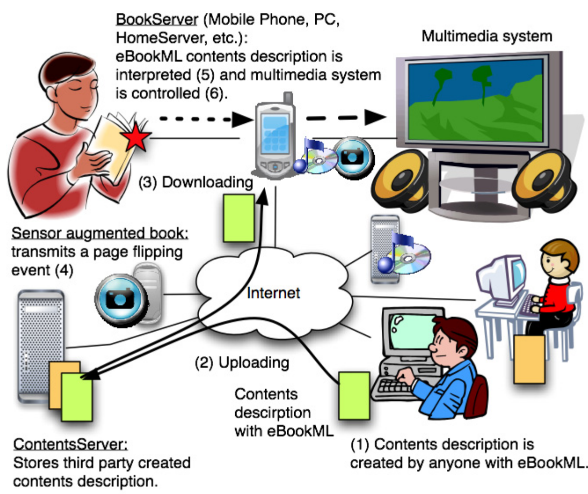



**Figure 3. Overall System Architecture**

Figure 4 represents a typical usage scene of the system. One full screen image is presented at a time. If more than two pages are assigned to one page flipping event, they appear in turn with an interval specified by a creator. Meanwhile, a black screen is shown if a contents creator does not want to show any image, otherwise the same image is presented until the next number-contents mapping appears. To provide a feedback on the page flipping, the accumulated number of flipping is presented on a display. Also, sound of page flipping is played as an audio feedback. Furthermore, a caption is shown at the bottom of an image so that a reader could fill the gap between the timing of the presentation and the actual appearance of the corresponding word(s).

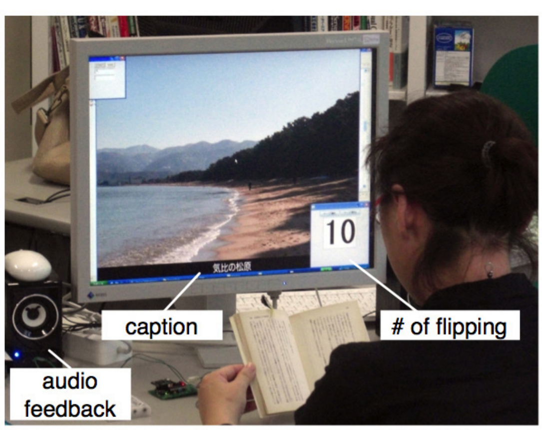



**Figure 4. Typical Usage Scene of the System**

## EVALUATION

We have evaluated both the augmented book and the virtual illustration system.

### Methodology

First, the performance of the page flipping detection and the usability of the add-on devices have been evaluated. Twelve people (10 people are undergraduates and the two are an adult couple in their 50's) were recruited for these purposes. To assess the intuitiveness of the augmentation, we did not tell them the usage for the first trial (0). Then, they were instructed the correct usage and the principles of the page identification. Three types of usage have been tested to see the robustness of the algorithm: (1) horizontal on a desk, (2) with slope on a desk, and (3) in air without any immobile object. The subjects were told to flip 20 times (40 pages) for each type. The memorability was also tested. Two of them were asked to have the test a week to ten days after. They are the subjects who could not find out the methods without the instructions in the first trial. Finally, to see the perceived difference from traditional paper-based book reading, the subjects were shown a demo clip and asked the impression of the usage of the two devices.

The evaluation on the virtual illustration system has been conducted in this way: the level of acceptance of the system both as a user and a contents creator was asked to the same subjects group as above. Then, three subjects (two of them were newly recruited.) actually utilized the system with the bookmark version. Here, a travelogue "Kaido-wo Yuku" by Ryotaro Shiba has been selected, where the author's experiences and random thoughts during a travel along a country trail are described. The contents have been created by the other person based on his preference. The images and sound clips have been found in the Internet. The images include an old and a contemporary maps, an illustration of an old Samurai-battle, a landscape, a novelty animal, etc. Also, the sound clips are about a war whoop, the lapping of waves against the shore, and the sound of a rain shower. After reading some sections (34 pages), we had a semi-structured interview session. Note that all the subjects did not have any prior knowledge about the places and events described in the book.

### Results and Discussion

*Performance of Page Flipping Detection*

Table 1 shows the detection accuracy. The accuracy of the flipping detection is defined by the ratio of the number of the counted pages to the total number of the pages that the subjects flipped. Standard deviation (The number in the parenthetic area) is also calculated to see the variation in individuals. The averaged accuracy for the book cover and the bookmark version are 88.1% and 92.5% (standard deviation in individuals are 11.4% and 8.3%), respectively. This indicates that the bookmark version detects the page flipping totally well with small variation in individuals. We consider the reason for the difference is that the book cover has a wide range of motion, which could lead to the variation of utilization among individuals. Also, this makes it difficult to detect using the simple thresholding. Furthermore, the algorithm is robust in that the differences among the three styles are small.
The case without explanation shows low accuracy and large deviation. In case of the book cover version, seven subjects

**Table 1. The Performance of Page Flipping Detection**

| | Book Cover (N=820) | Boomark (N=960) |
|---|---|---|
| (0) Without explanation | 84.4%(*) (20.3) | 21.3% (18.5) |
| (1) Horizontal on a desk | 88.7% (8.5) | 92.1% (8.5) |
| (2) With a slope on a desk | 85.2% (15.4) | 91.3% (9.2) |
| (3) In air (above a desk) | 90.4% (11.4) | 94.2% (8.3) |

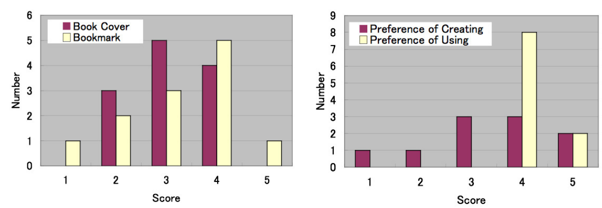
could not find out picking up the cover when they were not told anything. They just put the flipped pages *on the cover*. We consider the gesture *putting the flipped page under the inside part of the cover* was far from natural reading. On the contrary, in case of the bookmark version, the accuracy is enormously low. This is because none knew the way of flipping, but they continued to read the book anyway. However, once they were instructed, the accuracy and the deviation were improved. They are easy to learn due to the simplicity and the seamless integration into ordinal book reading. Regarding the memorability, the result shows the accuracies of the three cases were almost the same as before. We consider this is because they were told not only the way itself, but the principle of the flipping detection. Also, the physical appearance of the devices reminded them of the usage.

The mis-detection in the bookmark version generally comes from the case with which the flipped page goes through the beak part without large movement. By making the material of the bookmark harder, the part can firmly hold the page to be flipped next. Then, the detection might be more accurate due to the larger bouncing acceleration of the beak. However, at the same time, it would become difficult to flip and sometimes the page might be damaged.

The common limitation in both cases is that they do not support *random access* to the contents. This comes from the method of identifying the current page. The advantage of random access is that not only it allows a system to know the page number that a reader opens suddenly, but also it can eliminate the accumulative errors of the page flipping detection. Although the performance of the detection is high (Table 1) and still there is room for improvement, this becomes problem if the book has large number of pages, i.e. more likely to make mistakes. Recognizing a page number by a video camera might remove the barrier although the complexity of the system increases. However, the technology should be carefully utilized in a public space since it looks like a spy camera. We will investigate an extension of the current devices with error correction or page number adjustment functionality while taking into account of the impact on a traditional reading style.

### *Usability of the Add-on Devices*

Figure 5 a) indicates the perceived difference from an existing book (1: very obtrusive, 5: not obtrusive at all). The proposed devices have been designed to keep the traditional reading style as much as possible. The subjects felt less obtrusive against the bookmark version than the book cover version. The bookmark version requests a user to pay attention to the beak part to some extent, however it has great advantage over the book cover version. The beak holds the page to read the next (Figure 1-(b)), while the flipped page is hold by the book cover (Figure 1-a). This means a reader of the book cover version needs to open the cover when he/she wants to check the flipped pages again. This causes the mis-detection of the flipping since the movement of the inside cover is the same. In contrast, the bookmark version has no such limitation. The information is provided based on the incremented page by the movement of the beak. So, a reader would be presented different information while he/she is checking a page that he/she flipped before. We consider this is not so big problem in a novel book since the activity is basically *confirming* unclear point. However, the *pause* button can be added to the beak or somewhere to improve the usability.




(a) Perceived difference from an existing book (1: very obtrusive - 5: not obtrusive at all)

(b) Preference of creating contents and utilizing the system (1: do not like to do it at all - 5: like to do it very much)

**Figure 5. User Survey on the Acceptability of the Devices and Preference of the System**

### *Preference of Virtual Illustration System*

The preference of creating contents and utilizing the system is presented in Figure 5 b), where all the subjects liked to utilize the system (score = 4 and 5). They agreed with the concept of *making reading experiences rich with an existing book*. Furthermore, some subjects requested additional functionalities: the improvement of the efficiency and the environment of reading, i.e. virtual bookmarking of preferred pages, finding the meaning of unknown words, automatic adjustment of ambient light, bad posture warning, etc. Currently, the eBookXML description is edited by a text editor basis. On the other hand, the subjects did not like to create contents so much as utilizing them. To increase a creator in order to work the contents distribution system well, we will investigate a sophisticated authoring tool in the future. The tool may retrieve suggested contents based on a keyword specified by a creator from an online photo sharing service like a Flickr.

### *User Feedback and Implications*

The subjects preferred the images of maps. Although there is a hand-written map at the beginning of the book that illustrates the positional relationship of typical places, it was too abstract and insufficient for them to understand. The positional relation of many other places remained unclear. It was critical since the book is a travelogue. Other images that the subjects preferred are the pictures of a novelty animal, i.e. ermine, and a mountain path because they were informative. The audio contents were not preferred since they were played at a wrong time.

As can be seen in Figure 4, a user looks at an image over a book. Although the distance of the eye movement is minimum, two subjects felt rather annoying. They tried to see an image every time it appears. So, they often felt interrupted when more than two images are assigned to one flipping (a two-page spread) and they change in a short time. Actually, the time to change an image was set to 3 to 7 seconds for the first two subjects, and the third subjects who did not feel annoying utilized the interval of 10 to 40 seconds.

Even though the rate of the change is low, the appropriateness of the timing of providing contents is very important. The subjects also felt annoying when an image or a sound clip had been presented too early. This sometimes happened for the contents that are related to the left page (latter part). Our approach handles only the page flipping detection, which makes it difficult to identify the exact timing to present contents. Through the interview session, we have noticed that contents presentation at exactly right timing is not necessary. Not all the contents was interesting to a reader, where such a "force presentation" was rather annoying. We consider a *semi-automatic* presentation would address this issue: thumbnails and corresponding keywords are automatically shown in the screen, which are assigned page-by-page basis as the current version does. A reader can see the presence of some information when they appear, and then he/she can obtain the actual contents based on his/her preference.

## CONCLUDING REMARK

In this paper, we have proposed an augmentation of an ordinal book with page flipping event detection. Accumulation of a page flipping event is utilized to estimate the current two-page spread. Two types of add-on devices, i.e. a *book cover* and a *bookmark* version, have been investigated in combination with two accelerometers. The augmentation allows a system to provide a reader with value added experiences while keeping the original sense of utilization intact, e.g. a texture of paper. The complex copyright issues do not need to be addressed because it utilizes an existing paper-based book. We have also developed a prototype application called virtual illustration system. It automatically provides multimedia information based on the page that a reader is reading. Everyone can publish the contents written in *eBookML* like an HTML document and share them with others.

The add-on devices have been evaluated regarding the performance of page flipping event detection and the usability. The detection accuracy of the book cover and the bookmark versions are 88.1% and 92.5%, respectively. We consider that a book with sequential access to the contents and the small number of the pages is appropriate for the proposed devices, e.g. short novel. We are planning to investigate a mechanism to correct or adjust the page estimation by a user for more flexible service. The concept of the prototype application has mostly been accepted. The user feedback from the experiment with real contents has shown us the need for on-demand contents selection to minimize the interruption to a reader. This also relaxes the constraints of the devices that relies on the detection of page flipping.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# Ambient Information Systems

**William R. Hazlewood, Lorcan Coyle, Zachary Pousman, Youn-Kyung Lim**

## PREFACE

Current research in pervasive and ubiquitous computing is guiding us to a future where we are surrounded by innumerable information sources all competing for our attention. These information sources may manifest as both novel devices and as devices embedded in common objects, such as refrigerators, automobiles, toys, furniture, clothes, and even our own bodies. While this vision of the future has prompted great advancements in context-aware computing, wireless connectivity, multi-sensor platforms, smart materials, and location-tracking technologies, there is a concern that this proliferation of technology will increasingly overwhelm us with information. Our belief is that information should move seamlessly between the periphery and the center of one's attention, and that good technology is highly transparent. We see ambient information systems as a way to support these ideas. Ambient Information Systems describe a large set of applications that publish information in a highly non-intrusive manner, following on from Mark Weiser's concept of calm technology. This form of information delivery has manifested in several different implementations, but the overall theme revolves around how best to embed information into our surroundings.

The Second International Workshop on the Design and Evaluation of Ambient Information Systems was held in COEX, Seoul, South Korea, on September 21st 2008, in conjunction with the Tenth International Conference on Ubiquitous Computing. Building on the success of last year's workshop at Pervasive 2007, we brought together researchers working in the areas of ambient displays, peripheral displays, slow technology, glanceable displays, and calm technology to discuss and collaborate on developing new design approaches for creating ambient information systems.

**The workshop topics were for the most part listed as a set of questions:**

• How are ambient information systems distinct from other information technologies?

• What are examples of useful heuristics, frameworks, taxonomies, or design principles for the implementation of ambient information?

• Should Ambient Information Systems move beyond the traditional scope of vision; is there merit in Ambient Noise, Ambient Smells, Tactile Ambience, and Ambient Taste?

• How much ambient information can one perceive and comprehend?

• What, if any, are the appropriate interaction methods for these information devices?

• Where should ambient systems be placed to improve their chances of being used, without becoming distracting or annoying?

• What sorts of information are best conveyed by an ambient display?

• What are the appropriate methods for evaluating ambient information systems, particularly those that are not necessarily task-based?

• How do we describe the values of these particular technologies in our everyday lives?

• How can we make use of existing technologies? (e.g. smart materials, wearable systems, etc.)

• What knowledge from other domains should we apply? (e.g., from art, cognitive science, design, psychology, sociology)

**We were also particularly interested to hear about ambient information systems in the following areas:**

• Resource Consumption, e.g., power, heat, water, food, and for shared or personal resources

• Work and workload ``progress'' (e.g., explicitly or implicitly gathered data, or those based on a workflow)

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# Ambient Façades

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**ABSTRACT**

Public spaces get increasingly equipped with displays in terms of shopping window plasma screens, electronic advertisements at the point of sale, kiosk systems at points of interest, etc. While this trend enables numerous applications in the pervasive display systems domain, it also has effects on how people perceive urban environments. In this work we describe the concept, implementation and first experiences from a real life setup of an *ambient façades framework* expanding the idea of public displays to façades of arbitrary buildings without modifications on the buildings themselves. With such a framework it is possible to integrate information into buildings in a very unobtrusive way and without interference with the building fabric.

**Keywords**

Ambient Displays, Content Adaption, Simulation, Public Display Systems

## INTRODUCTION

Public displays are being increasingly used for displaying diverse information, including corporate propaganda at in-store installations, advertisements at the point of sale and location-aware information at points of interest. In Vienna the headquarter of the UNIQA insurance company, the UNIQA Tower, has been covered with more than 180.000 LEDs that are controlled based on video signals with 25 frames per second [18, 19].

We believe that public displays can be perfectly used as visual interfaces for ambient information systems by leveraging the ever increasing availability of such displays and one of the most interesting features of ambient displays: information hiding. Depending on the level of abstraction, the information depicted in ambient displays can be understood by almost anyone passing by or it can be revealed to informed people only – uninitiated people just see images, icons, figures, etc.

Implicit and explicit interaction metaphors and techniques have already been discussed in the literature and even though we don't believe that this topic is solved (on the contrary – feasible solutions still need to be invented), we do not attempt to give an answer on specific interaction styles but concentrate on the visualization on data on façades.

## RELATED WORK

Ambient displays have been thoroughly discussed within the last decade, starting with early instantiations as physical displays in the late 90s, characterizing ambient displays as entities that "present information within a space through subtle changes in light, sound, and movement, which can be processed in the background of awareness" [1]. Even though some of the concepts have been proposed earlier, the ambientROOM and two ambient fixtures have been presented in [1] and [2] describing indoor mounted displays comprising light, sound, airflow and physical motion as the ambient actuators. In [3] the concept of ambient media has been broadened to "the use of our surroundings for information display", which represents a key concept of what we think of ambient displays: integration into our lives by either imitating commonplace objects or by extending existing objects with somewhat smart behavior.

By specifying different zones of interaction (ambient, notification, interactive) a hybrid approach is prosecuted: depending on the distance of a prospective user to the ambient display (the Hello.Wall) the type of interaction is determined [4, 5]: in the ambient zone the display shows general information about the overall level of activity, number of people in the building, etc. In the notification zone the ambient display reacts on the physical presence of a specific person and provides means for explicit interaction with the ambient display over a handheld device. In the interaction zone the user can interact with the display at a very low level and allows for playful and narrative interactions.

An extension of this concept is presented in [8] where the three zones are interpreted as four phases of interaction (ordered from far way to close): ambient display, implicit interaction, subtle interaction and personal interaction. The basic idea is that the ambient display resembles a common context that should not be destabilized by the other phases. Transitioning from one phase to another should be very smooth and happen only if certain "interruptibility" is detected.

Regarding the type of visualization within ambient displays an interesting concept has been presented in [12], using particle systems, as they are able to "accurately portray complex data with breadth, depth, and elegance". Particle systems seem chaotic and incomprehensible in the first place but can be rich in information, if used with caution.

We, too, believe there is a certain power within particle systems as they can deliver information extracted from the single particles and a particle system has an overall appearance (shape, volume, etc.) that can unveil even more information. The ambient display framework described in this work also makes use of the low-level and high-level statements of a high number of objects on an ambient display.

[16] shows a possible solution for displaying text in ambient displays in an aesthetically pleasing way by using kinetic typography (animated text) for displaying e-mail messages in the AmbientMailer system. This work is interesting, as (especially high throughput) textual displays often lack aesthetic emphasis [9].

In [10] a general purpose software framework for informative art display systems is presented and some general aspects of typical ambient displays are depicted, including themes, symbols and connotations. On the basis of real paintings, methods for integrating information therein are proposed and implemented in the peripheral display framework. Subsequent research led to the proposal of more user-oriented, participatory design process for ambient displays [11], by letting the user decide on the specific theme a peripheral display is operated at. Different elements of various artworks are manipulated to resemble sensor data or abstract context information thus leaving the decision for the concrete piece of painting used for displaying ambient information to the user.

One of the rather seldom seen examples of large public displays is presented in [17], explaining a detailed observation of the multi-touch display called City Wall. While the emphasis of this project lies on the multi-user interaction possibilities, it also shows some interesting aspects of how people approach public displays. Depending on the current usage of the display, people need to wait for a free slot if too many people are interacting already, or they can start interacting immediately if nobody is using the display. The empiric data shows however, that there are usually at least two steps involved: (1) noticing that there is a display, (2) interacting with the display. One conclusion of [17] is that "City Wall's large physical size appeared to support making interactions visible". During eight days of operation 1199 people interacted with the system.

### Evaluation of Ambient Information Systems

Regarding the evaluation of ambient displays, several approaches have been presented, such as a method to evaluate the comprehension of such displays [6]: it is argued that there are three levels of comprehension, each being a prerequisite of the next:

1. *That* information is visualized
2. *What* kind of visualization is visualized
3. *How* the information is visualized

The author emphasizes that it is important to consider the first two steps in the system design process and not start (blindly) at level 3 [6]. We believe however, that some settings, especially when involving public displays, single or even all three steps are not explained on purpose, so that only informed people know about the informative value of such displays.

Users' experiences with an at-home ambient display have been presented in [7] with the CareNet display which supports an ambient and an interactive mode. Situated in the field of elder care it was shown that people with different roles used the display in different ways: basically, the less the people were integrated into the care-process, the more often they actively used the display (interactively), while seriously dedicated people used the display as ambient information system.

In [13] the success of ambient displays is identified as the combination of effectiveness in promoting awareness and the level of enjoyment in the users. This statement is derived after observing users and installations of four different ambient information systems of both tangible and (abstract) 2D display type.

In [14] a taxonomy for ambient displays is proposed comprising a set of design dimensions that can be applied to the various systems and allow a detailed classification. With the 19 projects already included in their taxonomy, a tendency to private, visual and highly abstract displays has been determined. However, we believe the number of public ambient displays is going to increase with the rise of public displays in general.

A very critical look at public displays is taken in [15] where large ambient displays in public settings have been observed regarding their use practices. It is stated, that large public displays are not necessarily eye-catching and appealing, but that glancing and attention is a rather complex process. One of the key statements is that "people make extremely rapid decisions about the value and relevance of large display content", devaluating content that takes more then a few brief seconds to absorb. Also the displayed format is very important for the perception: video is more attractive than text, animated text or still images.

Regarding these findings of previous work, we propose the virtual façade framework for using suitable façades of buildings as solid basis for ambient information display.

## VIRTUAL FAÇADE FRAMEWORK

Examining façades as hosts for ambient displays is a very exciting thing, as the discrepancy between private data and public accessibility is very high. Nevertheless, the aesthetics of fascinating buildings can offer a great set of structures "to lean on" (cf. Figure 1).

Figure 1: Interesting features of a façade include borders of windows, various areas (separated by different colors, shapes, etc.) and ornamentation.

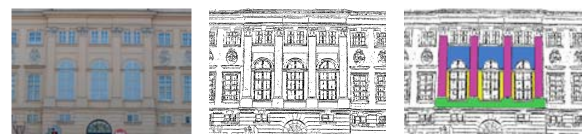
**Purpose**

In order to be able to support future development of façades as displays in combination with the ambient display metaphor we decided to implement a robust framework as a basis for further ideas and implementations.

We enunciated the requirements for the framework very roughly, as we wanted to narrow the choice of technical solutions as less as possible:

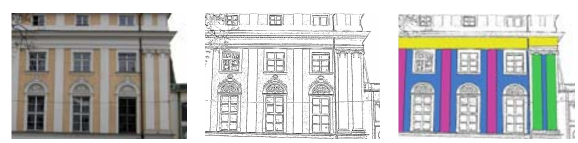
- Text: There might by a need to display text of any size, font type and color. However, with regards to ambient displays text is usually avoided in favor of graphical solutions – thus it is a minor requirement.
- Still images: Support for embedding images into the visualization including scaling functions (each axis independently) and, of course, free positioning.
- Moving images: The framework should be able to render videos and support both live camera streams and produced videos:
  - Live camera streams: Since our first façade was to be the one of the Theatre Linz, we opted to integrate the possibility to render live camera streams to the façade. This thought was driven by the idea to present the current action on stage simultaneously outside.
  - Produced videos: In addition to live video, our system should support readily available videos in order to visualize perfectly pre-arranged content and selected scenes. Also, in case of a live camera failure, locally available videos could be applied to the visualization.
- Fragmented objects: The visual content is required to be displayed fragmented, as one of our main claims is to adapt visuals to the structure of façades and they often comprise compact areas discontinued by some ornamentation, windows or the like. It should be possible to load a single resource and split it into several parts for wide spread display.
- Dynamics: The framework was supposed to support animated content by means of moving, rotating fragmented objects, either by specifying the animation over a separate tool (even at runtime) or by introducing some kind of automated animation mechanism.
- Content management: A content management system supports the integration of different resources (images, videos, streams) at runtime and provides a way to define the position and shape of structures and ornaments of the façade to project on. For better results, the definition should take place on-site, when projection distance and angle are known. Additionally, the support for on-site structure definition paves the way for automated mechanisms, e.g. via a camera based system driving edge detection or other image processing algorithms.

Aside from these requirements we also had a picture in mind of what we would like to achieve. A relatively coarse illustration thereof is depicted in Figure 2 and Figure 3.



(a) (b) (c)

Figure 2: The façade of the MuseumsQuartier in Vienna/Austria to project on (a), an automated structure detection algorithm, such as Difference of Gaussians (b), and the final fragmentation into separate regions, using e.g. Flood Fill algorithm (c).



(a) (b) (c)

Figure 3: The façade of the Theatre Linz (a), after edge detection (b), with detected regions (c).

**System Architecture**

Based on our visions and derived requirements we decided on a simple system architecture comprising a software framework running on a PC which renders the visuals to a projector system and receives data from several resources as well as user input for the content management system. A rough system architecture is illustrated in Figure 4.

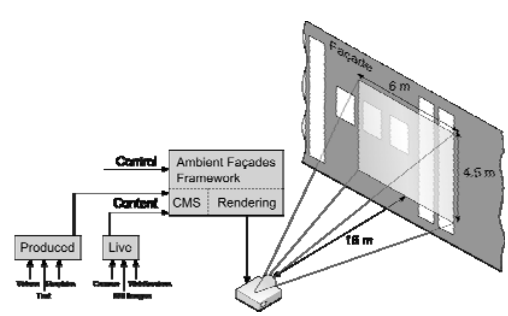



Figure 4: System architecture of the ambient façades framework: different content types are handled by a content

management system and forwarded to a rendering engine which outputs the visuals to a projector system facing a suitable façade.

A separate control channel gives the chance to modify parameters at runtime – a basic feature of ambient display frameworks, as this control channel is used to send e.g. sensor data to the visualization system which in turn can modify size, position, speed, color or similar features of visualized objects for sensor data representation. The control channel is also used to configure the visualization system regarding a specific façade setup (distance, angles, structures, etc.).

## Technical Implementation

### *Hardware*

Our setup was executed on an IBM laptop with a 1.7 GHz Pentium M CPU and an ATI Mobility Radeon 7500 integrated graphics card running Windows XP SP2. The projected image was required to fill an area of at least 4.5x6 square meters on somewhat light façades. To provide a bright and high-contrast picture we decided to use a Barco SLM R12+ Performer large venue projector with 12000 ANSI Lumen, to be positioned about 18 meters from the building. The resolution chosen for the projection was 1024x768 pixels. For receiving live video streams we added a Logitech QuickCam Pro 9000 webcam connected via USB 2.0.

### *Software*

Before we started implementing a structured framework, we did some technology research and created simple laboratory demos in order to be able to estimate implementation effort and feature richness of the tested components. One of the key findings was that our framework is only required to support two dimensional positioning, moving, etc. as we intended to project on flat surfaces only and wanted to interact with structures of these surfaces. It occurred to us that a 2D physics engine would help our efforts a lot, especially by solving the question how to animate components as to provide constant motion. A quick research in the physics engine "market" disclosed the Chipmunk 2D physics engine which is licensed under the unrestrictive MIT license and is written in pure C99, which led us to the decision to use OpenGL as the rendering engine. Even though we did not want to support full 3D applications, the use of a three dimensional graphics engine allowed easily integrating different layers, usually referred to as z-order of visual components.

The visuals would be implemented as textured meshes of arbitrary shapes and sizes. Texturing meshes with still images was offered by the DevIL library, uniformly colored meshes were pigmented using OpenGL's `glColor*` functions. AVI video files were read using the Video for Windows API and the grabbed frames were converted into texture compatible byte arrays. Live video streams were realized with the OpenCV library through the HighGUI API. To ensure the correct color order of the webcam content, the respective pixel buffer is displayed in `GL_BGR_EXT` format.

Figure 5 depicts the implemented software architecture for the demonstrator. A user input module allows interacting with the scene during runtime by adding/removing obstacles, throwing requisites and defining/undefining black areas in the projected image (such as to exclude windows from being projected on).

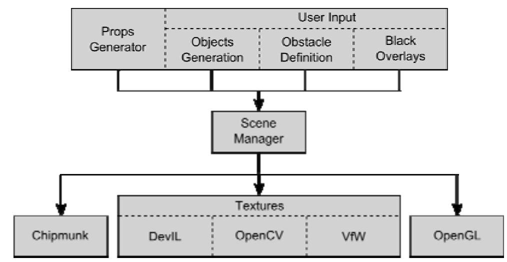



Figure 5: The software architecture used for the Ambient Façade Framework wraps the underlying C-libraries into convenient C++ classes; instance management is handled from a central entity "Scene Manager".

The central management entity is responsible for rendering the components by providing a simple scene graph, which is altered by user input or a parallel process generating random pieces to be integrated as falling objects into the scene. It calls the appropriate functions of the underlying C-libraries and is supported by a separate thread responsible for continuously buffering webcam content in a byte array to be used as texture.

The user input is performed using a pointing device such as a mouse for positioning obstacles, black areas and for throwing requisites around. The basic workflow is to define façade structures and unprojectable areas once the application is running and projected onto the façade. The demonstrator is then ready to go and starts dropping requisites from somewhere above the screen into the scene. With a keystroke the direction of gravity can be adjusted to any of top-down, bottom-up, left-right, right-left. The requisites are generated using random numbers and can differ in type (shape, texture), initial coordinates, initial velocity and direction and angular rate. The interval between the creations of two consecutive requisites is between 100 and 600 ms. The coordinates of each requisite are tracked and compared to the borders of the viewport; in combination with the current direction of gravity the requisites are deleted and respective memory freed if a certain distance threshold has been exceeded and the objects are not to return to the viewport anymore.

Of course, also elements that are not managed by the physics engine can be included, to realize static elements, e.g. used for fragmented video visualization, as depicted in Figure 6.

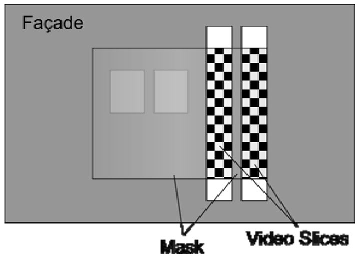



Figure 6: The frameworks shows fragmented video content only in areas not masked. The mask is adjusted according to the underlying façade structures.

One important aspect of the projection based system was to avoid bright light flooding the rooms behind the façade and probably blinding or disturbing people working or lingering therein. To overcome this issue, we added a mask layer on top of the rendered scene where black (not to be projected) areas could be defined. Ultimately, even if a collision detection would fail, a requisite falling into a window would not be visualized but filtered out by the black masking layer. It is therefore possible to use this layer to display fragmented video slices by simply erasing parts of the content from the overall video (cf. Figure 6).

We implemented the concept of textures as abstract as possible, ending up with a system that allows comfortable exchange of textures and sharing of textures between multiple objects regardless of the texture type (image, color, video, none).

The performance of the system was satisfying and ran fluently on the specified (aging) system. The most influential bottleneck was the physics engine as it considerably slowed down if more than two hundred objects were to be considered.

A built-in simulation mode helps understanding the basic behavior of implemented features by rendering the complete scene to a separate texture and blending it on top of a façade. The section of the façade to be projected on can be adjusted to any extend required. It is possible to view the whole façade or just the part where the projection will take place (cf. Figure 7).

(a) (b)

Figure 7: The simulation mode of the Ambient Façade Framework allows viewing the section to project on (a) or the whole building with the visuals blended on top (b). In the simulation depicted here a fruits theme was used instead of the theatre theme illustrated in Figure 8.

**REAL LIFE SETUP**

We tested our Ambient Façade Framework during a performance of La Traviata at the Theatre Linz to mainly find out two things:

1. Is the technical realization good enough regarding brightness and contrast of the projected image and the size of the fragments?
2. What is the (subjective) overall visual impression like?

The first question can be answered quickly: the chosen Barco projector illuminated the façade of the Theatre Linz at an amazing level of brightness and contrast. Of course, the façade was a very complaisant screen as it was unenlightened and had a very pale yellowish color resulting in almost no color variation. The displayed visuals were good to perceive, however some of the objects used for the dynamics simulation turned out to be too small.

The overall visual impression of our live demonstration was outstanding. Invited representatives of the Theatre Linz and our colleagues were impressed by the quality of the displayed content and the ease of use concerning the setup process which took roughly one minute to mark structures and ornamentation using a simple pointing device. The dynamics engine emerged to be very attractive and created a very harmonic relation between the façade and the displayed objects. Changes in gravitation were easy to follow and the bouncing elements made sure that there is motion at any time. Animated elements were not necessary for displaying video streams, as the moving images are attractive enough when displayed on their own, as static elements filling certain areas of the façade.

(a) (b)

Figure 8: The framework at runtime, projecting on the façade of the Theatre Linz: requisites fall down the façade and interact with structural elements of the façade (a). Fragmented video elements are projected on the two pillars on the façade.

The live demonstration did not incorporate any sensor data, but was controlled manually, because we mainly wanted to test the visual appearance rather than the correct transformation of sensor data into ambient information objects.

## CONCLUSION

We have presented the design and implementation of an ambient façades framework that uses façades of buildings and their underlying structures and ornamentation together with large venue projection technology to form a new type of ambient display in urban spaces. The presented frameworks is able to display dynamic particles resembling pieces of information regardless of their type (video, images, text) by considering physical barriers on a façade, which can be edited at runtime and customized to various façades.

The current status of the demonstrators hash shown some potential for further improvements. In order to adhere to a fully automated configuration of masks and obstacles, image processing methods could be of a great help. By detecting edges in an image taken from the façade, it would be possible to automatically define obstacles like window borders and ornamentation. Edge detection combined with recognition of connected areas would enable the automated finding of areas for video display. Of course, camera and projector need to be calibrated in a way that allows the mapping of camera-based coordinates to coordinates within the projected renderings. Currently such a feature is not implemented in the framework, but the structures need to be defined by hand.

## ACKNOWLEDGMENTS

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Finally, we would like to thank Thomas Königstorfer, commercial chairman of the board of the Theatre Linz, for his encouragement to try our framework on the façade of the Theatre Linz during a performance of La Traviata. We also appreciate his precious comments and feedback regarding further development.

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# Ambient interface design for a Mobile Browsing Experience (AMBE)

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**ABSTRACT**

Our preliminary research focuses on the development of an Ambient Mobile Browsing Experience (AMBE) system. AMBE is a communication and synchronisation framework that will provide integrated connectivity across heterogeneous geographically distributed devices. The intention is to provide persistent location-independent and appliance-sensitive viewing for the user, thus enabling Internet mobility. Human technology interface communication will be abstracted to a representation that facilitates optimisation and customisation across a number of different displays. This will help to ensure seamless continuity between components providing usability and maximum user convenience. An emphasis of our work is the application of a human-centered design ethos.

**Keywords**

Ambient interfaces, peripheral displays, ubiquitous computing, mobile digital communication, sensor technology, context awareness.

## INTRODUCTION

Denning and Metcalfe affirm, "*to become attuned to more information is to attend to it less*" [5]. This cause is central to Ambient Information System (AIS) design within Ambient Intelligence (AmI). The ethos of which lies in the classification of center (the user) and periphery (computational devices) for intelligent knowledge management, with the objective of controlling information overload and unnecessary complexity. Carbonell reflects on ambient interface interactions as having to be reconfigured for throughput to output terminals of varying media and screen dimensions [4]. Implementation of these constraints gives rise to 'interface plasticity' and 'adaptive multimodality' [3]. However maintaining simplicity whilst asserting notions of 'calm' [20] remains the consummation in these phenomena and a reflection of the technology we seek.

The principle of AIS, is captured in the following instance and subsequent descriptions; *"When you look at a street sign, for example, you absorb its information without consciously performing the act of reading. Computer scientist Herbert A. Simon calls this phenomenon "compiling"; philosopher Michael Polanyi calls it "the tacit dimension"; psychologist J.J. Gibson calls it "visual invariants"; philosophers Hans Georg Gadamer and Martin Heidegger call it "the horizon" and the "ready-to-hand", John Seely Brown at PARC calls it the "periphery". All say, in essence, that only when things disappear in this way are we freed to use them without thinking and so to focus beyond them on new goals"* [20].

Nature in her pureness has provided simple informative cues that act on the subconscious delivering subliminally

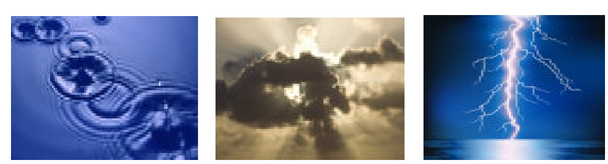

**Figure 1. Ambient information existing in nature.**

and with critical effect. Take the occasion of a raindrop, a signal and a suggestion requiring little cognitive effort, yet retrieving from memory past experiences stimulated by similar impetus to deliver appropriate actions. Nature's ambient sound and light further inform our everyday state of existence. With this in mind it is perhaps to nature we must return in order to re-balance the information congestion that exists combining nature's intuition with twenty-first century engineering. 'DataFountain' reflects this concept. 'DataFountain' is an Internet enabled display of currency comparisons for the Yen, Euro and Dollar, and uses pressurised water levels from three points to provide particular information with calming aesthetics [14]. Another example is 'PlantDisplay' appealing to human emotion through organic changes in the plant's appearance [13].

Human-centered design is attempting to capture this vision in computing technology by augmenting consciousness and accommodating human-machine co-operation. The emphasis is on efficient user-affable and immersive interfaces with distributed virtual services that surround; empowering the user with control [12].

This anthropomorphic model of interaction refocuses the user to the foreground and creates synergies between the user and the environment [15]. Operations are intended to be omnipresent, non-intrusive and transparent. It is in the application of ascribing human characteristics such as sensory perception, and cognitive behavioural interactions to physical or hidden phenomena that the essence of ambient intelligence is encapsulated to provide enhanced user proficiency [12].

Ambient information displays are about the analysis and representation of information in public, semi-public and private space, incorporating subtle techniques and communication methods through peripheral perception [19].

Ambient displays rely on our multimodal senses, operating subliminally and below the threshold of consciousness requiring only subconscious recognition [2]. The classic example is Jeremijenko's Display Installation entitled 'Live Wire', which attracts either aural or visual attention as the incitement requires [11]. More recent ambient displays include 'The Kandinsky system', which generates aesthetic information collages converting textual input to image output [8]. 'IMPACT' monitors daily physical activity and provides feedback through detailed and abstracted displays [9]. 'Ambient Orb' presents ambient information through wireless configurations to track personal portfolio interests such as market shares [1]. 'Hello.wall' uses a large ambient display coupled with a hand-held device exploiting our ability to perceive information via codes [19]. Real time data panoramas map to visual components such as ocean waves and sun strength reflecting stock market activity. Consistently the purpose is to refine knowledge to a symbolic representation requiring little cognitive effort [10].

## MOTIVATION

The motivation for this research is to provide sensor-activated communication. This will enable contextualised content viewing to be available at the current terminal or display screen demonstrating visual peripheral information updates for the user.

The primary objectives of this study are in the development of a framework intrinsically linked to the porting of browsing session information over the network. This will be demonstrated through the implementation of a scalable solution distributing current context information to appropriate selected device displays. The requirement is to ensure user interface continuity and optimisation between distributed devices such as Personal Digital Assistants (PDAs), Personal Computers (PCs), flat screens and smart mobile phones by using appropriate sensor technology. Where appropriate the incorporation of abstract symbolism via an artefact may filter information to ambient displays in public space for personal user discernment. Customisation and synchronisation of multimedia input and output between the distributed devices are to ensure continuity of the user experience.

In pursuing the objectives outlined, several research questions will need to be addressed. For example: What sort of profiler will be required to track and perhaps interpret the user behaviour/movement, both within the context of the virtual environment and the physical one (*possibly intelligent algorithms coupled with infrared, or Radio Frequency Identification-RFID tags*) to provide persistence and session continuity?

In addition how will the profiler store the user's session, will it cache and co-ordinate seamlessly to a new device from decentralised clients (*subsequently passing from web script to client – client-side facilities*), or from a central repository (*heavy overload for concurrent sessions – server-side facilities*)?

How will AMBE tailor context sensitive intelligent user interfaces with automatic profiling to optimise the mobile user experience?

What symbolic abstraction will be incorporated to release sensitive information in public space, for example what indicators will alert the importance of an incoming electronic message in an operating theatre or surgical room where disturbance of external influence is unwelcome, yet may be critical information required by the main operator within the given environment. Will this utility be incorporated through artefacts of two or three dimensional composition? Or perhaps through colour coding or contour configurations adapted from existing works such as the Kandinsky paintings illustrated in Figure 2. Would this approach eliminate the beep and buzz of phones and pagers providing social and acceptable communication etiquette, and in a minimally intrusive manner?

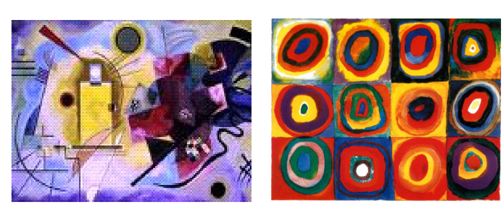

**Figure 2. (i) Marcadores (ii) Squares with Concentric Rings by Kandinsky.**

An ethical issue that arises is that the abstracted notation for information is reliable and consistent for the initiated users specified; otherwise it could lose all purposeful functionality. Privacy related data may need to be tagged as 'sensitive' and filtered away from any public form of display to enable security and dependability within the design.

### CHALLENGES

Amongst the challenges for this system, there exists the requirement to work in real-time and to cope with varying levels of ambiguity, such as changes in user predilection, user idiosyncratic actions and weak sensor signals. Adaptability to new heterogeneous devices (Figure 3) and amended environments will result in readjustment to meet user specification and compensate for device failure supporting integration and interoperability. Whilst dynamically adapting to user requirements through reconfiguration, 'trust,' 'security' and 'safety' standards must also be adhered to, and integrated into the system design.

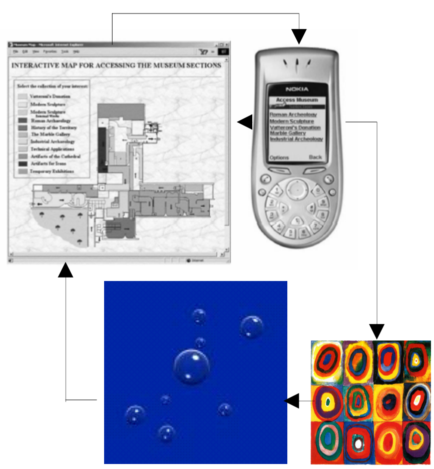


**Figure 3. High-level schematic of AMBE.**

The core of the application architecture is to provide natural interactions and abstraction of the underlying technical communication infrastructure; hiding complexity, whilst enhancing experience and confidence. Successful ubiquity however, requires transparency integrated into the ecology of ones environment facilitated through peripheral interfacing.

The key components of AMBE work to ensure continuity of service between multiple parts and include a sensor network, web server, session server, and user session (to store user history, cookies, current web page state and bookmarks amongst other user facilities) to different displays. The server side can act as a coordinator to manage the data, and facilitate screen resizing before exporting to a newly activated device. The client side component will have the necessary functionality to manage session synchronisation as a feature. The server must also maintain a user's personal profile and orchestrate this profile to heterogeneous devices within dynamic environments. In addition the server will also be responsible for carrying out routine authentication and authorisation and provide session state and mobility handling within the system.

### CONTEXT AWARENESS

The design process of AMBE will rely on the concept of context awareness. Adaptability to a user's situation is enabled by context awareness, "*Context is any information that can be used to characterise a situation of an entity*" [6]. This entity can be a person, place or computational device, alternatively has real existence and can change dynamically. Schmidt et al., say *"context can give meaning to something else* [17]. A challenge highlighted in the development of deployable context-aware services is the aptitude to lever ambiguous contexts as both sensed and interpreted context is often unclear. In addition deployment of contextual information to mobile applications brings to light the trust and privacy features - critical with automated processing of sensitive information. The sources available to capture contextual information in this research include sensors in mobile devices, RFID tags, network servers and application servers among others. Contextual awareness between disparate entities seeks to facilitate interoperability between application platforms with some context immeasurable, but derived through inference [18].

#### Activity Theory Modeling

Activity Theory Modeling is taken from the psychology and social science disciplines, working in the areas of consciousness and cognitive acts within phenomenology [16]. Activity theory applied in AMBE finds application in the areas of context awareness and situational descriptions because of its adaptability to socio-technical perspectives and centers on three key concepts namely; action, situation and presence to give context [16]. The ability to capture the context of the user in state, application and service requires interpretation of the '6 W's; 'Who?,' 'What?,' 'Why?,' 'Where?,' 'When?' and 'hoW?' and is central to the design and profile of the user. Context is argued to be a feature of interaction in any human-computer symbiosis [7]. It is based on the premise that intelligence is action orientated and context can be used to bring order and clarity to unclear situations in order to deliver appropriate actions. Therefore context is seen as a tool for action selection. Within AMBE enabling device exchange whilst sustaining the capabilities and resources of the current session is part enabled by context awareness. Location information is another form of context aware information. 'Activity Theory Modeling' may be incorporated further into the design process of AMBE as a means to capture information concerning the user. This modeling may encapsulate the user's intentions towards a display terminal, the capabilities of their display equipment and their surrounding interfaces. Additionally this information could form a 'migration theory' between the user, their session and their display.

**CONCLUSION**

Ambient Intelligence is a dynamic vision, one in which technology serves information filtering. AMBE seeks to provide an information utility through seamless coalescence and switching of display devices activated by sensors. This is achieved by caching the associated objects and relaying them to another possibly central repository, to facilitate viewing to commence on a different platform. Context-aware and context-dependent information will be captured to provide the dynamics in supporting this feature. The question that arises is how we deliver critical information via ambient displays to highly intensive environments of people centered care through human-centered design. In addition, by incorporating interface plasticity and multimodality how should we test and with what recognised metrics, do we quantify, qualify and assess the standard since these systems are designed not to occupy our full attention rather to augment it. In addition how interoperable are these systems and what future dependability and security features can be applied.

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# Ambient Life: Interrupted Permanent Tactile Life-like Actuation as a Status Display in Mobile Phones

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**ABSTRACT**

In this paper, a novel means of status display in mobile phones is discussed: A permanent tactile heartbeat-like pulsation of the phone. In the study presented, this pulse was used to let the phone continuously communicate a calm state of 'Everything is okay.' – then, this pulse was suddenly interrupted, as soon as the phone needed the user's attention. We hypothesized that the users would instantly notice the missing pulse.

The participants in our study wore the phone for one day and were interviewed afterwards. Also, a log file about the events and user responses was kept on the phone.

The results suggest that the proposed system is not sufficient as a means of notification; only 55% of the events were noticed within the first minute. While some users were simply annoyed by the pulse, others did like the reassurance that the phone was 'present and calm', but 'easy to ignore' at the same time. These results indicate that the system might be eligible as an ambient status display for mobile phones.

**Author Keywords**

Mobile phone, tactile actuation, notification, annoyance, status display, silence

**ACM Classification Keywords**

H5.1. Information interfaces and presentation

## INTRODUCTION

When carrying a mobile phone, the state of 'not ringing' is currently ambiguous: It might mean that *nothing happened*, that a call was *missed* (Fig. 1a), that the phone is *off* or that it is simply *not there*. Mobile phones do not employ a clearly distinguishable state of 'I'm here, and everything is fine.'.

Regardless of where and how the phone is worn, mobile phone users are bound to miss calls sometimes [12] - and this can lure them into a habit of frequently checking their phone for missed events. In this context, new psychosomatic syndromes have been described, *phantom ringing* (or 'ringxiety') and *phantom vibration*s ('vibranxiety') – which points out the often problematic character of current mobile phone information systems [8, 16].

In on-the-go interaction, the audiovisual senses are often busy, or simply not applicable as a channel of interaction, and so utilizing the modality of touch is promising: Tactility and proprioception have come to special attention in mobile interaction design.

## RELATED WORK

Existing research has investigated different ways of vibrotactile, surface- and shape-based information design for mobile devices: Brewster, Brown et al. proposed *Tactons* [3] to convey information to the user through vibrotactile patterns; in order to create a feeling for who is calling [4]. Horev [11] proposed dynamic haptic icons on a device's surface, while the FlashBag USB stick and the Dynamic Knobs phone [10] change their shape according to their internal status. However, none of these systems can easily be realized using existing mobile phone hardware. A simple system that utilizes the common vibration motor is therefore desirable.

Some existing mobile phones ([15], e.g.) have the feature to vibrate every 5 minutes after a missed call – however, this leaves the problem unsolved for the time remaining between these reminders: During this time, the phone is silent, and still requires to be checked.

Other recently released mobile phones [14] feature a button for a 'tactile echo' of the phone: When the button is pressed, the phone will vibrate in a certain pattern, depending on its state (short vibration = nothing happened, two short vibrations = text message, one long vibration = missed call, etc.). While the principle itself is very efficient, as the phone can be checked through the pocket, the cognitive effort to read 'decode' the vibration pattern is still considerably high.

Investigating a system based on patterns that we understand inherently, and cognitively effortless, might be worthwhile, especially in the age of distraction, interruption and information overload [1, 2, 7]. Therefore, we recently proposed a system that uses a calm and a excited pulse as a means of status display for missed events on the mobile phone [9].

The concept of a 'living' mobile phone is based on the hypothesis that as social beings, we are inherently able to interpret signs of life. For example, psychological research has shown that children are able to categorize living and non-living objects already in early phases of their development [6, 17, 18]. What was in question was if an ambient information system could be based on these instinctive abilities.

The difference of this study to its predecessor [9] (Fig. 1b) is that in this case, the pulse would not switch into an 'excited' mode upon a missed event, it would instead stop (Fig. 1c). Because of the user comments in the previous study, we hypothesized that the users would instantly take notice of the missing pulse: They reported a 'gap' when they took the phone out of their pocket in the evening.

## PROTOTYPE AND USER STUDY

The prototype in our study consisted of a Sony Ericsson W880i mobile phone, which was running a Java application: The software continuously generated short, pulses on the phone's vibration motor. For every heartbeat, which occurred every 800ms, the vibration motor was activated twice in a short sequence, resulting in the classical heartbeat rhythm.

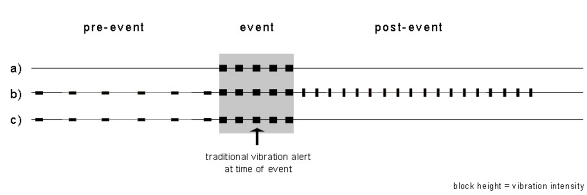


**Fig. 1: Vibration occurrence and intensity in a) traditional notification; b) the calmness/excitement-based system [9]; c) the system discussed in this paper (stopped pulse signalizes need for attention)**

The intensity of the vibration could be adjusted by the users. The available strength reached from very subtle beats ('ticks', resulting from less than one rotation of the vibration motor) to distinct, repetitive 'vibration motor vibrations' (multiple rotations of the motor). The heartbeat-like rhythm, however, was existent for all intensities.

The default intensity was a 50ms activation of the vibration motor, resulting in a subtle force, comparable to a gentle touch of a finger. According to another study, this is a 'comfortable' [13] intensity for tactile actuation.

We conducted a qualitative user study with 6 users (3f, 3m, 22-33 yrs.). We used video interviews and user observation through log files on the phones as our methods of inquiry.

The software simulated a missed event and stopped generating the pulse at some randomly selected point of time (with a minimum distance of 10 minutes between the events), which was written to a log file. The users were asked to push the 'OK' button on the phone as soon as they noticed that the pulse hat stopped (to 'reanimate' it). No other cues for the event, like ringing or traditional vibration alert, were given. All subjects were familiar with the device already, as they took part in the previous study [9] as well. The users wore the phone for one day, and all users wore their own mobile phones in addition.

The users were encouraged to keep a diary of their activities while carrying the phone, with special regard to situations in which using the functionality would be different than in others (e.g. in a library, as opposed to at a concert).

## RESULTS

The users reported that the suitability of the functionality as a means of notification depended on the strength of the vibration and the situation they were in – sometimes, they would just miss it when it is not strong enough. At the same time, the stronger the vibration was, the more annoying they found it. Most users stated that they were able to ignore the pulse at low intensities, and shift their attention to it to check it 'on demand'. At higher intensities, the system was mostly found to be "very annoying". Users reported that they were well able to perceive the pulse while sitting in a calm environment, and were hence able to react to its sudden end. While walking, they were not able to feel the pulse, and had to 'check' for it by grasping the phone through or in the pocket.

Some users particularly enjoyed that either 'everything was fine', or, be it 'because of a missed event' or 'because I did not wear it close enough', it required them to do something. Silence, in this system, is never good.

Users stated that they found it difficult to immediately react to the death of the phone and that they often had the feeling of being 'too late'. They also reported an 'inverted phantom vibration', in which they thought the phone had stopped beating, but it had not. Overall, the users felt that they were not really good reacting to the stopped pulse, and estimated the average common time to be about five minutes. They reported that when they checked their phone, which was often 'accidentally', that it was often dead already, presumably for a longer time.

The log files revealed the actual reaction times (to a total number of 194 events): 19% of the responses occurred within the first 10 seconds, 44% within the first 30 seconds. 55% of the responses to a stopped beat occurred in the first minute after the event (Fig. 2). After 10 minutes, 90% of the events were confirmed.

## DISCUSSION

Many users in our test group were quickly annoyed by the pulse, only few got used to it. Similar to the previous study, the pulse was found to be more annoying in silent situations, while it was rated 'easily ignorable' and 'helpful' in busy situations.

The permanent tactile stimulation that the system produced was helpful for the users to be aware of their tactile contact to the device. For people in special user groups (e.g., emergency doctors or security staff) that have to be permanently sure that their network reception, battery status, etc. are fine, that they have no calls missed, and that they have not lost tactile contact with the device, such a ongoing reassurance could be helpful.

A result of only 19% recognition rate within the first 10 seconds and 55% within the first minute is not sufficient for a notification system. Instead, it seems more plausible to use the system as a permanent status display.

Even though the task 'When the heartbeat stops, press the center button to reanimate it.' was plausible to the users, they did not state that they treated or perceived the phone as a pet: While the metaphor of the 'living phone' was clear, it is still uncertain if a non-lifelike stimulation would have produced different results.

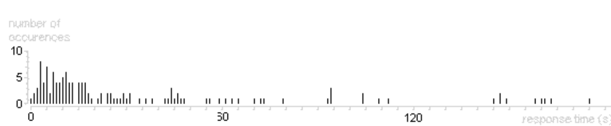


**Fig. 2: User response times to interrupted pulse**

Interestingly, the users stated that they 'just accidentally' looked at the phone when they discovered that the pulse had stopped. It is, however, unlikely that every user accidentally checked the phone every minute. What might be possible instead is that they took notice of the stopped pulse subconsciously. It has been argued before that some decisions are largely based on external subconscious cues, even though they feel like free will [5].

Permanent life-like tactile actuation as we propose it should be looked at critically: We do not know the bodily and psychological consequences of a continuous external heartbeat – nonetheless, we think that it is a worthwhile undertaking to study it.

## CONCLUSION

This research cannot answer the question of whether permanent information should be preferred over permanent checking. Still, a status display like the one proposed might be suitable for users that need permanent reassurance about their phone's status.

People that show addictive behavior to their mobile phones should also be taken into consideration. The permanent stimulation might satisfy their need to be in touch with the phone, but in terms of addiction, it might make things worse.

This study contributes to the ongoing research in tactile mobile interaction design. The proposed system cannot replace traditional notification and status display systems, but investigating permanent systems is worthwhile: How can users be comfortably informed, and should this information occur in bursts, or in a stream?

## FUTURE WORK

Most of the subjects in this study asked for an inverted principle: Silence, when nothing has happened – and a subtle, yet perceivable pulse after a missed event. This will be investigated in a future study.

Clearly, a long term study is needed, that examines the costs and benefits of permanent tactile actuation in mobile phones. What needs to be investigated as well is whether life-like movements are indeed more suitable in the proposed case than non-life-like movements. In this context, it would also be important to find out how the relationship to the device changes when it behaves like a living being.

It could also be thought of externalizing the actuator from the phone: Users that do not maintain body contact with their phone (e.g. when wearing it in a bag) would probably prefer an externalized version.

Ultimately, this project aims to create a 'gut feeling' for the phone; Users should not have to think about checking their phones. Until that point is reached, we face the ambiguity of silence in mobile phones: No news is no news.

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# Stay-in-touch: a system for ambient social reminders

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**ABSTRACT**

Social interactions among a group of friends will typically have a certain recurring rhythm. Most people interact with their own circle of friends at a range of different rates, and through a range of different modalities (by phone, instant messaging, face-to-face meetings etc.). When these naturally recurring interactions are maintained effectively, people feel at ease with the quality and stability of their social network. Conversely, when a person has not interacted with one of their friends for a longer period than they usually do, a problem can be identified in that relationship which may require action to fix. We present Stay-in-touch, an ambient information system which provides peripheral cues to the user which serve as occasional recommendations of which of their friends they should contact soon in order to keep their social network in a healthy state.

**Author Keywords**

Ambient displays, reminder systems, information visualisation, social networks analysis.

## INTRODUCTION

When modelling the social interactions among a group of friends, a certain recurring rhythm is identified, which will differ between social groups. Within this group, a single person may have a range of different rhythms with each of their friends, due to the similarity of their schedules, the differing strengths of those friendships, and a range of other social factors. When these rhythms are maintained well — that is, the person interacts with that friend at the regularity that they normally do — the health of that friendship will feel natural. If on the other hand the friendship falls out of rhythm, through neglect or unfortunate circumstance, and the two people do not see each other or otherwise interact, this gap will be felt, though perhaps not always understood.

A person's "social rhythm" describes the rate and regularity with which they interact with the various people they know. In this regard it is a fuzzy metric; if asked how often you interact with a certain friend of yours, you will probably reply with "about twice a week" or "most days", not something like "once every 37 hours". Stay-in-touch is an application we have developed to notify a user when it detects a lull in one of their social connections. It does so by analysing their social interaction history through data gathered from a multitude of sources, and attempting to quantify their social rhythm.

A person's ability to regulate their own social rhythm relies on their perception of time running like clockwork, but the human mind's perception of the passage of time is capricious at best [5]. Numerous studies have pointed to the fallibility of this ability [3, 14]. Without external prompts, keeping up with friends — especially peripheral friends, who are not part of one's close social circle — can become a matter of chance and circumstance. Because social interactions are inherently vague and intuitive, there is no single point in time at which one is motivated to rekindle a dwindling friendship. For this reason we believe that explicit cues based on historically observed rhythms would help in this area, while still feeling natural and unforced.

Stay-in-touch provides the observer with suggestions of actions they can take to maintain the stability of their social network through a visual interface. This encourages users to contact their friends regularly, but also helps them to identify problems with certain friends early, so that they can take steps to correct a deviation before it becomes more pronounced. Thus, if a user tends their network well, they will have stronger ties with a wider and more diverse set of friends.

We are particularly interested in studying the effectiveness of these social reminders in the context of calm computing, as defined by Weiser [15]. Our intuition is that oftentimes it is an artefact that you come across arbitrarily which spurs you into contacting a friend about something. For example, seeing a photograph of you and a friend may prompt you to talk about an experience you shared. It is along these lines that we seek to provide subtle reminders of a friend at the right time, to lead a user into reestablishing contact. If the user can ignore the system when all is well in their social network, they will be more likely to engage with it when an issue does arise. Conversely, if the system demands attention at too frequent an interval, the user may become frustrated and begin ignoring notifications. Finding the ideal balance between avoiding interrupting the user's workflow and effectively providing information when it would be beneficial would provide valuable insights into how a busy person's attention is divided.

In the next section we will describe some social network analysis research that is relevant to this project, followed by a discussion of the the design of the system we have built. Next we discuss the applicability of this type of data to ambient information systems and describe how we could evaluate this sort of system.

## SOCIAL NETWORK ANALYSIS

Previous studies have analysed social rhythms in socio-technical systems, although the focus of these studies was on the general trends of social rhythms apparent on a large scale. Golder et al. studied interactions between college students over the social networking site Facebook, and found that students' social calendars were heavily influenced by their school schedule [12]. Leskovec et al. analysed all conversations conducted over Microsoft's Messenger instant messaging service in the month of June 2006, and concluded that users of similar age, language and location were most likely to communicate frequently [7].

"Dunbar's number" is a proposed upper bound to the number of people an individual can maintain stable social relationships with. Among humans, this bound stands at approximately 150, and is due to the cognitive overheads involved in remembering and being able to meaningfully interact with others [4]. Although social networking applications have long allowed users to have many more than this number of "friends" identified within the system [2], it is unlikely that a user would report that they are friends with all of these people in the traditional sense [1].

Online social networking sites are generally used to maintain social connections which were originally forged offline [10]. These websites present a low-cost way for people to stay in contact with a wide array of friends and acquaintances. Combined with temporal reminders, sites like Facebook are an ideal avenue through which to evolve, maintain and reenforce a user's social circle.

That said, a person's social network cannot be described by data from any one source. Though the majority of a user's friends may indeed be present in an online social networking website, they will also have friends that they interact with purely offline, or mostly by phone or email. These ongoing social interactions are equally valid in characterising a user's circle of friends.

## VISUALISING SOCIAL INTERACTIONS

There have been many visualisations generated of social networks, particularly since the rise of social networking websites and the rich data sets they present. Many visualisations use a familiar node-link diagram of a graph [6]. These visualisations will often present the graph from an "ego-centric" perspective, where the user being analysed is shown at the centre of the view, with their friends arrayed around them. In this project, because we are not interested in the network links that exist between friends, we can dispense with this network view, and focus on the strength of the connections between a user and their immediate network of friends.

A weakness we have identified with existing network visualisations is that they treat all edges in the network as being uniformly-weighted. That is, an edge is either present or not present; there is no gradation to the strength of each link, and all links are drawn with equal length. In real life, we know that friendships do not behave like this. The social links between people become weaker over time and grow stronger through positive interactions. We wish to visualise these details of the network from a single user's perspective, and allow them to answer questions about the health of their network at a glance.

### Data Sources

Ambient systems can leverage the vast amounts of data available from the physical and virtual worlds. We now leave digital traces of most of our social interactions: all of our email is archived on a server somewhere, our instant messages are logged locally and remotely, posts to social network profiles are publicly visible, and so on. Even co-location data can be recorded if the users both wear a tracking device of some kind, allowing the identification of events like two people conversing in a research lab.

Though all of this data is attractive, for this first version of the Stay-in-touch system, we decided to focus on records of mobile phone interactions, which we are able to access from our telecommunication provider's website. The software has been built to be agnostic to the nature of the interactions, so adding support for emails in future, for example, is a matter of writing a small client to parse the user's inbox and find mails that they have sent or received from their friends. These, along with other discrete interactions, can then be entered into the system.

### The visual display

Our visualisation is built using Processing [11], a Java-based visualisation framework which supports rapid prototyping of visualisation techniques.

Stay-in-touch presents a time series plot, visible in Figure 1. Each row represents a person's social interactions with one of their friends, showing mobile phone interactions; blue dots indicate phone calls, with the size of the dot reflecting the length of the call, while red dots indicate text messages and are uniformly-sized. Weeks are subtly delineated by differing background colours to provide users with an indication of their longer-term habits at a glance.

The current day is highlighted, and the next week is visible on the right of the display. Cues for future interactions are displayed in this area in the form of hollow circles. Their colour and size indicate the type of interaction suggested, based on a prediction algorithm that we have written for this purpose. Predicted social interactions are drawn on the day that our algorithm has calculated to be most likely for them to occur, but the user can see them a week in advance. This gives the user several opportunities to act on the information being presented to them at an appropriate time.

If the user does not interact with their friend in any way before the suggested interaction , an "X" is marked at this position and this is counted as a "miss". The prominent marking of these events (or non-events, if you will) serve to draw the user's attention to these more critical cues.

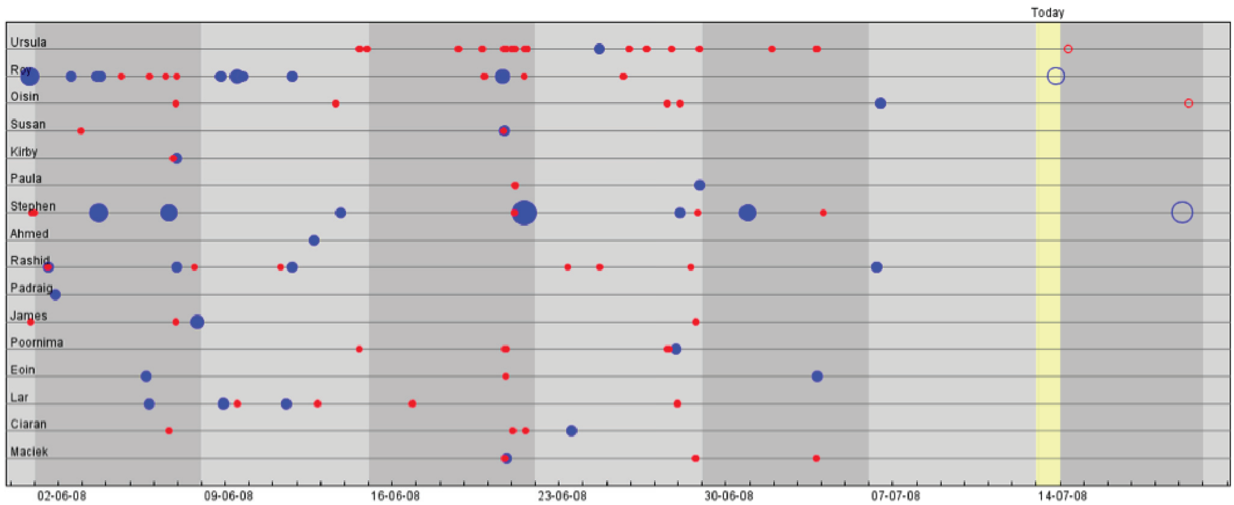


**Figure 1. The Stay-in-touch display, showing a record of a user's interactions with a subset of their friends. Blue circles are phone calls; the size of the circle reflects the length of the call. Red circles are SMS text messages. Suggested future social interactions are indicated by hollow circles on the right, giving the user time to act on those suggestions when it is convenient.**

## AT ODDS WITH AMBIENCE

Neely et al. have previously explored their hypothesis that some context sources are more applicable to being presented in an ambient manner than others [9]. The reasons they described are precision, criticality, periodicity, interpretability and self-descriptiveness.

We add to these three properties of the system's primary output which we think make it a good candidate for application in an ambient display — the reminders are passive, temporal and simple. Passive means that changes in the information do not always require immediate attention; users can take note of reminders but choose not to act on them until later. Temporal means that the data changes over time; if the display remains at the periphery of a person's attention, they can monitor for changes while concentrating on other activities. Simple means that the information can be digested easily; at a basic level, a reminder simply consists of the name of a friend who they should contact soon. Other information may be present, such as a suggested contact time or medium, but this only serves to augment the primary information.

These three properties correspond well to the interaction, reaction and comprehension model proposed by McCrickard et al. [8]. Not all notification systems are as well-suited to an ambient implementation. Consider as a counterpoint the visualisation an air-traffic controller uses to direct planes at an airport. It satisfies none of the above criteria: the information requires immediate response, as planes must be given clearance to land or take off as quickly as possible; while the data does change with time, typically while there is any activity it is in a constant state of flux, and must be monitored constantly; and there are typically a huge number of variables to take into account for each notification, such as the plane's location, scheduled departure/arrival time, current velocity, etc. It would of course be possible to create an ambient display which delivers information about planes arriving and leaving an airport; while passengers might find this interesting and informative, air-traffic controllers would have no use for it.

This example highlights the fact that only certain classes of notifications suit application as an ambient display. This leads us to our key question: to what degree can reminders and notifications be incorporated into ambient systems, before the notion of calm computing is rendered meaningless?

## FUTURE APPLICATIONS

The implementation described above could be used as both an interactive display, where a user filters the information processed by the system manually to achieve insights into their social trends, or as a information display, which allows a user to passively get a feel for the general health of their social environment in an instant. However, the application of the Stay-in-touch model to a more inherently ambient solution could take a radically different form. An example of such an ambient display in the area of social information is the Whereabouts Clock developed at Microsoft Research [13]. This is a glanceable ambient display placed on a wall in a home, which displays the current location of all of the members of the family. One could imagine a similar display for the Stay-in-touch model, which displays a collection of avatars representing some of the user's friends. The health of the social connection for each friend could be indicated on a danger scale — green meaning the relationship is growing in strength, yellow indicating no change and red suggesting a decline in the frequency of interactions.

Since the critical information output for the user — reminders indicating when a friendship is stagnating — is atomic and relatively simple, it could be used in conjunction with a number of lo-fi data delivery methods. The user could subscribe to receive suggestions as text messages on their mobile phone, or through email or twitter tweets, informing them of the person they need to catch up with. There is also the possibility of using small personal devices, such as the Chumby or iPhone, to allow more convenient access to reminders and provide a simplified version of the main visualisation.

## FUTURE EVALUATION

We see an ideal evaluation of the system as a diverse user-based study; one would record the suggested social interaction time and type and along with the actual time that the person next contacted the friend in question. This data would be collected over a sustained period, and two parallel sets of social interaction data would emerge; the smaller the discrepancy between these two data sets, the more helpful the system is. A control group would be made up of a subset of the testers who would have their social interactions predicted as normal, but not shown to them. If the average difference between prediction and interaction is much lower for the informed group, then this would suggest that not only are the reminders influencing those users' social habits, but that they are promoting a more regular and sustained social rhythm.

In addition, if the study was administered to several groups of people, each with different levels of notification, we could get a good idea of when adding more frequent notifications or more vivid animations stopped being helpful and starting being distracting.

## CONCLUSIONS

We have presented Stay-in-touch, which presents ambient information to a user based on the interactions that they have with members of their social network, and suggest how this kind of information can help a user to keep their social network in a healthy state. Given sufficiently careful treatment, infrequent notifications can become a useful addition to an ambient display. We have postulated that certain traits are desirable in an ambient reminder system; these are a long possible response time, variance in the timing and meaning of reminders, and simple, easy to interpret reminder information. Only extensive user testing can confirm that these qualities give an indication of the suitability of a type of reminder to ambient systems.

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# User Generated Ambient Presence

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## ABSTRACT

Presence is an important part of our day to day lives. Often we will have a sense of who is around us and what they are doing by the sounds of doors closing, cupboards banging, footsteps on floors, voices vaguely heard through walls, etc. In digital spaces, such as GUI desktops, presence enhances our sense of connection with geographical separate friends and colleagues. In this paper we report on Ambient Jewelry, which is a project exploring the intersection of individual and user generated customization with ambient presence displays. With this research we are seeking techniques that enable people to invent, discover and find new forms of ambient presence visualisations.

## Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces

## General Terms

Presence, Ubiquitousness, HCI, Instant Messaging, Communication Patterns, Digital Presence

## 1. INTRODUCTION

Ambient Jewelry is a work-in-progress project that explores the intersection of individual and user generated customization with ambient presence. The aim is to enable the creation of more personal and richer forms of ambient presence, with the aspiration that this will allow us to more deeply connect with our friends and family in a non-intrusive manner. Within this project we used small rounded windows that we call Jewels, to display the User activity. An example of this Jewels can be seen on Figure 1.

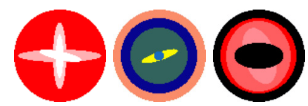

**Figure 1: Examples of three different Jewels.**

Awareness of presence is an important part of our day to day lives. Often we will have a sense of who is around us and what they are doing by the sounds of doors closing, cupboards banging, footsteps on floors, voices vaguely heard through walls, etc. In digital spaces, such as GUI desktops, presence enhances our sense of connection with geographical separate friends and colleagues. For example when you use an Instant Messaging (IM) client you see which friends are currently online or away, and when engaged in IM chat you are also told whether the people in the conversation are typing. On social network sites, such as Facebook, presence has a more explicit form. We are told what the people in our social network did, e.g. Mark joined the Ireland network, Germán and Mike are now friends.

As of yet presence representations, such as in Instant Messaging clients, rarely enable us to control how our presence is represented. We cannot decide to design colourful Jewels rather than virtual flowers (ambient presence avatars) that spin on our friend's desktops to show how fast we're typing. Nor can we create the relationships between arbitrarily designed presence avatars and how transforms of the avatars encode actions.

The representation of presence tends to be specified by the designers of the presence systems. A designer decides that colourful squares on a desktop cube are suitable for representing a remote friend's movement, while another designer designs a presence representation where an artifical flower opening means a friend is walking into a distant room, or flowing water represents variations in currency exchange rates [10].

Within the project we took an open design approach. That is we acknowledge that users may be better suited to inventing presence representations to suit their needs, social status and social connectedness. There are two different roles for users to design and personalise Ambient Jewelry presence:

1. The Creator of an Ambient Jewel: They design an Ambient Jewel to fit their likes, e.g. they create the initial graphical design of a Jewel from a family pho-

tograph (static content). Then they make the Jewel dynamic by setting up how the graphical look of the Jewel changes based on their actions, e.g. type fast and Jewel blinks fast.

   Once a Creator has made a new Jewel they may share it with their friends. When a Jewel is shared with friends it is sent to the friend's remote desktop GUIs. When a Jewel is shown on a desktop it continues changing based on the Creators remote actions.

2. The User of Ambient Jewels: The User is the person who receives the Jewel and who sees it visually changing on their desktop.

   The design process still continues with the User because the User is able to use their friends' Jewels to decorate their desktop. A User with more Jewels has more options to arrange them into aesthetically and artistically appealing patterns, shapes and clusters.

In this paper we outline our framework for and approach to enabling Users to become designers of their ambient presence displays. We are especially interested in understanding how the Users of a Jewel perceive the Jewel Creators actions.

By introducing sharing of the ambient displays we are indirectly forcing Users to reflect on their meanings. Will groups of friends converge and create the same style of Jewels, almost forming a shared ambient display graphical language that is specific to their group or community? Or will certain graphical representations and Jewel transforms emerge across all Users, because they make "sense" in an ambient display?

We are aware of the possible disturbing effects that could be created by people (especially by blinking and other distracting effects). The base effects are smooth and slow, but Users are allowed to alter and speed them up using modifiers. We consider interesting what the outcome of these broader limits may be. Will users tend to create disturbing effects? Or will they socially agree not to use them?

With this research we are seeking techniques that enable people to invent, discover and find new forms of ambient presence visualisations.

## 2. BACKGROUND

Presence and Ambient Displays have been explored in many innovative research projects [2, 11, 8]. For example InfoCanvas is an implementation of a user customizable ambient display where users can design the contents of the ambient display as part of information art[7]. Another similar display is Scope [9], which consists of small iconic representations based on notifications.

There are numerous different approaches to digital presence awareness. In Prior et al. tell us about an interface they created based on metaphors of the real world to help older adults understand the concept of Instant Messaging [6]. While Kranz et al. [4] created a novel physical device to share our on-line status.

**Figure 2: Examples of two different Jewels changing.**

BuddyBeads[3] is an example of research into creating physical Jewels that represent different emotions as non-verbal messages.

Another interesting example is Ambient Furniture that connects two geographically separated family tables, e.g. place a cup on one table and a vague outline of the cup appears on the other table [5].

Studies have shown how the design of Instant Messaging communication software affects interpersonal relationships [1]. From these studies we understand how technology can be redesigned to improve human communication and connectedness [11].

Based on the results of the preliminary discussions from [6] we understand that some participants got confused by the concept of an unrelated picture (avatar) representing them or their fellow participants. The same issue applies to Ambient Jewelry, since each user is able to create a unique Jewel with unique changes based on what they do and what they want to represent. We discuss this further in Section 4.

## 3. AMBIENT JEWELRY OVERVIEW

Ambient Jewelry consists of a cross-platform framework that easily lets people create and share their presence avatars. These avatars, which we have called Jewels, consist of small shaped windows of approximately 20-100 pixels. The Jewels allow the display of people's actions on their friends and colleagues' computers. So if a friend of mine has my Jewel, he will be able to know if I am connected, typing, or moving the mouse about. Furthermore, he will know I am doing such actions by watching what my Jewel does on his desktop. For example, I could design my Jewel to visually fade while changing color to red in order to display that I am really busy typing with my keyboard. There are many more actions that can follow the scheme:

ACTION -> EFFECT

Visually fading a Jewel is like this:

Typing -> Fade-Red

Other possible actions include:

Open-Windows->Sparkling
Mouse-Movement->Rotation
Listening-Music->Blinking

### 3.1 INTERFACE

The main Ambient Jewelry program consists of:

**Jewels** (Figure 2): Shaped display windows that represent other people's presence. They are placed on the desktop.

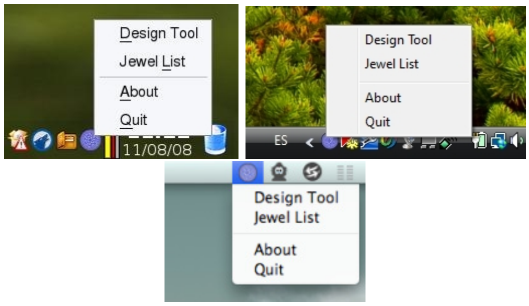


**Figure 3: Cross-platform system tray application icon with menu (Linux, Windows and MacOS).**

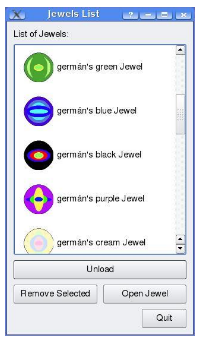


**Figure 4: Jewel Manager window for managing Jewels.**

This is the part of the Ambient Jewelry software with which the User of Ambient Jewels interact with. Each Jewel has its own window.

**System Tray Icon** (Figure 3): This icon is the control point for all the other windows. Through it the User can access the different functions of the software via the popup item menu. Even if no Jewels are being displayed on the desktop the software runs in server mode gathering action data (e.g. mouse movement) and sending it to client Jewels. When the System Tray icon is used to quit remote Jewels stop getting updated.

**Jewel Manager** (Figure 4): Displays the list of Jewels available in the system. The Jewel Manager allows a User to carry out management tasks such as the installation of new Jewels, or adding Jewels to or removing Jewels from the desktop.

**Design Tool** (Figure 5): Allows the Creator to build, customize and modify their Jewels. In this window they can design a Jewel or assign the actions to the graphical transformations applied to a Jewel. In order to achieve this, the window consists of different options such as sliders to control the amount of time, color and different movements (transformations, rotations, shakes, etc.) applied to graphics that represent actions.

**Jewel Desktop Layout** (Figure 6): A major feature of Ambient Jewelry is that it enables Users with Jewels on their

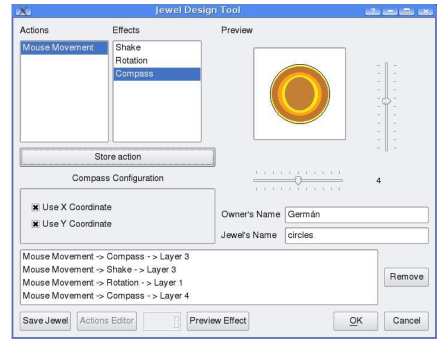


**Figure 5: Design Tool window for creating Jewels.**

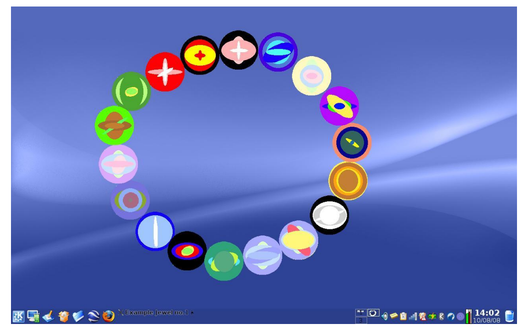

**Figure 6: Example of several Ambient Jewels laid out on the center of a KDE desktop.**

desktops to create formations, patterns and designs with them. By doing this the User could create their own form of ambient display consisting of other people's customized Jewels (ambient displays). We are aware of the possible complexity this system could have when loading a considerable amount of Jewels. In order to enhance the learning curve of who owns each Jewel, we are debating displaying each owner's name and action performed in small tags when a Jewel is clicked.

The idea of aggregating customization of others customization opens another facet of user customization. We are planning on expanding Ambient Jewelry to allow the User to personalize his own actions with other people's Jewel based formations. This can be thought of as an Object Orientated style inheritance of ambient displays. Another option is to include some physical interaction algorithms so as to let the Jewels get sticky with each other, or allow them to move and interact with other Jewels. With these features we could provide a totally customizable interface from the User and the Creator's point of view.

**Example of use**:

1. Creator: Creates their Jewel by using the Design Tool with the effects:

   Mouse-movement->Rotation
   Number-of-Windows-Opened->Sparkling
   Away-From-Computer->Fade

Keyboard-Typing->Smooth-Blinking

When finished designing the Jewel the Creator saves the creation to a *.GEM file that stores all the data. The Creator sends the GEM file to one of their friends via email, instant messaging, or through the network communication layer between Ambient Jewelry clients.

2. User of Ambient Jewels: Receives the *.GEM file and chooses to install it into their Ambient Jewelry software using the Jewel Manager window. When installed a new Jewel appears in the list of Jewels - with the static representation as an icon. Once installed the User activates the Jewel by clicking the "open" button. The Jewel appears on the desktop initially as a static image. After being displayed on the desktop the Jewel connects to the remote Ambient Jewelry server and starts to act following its script of actions (local *.GEM file) when receiving the action data from the remote host.

# 4. DISCUSSION

How will Users of the Jewels understand what changes in a Jewel mean? This raises an important aspect of our research - does Ambient Jewelry lead to discussions about Jewel meanings (encouraging back channel communication and socialization)? Also as was mentioned in the Introduction will a shared ambient display graphical language emerge? If so how much of that will be due to the expressiveness or limitations of the range of Jewels people can create with our software?

Users may need help in understanding what their friends Jewel transforms mean. In order to examine this learning curve issue we are considering having two control User groups. The first group would have small tags as part of the Jewels, which show keywords about the actions performed, while the second group would have no textual information about what Jewel changes mean.

When considering the business applications of Ambient Jewelry we realize that the core funcionality may not be enough. In order to broaden the use of Jewels in professional applications we may need to take a different approach to the actions grabbed. Multiple actions may need to be mapped to a single graphical transform, for example displaying the rhythm of work in a shop by making the Jewel move faster when more people come into the shop and buy milk. If we use this approach, we would create a Jewel linked to a business, not a person, so the Jewel would display the status of the shop. A potential issue with this approach is granularity of the ambient display - too many actions and too much information about actions may be impossible to meaningfully display in the small display space of a Jewel. This leads to the question: How can we measure or quantify the graphical expressiveness of an ambient display?

# 5. ACKNOWLEDGMENTS

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# The Invisible Display – Design Strategies for Ambient Media in the Urban Context

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**ABSTRACT**

This paper presents contextual strategies for staging ambient interfaces in public space. While ambient displays are often treated and evaluated as solitary objects in existing literature, I will argue that the experience of an ambient display is not determined in the first place by its intrinsic qualities, but essentially by the way how it is situated within its local context.

The six described strategies show how cultural notions and practices can be incorporated into the design of ambient displays. Some of them seem counterintuitive and take advantage of phenomena that a designer usually might want to avoid. At the same time they are an invitation for further experiments and cross-pollination between the fields of architecture, public art and interaction design.

**Keywords**

Ambient Media, Contextual Design, Urban Interfaces

**Introduction**

In the architecture community, the impact of large-scale outdoor displays on public space is currently intensely discussed. However, the discussion is mainly concerned with a rather traditional concept of the screen, designed to capture attention by displaying imagery on a prominent surface of a building. As a result of this narrow definition, much of the discourse revolves around the notion of the façade as an iconographic surface, resembling the discussions around the "architecture of the billboard" during the 1960's and 70's [1]. What is needed is a redefinition of the display, reaching beyond the traditional notion of a screen. For this purpose, a rich spectrum of methods can be deployed to display information through physical means[2].

Based on concepts of ambient media, I will try to make an argument for the architecture of the "invisible display", a display that is perceived in the background of attention and blends into the ambience its surroundings. For sake of simplicity, I will use the term invisibility for everything that we tend to overlook in our daily routine.

Ambient displays are architectural interfaces for presenting information that can be processed in the background of attention [3]. For capturing the viewers attention, ambient displays rely on a mechanism often referred to as the *Cocktail Party Effect* [4]: in the noisy ambience of a cocktail party with many voices simultaneously talking we immediately notice someone mentioning our name, while being unable to follow any of the conversations.

**The importance of Context**

Also the discourse among HCI designers about ambient displays could benefit from architectural design practice. A considerable body of research has been dedicated to the description and evaluation of ambient media, its possibilities and applications. However, the question of what makes a technology "calm", especially in the urban context, still deserves closer investigation.

In existing literature, ambient displays are often treated and evaluated as solitary objects. Throughout this paper I will argue that the experience of an ambient display is not so much determined by its intrinsic, absolute qualities, but essentially a result of its interaction with its surrounding and its references to cultural practices and preconceptions. Most evaluation criteria for ambient displays, such as the demand for minimizing the cognitive load [5], are relative and context dependent, and cannot be evaluated separately. This is especially true for aesthetic qualities, which are often reduced to the requirement for an "aesthetic pleasing design", however this might be understood. In this paper, the investigation of the ambient will not be a question of aesthetic judgment, but rather one of situation.

For the interface designer, ambient media poses a number of challenges, since traditional principles and best practices of user interface design cannot be applied, especially in urban public space. Communicating the mapping of a data source to an ambient display is considered a key problem [6]: what can be solved through learning how to read the display on in a private environment, is hardly possible for a general public und urban space.

A common strategy to overcome this problem is to reduce the amount of displayed information, down to a binary value that helps with a specific decision, such as whether to take the umbrella, when rain is to be expected [7]. This works well for alerting purposes, but already with a simple range of two colors can make the mapping incomprehensible. The D-Tower, signals the emotional state of a city through the colors red and blue [8]. What exactly does the color red stand for – is it happiness or rage? It is important to point out that this is not a problem of arbitrary mapping, since signs and language are arbitrary by nature. It is the lack of a common convention. The mappings of ambient displays have to be learned, but again, what works in a personal application might not work in public space.

### Design strategies

In this paper I will discuss contextual or situational strategies for the integration of interfaces into the urban ambience. They address the question how to stage ambient displays effectively in the public sphere in a specific social setting. Some of them are well established, while some seem counterintuitive and exploit phenomena that a designer usually tries to avoid. The presented principles cover different aspects of the relationship between observer, representation and environment.

### A. Animism

Animism is the idea that all things and objects are inhabited by a living spirit. The concept can be found for example in the visual language of animated cartoons - we are familiar with the notion of signs and inanimate objects suddenly coming to life. Accordingly, one of the earliest examples from animation history, dating back to 1906, features a cartoon figure interacting with the cartoonist while being drawn [9] - a topic that never has disappeared ever since. In this case, invisibility is understood as the existence of a latent reality, surfacing only under certain conditions.

There are a number of ambient interfaces that rely on the aesthetics of cartoons, such as the *nabaztag* [10]. Another example is the *thankstail* [11], a robotic dog tail for cars enabling drivers to communicate through non-verbal signals. Another popular animistic notion is the independent life of shadows, as illustrated by *Ombra* [12], a public installation that subtly animates the shadows of a bronze statue.

Beyond these figurative applications, the concept can also be found more abstract forms of expression. In fact, everything that is considered static and inanimate will produce the effect when animated in a proper way. For example, the project *Atemraum* [13] presents a wall with the ability to breathe according to a person's respiration. The effect is achieved by inflating a rubber surface covering the wall. On a larger scale, the public art project *txtual healing* [14] gives houses a "voice" by projecting speech bubbles with text messages from mobile phones pointing to open windows and doors.

In terms of ambient media the moment of transformation from a static object to an animate one is of special interest. It has been stressed that a calm technology should easily migrate from periphery of attention to its center and back again [15]. This strategy is a way to initiate this shift of focus through a language that most people are familiar with. Animism can make the transition surprising and humorous, yet at the same time plausible.

**Figure 1 Freddie Yauner, *signs of life* – an apparently ordinary sign coming to life.**

**Figure 2 *Atemraum*, making the walls breathe**

### B. Invisibility through Mimicry

The natural environment has been mentioned as a perfect example of an ambient display [6]. It conveys a plentitude of information that we have learned to read and understand. At the same time we also have learned to ignore most of what we encounter through habituation, we become blind to many things we see repeatedly in the course of our daily routine. This section investigates the possibilities of invisibility in the sense of this inattentional blindness. In the animal kingdom, mimicry is the strategy of a species to imitate the appearance of another, usually more powerful or dangerous species. In analogy, an ambient interface might be disguised as a familiar object that we tend to ignore, and therefore will slip the attention of the habituated mind.

Naturally, this works well as a subversive strategy for implanting alien objects into public space. One example is Leo Bonnani's design of an ordinary bus schedule, fixed on an existing pole in front of the main entrance on MIT campus. On closer inspection, however, the bus schedule turned out to be a historical chart of suicides that have occurred on MIT in the recent years [16].

On a more general level Mimikry creates what Bill Gaver calls *ambiguity of context* [17]: something may be understood in different contexts, each offering a different meaning. Gaver mentions Duchamp's iconic *fountain* sculpture as an example, a ready-made consisting of a urinal turned on its side. The thus ready-made generates an additional layer of meaning to ordinary objects. This double meaning is what differentiates Mimikry from existing examples of ambient displays, for example in the shape of furniture or picture frames. They may adopt the shape, but remain in the same context of interpretation as the referenced object.


**Figure 3 Bonanni's display disguised as a bus schedule.**

### C. Blending the Object and its Representation

When we talk about ambient visualization in the urban context, the map sometimes becomes the territory - the boundary between the visualization and the object it represents becomes blurry, with both occupying the same space and often having a similar scale. As a consequence, it can become unclear whether something is part of the representation or the visualized concept. The outdoor environment is a natural information display itself for those who know how to read it. Yet, at the same time it is also the subject of representation.

This ambiguity can be illustrated with a project for public focusing on the display of environmental information. The public installation *garden of eden* [18] uses salad plants placed under glass boxes where they are exposed to polluted air that has been generated according to environmental data from different cities in the world. The effect of the polluted air on the plants is the only form of visible representation. In this example, the distinction between the visualization and the visualized concept is blurred, since the plant can equally be considered as part of the environment and exhibits the actual effect - the impact of polluted air on the urban environment. The urban-scale project *Nuage vert* [19] offers an even tighter connection between representation and its subject. The project augments the emissions coming from the chimney of a power plant – whose size is connected with the energy consumption of the local neighborhood – with the actual data of this local consumption, being projected onto the cloud itself.

This overlap is unusual in traditional forms of information visualization, where data and representation are separate entities. In these forms of visualization, iconic and symbolic types of representation prevail: the content is expressed either through resemblance or abstract mapping. In contrast, the two projects described above are part of a new class of visualizations that have an indexical character, putting emphasis on the actual phenomenon. In interface design, ambiguity is usually considered something to avoid. In these examples, on the contrary, this ambiguity is employed to increase the understandability of ambient displays by integrating elements of common knowledge. Furthermore, the strategy can be also a way to increase the credibility of the presented information, since the effects can directly be observed. Finally, by incorporating natural phenomena, it adds richness to the representation.

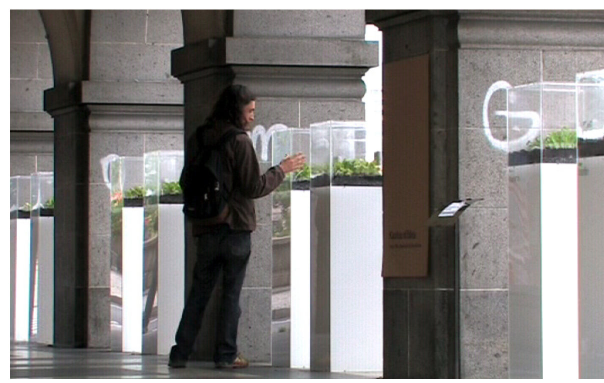

**Figure 4 Timm Wilks et al., *garden of eden***

### D. Embracing unstable Display Media

For traditional displays, the display medium has to be as generic and controllable as possible. Every influence from its local environment has to be minimized; the display should always appear in the same way in every light condition. Designers of outdoor LED displays are making big efforts in order to neutralize the influence of ambient light. In spite of these efforts, the outdoor environment is a different case and independence from context is not always possible to achieve. Consequently, architects have learned to incorporate successfully the impact of different environmental conditions on the appearance of a building into its design. What is a generally accepted as a site-specific quality of architectural design, could also make sense for urban interfaces – to embrace the influence of environmental conditions on the appearance and characteristic of the display.

An example from contemporary art history is Hans Haacke's *condensation cube*, using humidity as its primary medium. The piece is a minimalist sculpture in the shape of a sealed off glass-cube containing a small quantity of water, which causes a layer of condensation covering the walls. Through the continuous cycle of condensation and evaporation, the artwork's appearance changes constantly influenced by environmental variables like temperature or light. Inspired by this artwork, we developed the ambient display *dewy* [20], that displays pixilated pattern of condensation, facilitated by a matrix of peltier elements and a fan for erasing the patterns. While the display allows high-level control over the emerging patterns, the actual appearance of the condensation patterns depends a lot on external humidity, temperature and light direction.

There are numerous other examples and possibilities - especially plants are an interesting choice for a display medium: they interact with their environment on a number of levels, yet exhibit persistent features such as petal color. Examples of ambient displays include projects that exploit a plants' phototrophic behavior or the possibility to tint the petals by watering white flowers with colored water.

Ephemeral materials as display media are without doubt harder to control, and therefore offer less bandwidth for displayed information. Additionally, the display will never represent the data in a pure form, but blended with environmental influences. If these influences are taken into account and are conceptually compatible with the purpose of the representation, this approach might contribute an additional dimension to the display.

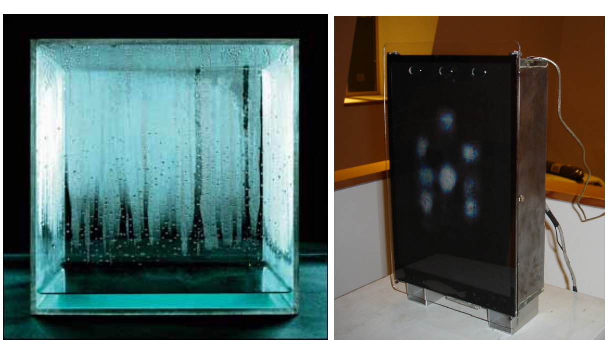

**Figure 5 Left: Hans Haacke's *Condensation Cube*; Right: Parkes / Offenhuber - *Dewy***

### E. Designing with Physical Wear

Physical wear is usually considered a mechanical problem that has to be minimized. Despite this prevailing negative connotation, physical wear offers a lot of interesting features as well, since it is a reliable record of an object's interaction history. The location of ditches in old marble staircase tells us about how people have stepped on it, the shiny parts on the patinated surface of a copper door-handle reveals how people prefer to operate it. In that sense, physical wear is an ambient information display – we include it into our perception of the value and age of an object. Wear and patina are major elements of what Walther Benjamin called the "aura" of an object [21], the totality of an objects subtle features that can never be completely described.

The emulated form of physical wear, *computational wear* as a metaphor for a documents interaction history was introduced back in 1992 in the "edit wear / read wear" paper [22]. It presents a text processor, displaying graphical wear patterns that indicate the amount of previous reading / editing of different parts of a document. The authors differentiate between active and passive wear. The latter is resulting from passive consumption or aging, while the former is a consequence of active editing or commenting. In a similar way, the *history tablecloth* [23] incorporates this concept of computational wear by recording the placement of objects on its surface.

Beyond the metaphorical treatment, there are also examples that treat wear in the literal, physical way. In one of our own projects[1], dust is used as a medium for recording interaction history. The project is a sound installation for a room with dusty floor, on which a number of phonographs are placed, playing back silent vinyl records. The visitors' movements stir up the dust, which subsequently accumulates on the records and generates a soundscape of noise. In the some examples the interaction irreversibly consumes the display or the interface, for example in the "email erosion" project [24].

**Figure 6 physical and computational wear (right: Gaver, history tablecloth)**

Comparing the metaphorical versus the physical treatment of the concept, the latter seems to be especially interesting for urban interfaces. In the unprotected outdoor environment, physical wear is a permanent issue and maintenance is a necessity. Incorporating physical wear into the design by carefully choosing materials instead of emulating it computationally could be a way to provide a subtle hints about an objects history. By taking advantage of the viewer's ability to assess material qualities, it offers additional cues about extent and age of previous interactions.

### F. Deliberate Exclusion of the User

In this case, invisibility is understood in the sense of opacity, by making it deliberately hard to understand what is presented. This seems at first paradox and nonsensical,

[1] "From Dust till Dawn" presented at ars electronica 2006

and in fact few examples of public interfaces come to mind. However, curiosity is a powerful motor, and with the right cues, this strategy can be a way to encourage the user to learn the conventions of an interface.

Observing the modes of visual communication in public space, the play between inclusion and exclusion of users is quite common. Fashion signals work on many levels – a part is universally understood, other parts of their meaning only by members of a certain group. Street art and graffiti are another example, where new codes are invented continuously as part of a somewhat exclusive, self-referential system. The spatial paintings of Felice Varini illustrate how public space can be engaged through a codified visual language that might not be immediately understood. Built upon the renaissance technique of anamorphosis, the visual elements of his spatial paintings are distributed in space according to projective geometry. From one single viewpoint, they form a coherent picture.

The strategy to obfuscate information is found also in real-world interfaces of alternate reality games. Invisibility plays a central role in the applied *this is not a game* aesthetic, mainly achieved through deep integration of game elements and puzzles into the urban context. Again, the goal is to awaken the curiosity of participants by withholding information.

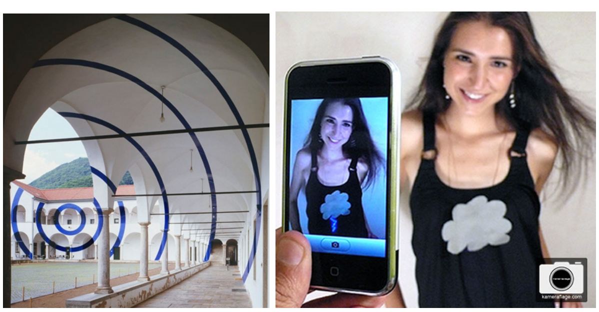

**Figure 7 left: F. Varini, *archi e corone*, 2004; right: Connor Dickie, *Kameraflage*, 2007**

Two examples for this strategy take invisibility in the very literal sense. *Kameraflage* employs near-infrared display elements that are not visible to the eye, but to digital camera devices. Similar and perhaps even more puzzling for the unsuspecting viewer is the *Image Fulgurator* - a device for injecting hidden content into other people's photographs in the moment when they are taken. The flash from a nearby camera activates the device, which then projects arbitrary content into the scene, just long enough to show up in the picture but go unnoticed by the photographer.

How should this strategy be used beyond the artistic application, given the introductory critique of arbitrary data mappings? The first challenge is to make the viewer recognize that some information is displayed at all [25], therefore the presence of encoded information has to be clearly communicated. In many cases, this might be more feasible compared to the heroic task of finding a mode of expression that is universally understood. Finally, without the burden of general accessibility, this approach might offer more value for the knowing user.

### Discussion

The strategies described in the six sections above illustrate ways for blending an interface into the ambience by establishing a relationship with the context of the interface. The presented principles focus especially on the transition process between background and foreground of attention. Depending on the direction of this transition, the described approaches fall into two groups:

The first group covers the transition into the background: it includes mimicry, embracing unstable display media and incorporating physical wear. They help to tighten the coupling between foreground and background. Mimicry accomplishes this by playing on tendency to blend out familiar elements, both unstable media and physical wear by increasing the influence of environment and users on the interface. The other group focuses on the opposite direction, the emergence from the background. It includes animism, ambiguity of object and representation and, to some extent, the deliberate exclusion of the user. These strategies increase awareness within a specific context. Animism helps by bringing supposedly static objects to life, ambiguity by putting emphasis on to an existing phenomenon that might be overlooked, and exclusion by creating a moment of irritation. This categorization shows general tendencies, however, many principles work in both directions, for example the strategy of exclusion.

### Conclusion

The presented strategies emphasize the importance of situation. They are an invitation to designers of ambient interfaces to reach beyond the current best practices of interface design and usability engineering and explore strategies that seem counterintuitive, and draw inspiration from art and architectural practice. They add a subversive, irritating aspect that might help us to see our environment with different eyes.

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# Ambient Displays in Academic Settings: Avoiding their Underutilization

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**ABSTRACT**

This work reports the findings of a case study examining the use of ambient information displays in an indoor academic setting. Using a questionnaire-based survey, we collect experiences and expectations of the viewers who are based on different floors of the same building. Based on the survey feedback, we offer some design principles to avoid the underutilization of large displays and make the most of their potential in indoor environments.

**Keywords**

Ambient displays, indoor settings, community awareness, aesthetics, design principles

**INTRODUCTION**

Ambient information displays have emerged as an effective way of disseminating information in an unobtrusive and low effort manner. They have found their use in indoor (e.g. classrooms, workplaces [2,4,5]) as well as outdoor settings (e.g. shopping malls, city squares, airports, train stations [3]). In spite of their deployment and evaluation in various settings, a sound understanding of factors that may cause under-utilization of their potential remains lacking. Huang et al. [3] undertook a comprehensive case study of the use of ambient displays in public settings. However, there is no counterpart of this study for ambient displays in indoor academic environments.

This work investigates the current use of ambient displays in the Complex & Adaptive Systems Laboratory (CASL) [1] at University College Dublin (UCD), Ireland. At present, there are five large displays installed in the CASL, each of them showing, among others, the profiles of staff members, research images, and news feed in a repeated loop. We report on the results of a questionnaire-based survey that was conducted among 59 members who are based on different floors of the CASL building and work in various capacities. We explain the survey methodology, experiences and expectations of the viewers we collected from the survey. Based on the survey findings, we present some design guidelines that may help the designers tackle the factors responsible for under-utilization of ambient displays in an indoor setting.

**AMBIENT DISPLAYS IN CASL**

The Complex and Adaptive Systems Laboratory (CASL) is a collaborative research laboratory at University College Dublin, Ireland. It is situated in a five-story building and hosts members of various disciplines in differing capacities. These include academic staff, post-doctoral researchers, post-grad students as well as human resource staff. In addition, there are also undergraduate students based here for 3-months long internship during the summer.

CASL draws researchers and students from various disciplines including business, computer science, electrical engineering, mechanical engineering, geological sciences, and mathematics. Cross-disciplinary research is the focus of CASL's mission and large displays have been placed in CASL with the prime purpose of advertising research activities.


**Fig. 1. Ambient Display in CASL**

CASL has five large displays, LCD screens of size 32" as shown in Fig. 1, one on each floor. Each display shows the university research management system web-pages of academic and research staff in a repeated loop. The research images in the top and bottom right corners of the display are also repeatedly changed in a loop. The header contains the logos of UCD and CASL. There is a clock shown in the top right corner and a news ticker at the bottom of the display. Fig 2. shows a schematic illustration of the design and layout of the display.

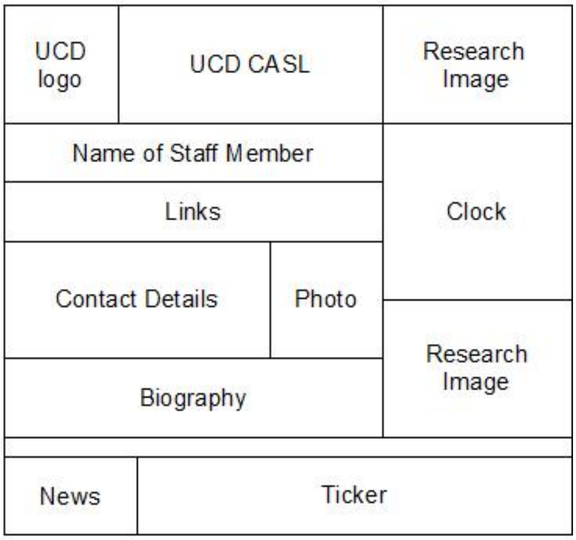


**Fig. 2. Design and Layout of Ambient Display in CASL**

## SURVEY METHODOLOGY

We conducted a questionnaire-based survey to explore the manner in which CASL members are currently using the displays in the building. The survey involved 59 participants in the age group of 17-50 who were based on different floors of the building. Among the participants, 28 were post-grad students, 3 academics, 11 post-doctoral fellows, 8 undergrad students and 9 administration staff. Before filling the questionnaire, each participant was given an overview on the purpose of survey. The participants were first asked to draw the design and layout of the display from memory without looking at it akin to the diagram show in Fig. 2. The next section of questionnaire was aimed at collecting their current experiences with the displays followed by their expectations and suggestions for improving these experiences. After completing the questionnaire, the first author held a 5-10 minutes long discussion with each participant to get a better understanding of their views. On average, the first author spent 20-25 minutes with each participant. The survey lasted for seven days and all participants were given a candy as a gratuity.

It needs to be mentioned there is a trade-off when asking participants to remember things from memory, as opposed to observing them in context. Huang et al. [3] adopted the latter approach in their case study. In the former approach, the possibility of recall bias on the part of participants cannot be ruled out. At least two participants failed to draw some contents from the memory but after looking at the questions in the next section of the questionnaire, they immediately determined the contents on the display. However, using this approach, we are able to collect quantitative data about what and where people look at displays.

## SURVEY FINDINGS: EXPERIENCES

The following section describes the experiences of participants with displays.

### Drawing the Design & Layout of Display

Most participants were able to recall the photos and profile details of staff members on the display. In contrast to that, less than half could recall news feeds, research images, UCD and CASL logos, and the clock. The results of this exercise are shown in Table 1.

**Table 1: Participants who recalled the contents on the display from memory**

| Contents on display | Participants who recalled |
|---|---|
| Staff member Photo | 50 (85%) |
| Profile details | 49 (83%) |
| News feed | 28 (47%) |
| Peripheral research image | 23 (39%) |
| CASL logo | 20 (34%) |
| Clock | 20 (34%) |
| UCD logo | 14 (24%) |
| Top research image | 7 (12%) |

Surprisingly perhaps we did not encounter any correlation between the ability of participants to recall the contents of the display and the time duration for which they had been based in CASL. Moreover, while they were able to recall the profiles of staff members, very few participants were able to identify all the profile details (e.g. contact info, bio, links) on the displays. This concurs with the observation made by Huang et al. [3] that people pay very brief attention to the large displays and are rarely likely to stop and go through the whole content in detail.

### Most useful contents on the displays

Among the contents currently being shown on displays, most participants regarded the profiles of academic and research staff to be the most useful information, followed by time and news feed. However, there was one participant who considered time to be the most useful content on the display near the reception desk while profiles of staff members on the display in the canteen.

Table 2 shows the results of what participants regarded to be the most useful contents on the display.

**Table 2: Participants who considered the contents on display to be most useful**

| Contents | Participants who considered it most |
|---|---|

| | useful |
|---|---|
| Profiles | 22 (37%) |
| Time and date | 9 (15%) |
| News feed | 8 (13.5%) |
| Time + profiles | 6 (10%) |
| Profiles + news | 3 (5%) |
| Time+ profiles + news | 3 (5%) |
| Time + news | 3 (5%) |
| Nothing | 2 (3.3%) |
| News + research images | 1 (1.7%) |
| Time+ profiles + news + research images | 1 (1.7%) |
| Time at reception + profiles at canteen | 1 (1.7%) |

**Places where they looked at the displays**

We determined that participants were most likely to glance at the display in the canteen on the 4$^{th}$ floor, as shown in Table 3. The canteen is where most members of the CASL gather during their lunch break every weekday. Moreover, there is a weekly tea party there at 4pm every Thursday. In addition to that, other social events such as birthday, farewell, and graduation parties are also held there.

**Table 3: Participants who are most likely to look at on display on different spots in CASL**

| Spots | Participants who look at displays |
|---|---|
| Canteen | 32 (54%) |
| Canteen + Reception | 8 (13.6%) |
| Floor where cubicle is | 7 (12%) |
| Canteen + Floor where cubicle is | 6 (10%) |
| Reception | 4 (7%) |
| Photocopier (1st floor) | 1 (1.7%) |
| Canteen + Reception + floor where cubicle is | 1 (1.7%) |

**Perceived Purpose of displays**

As part of a qualitative evaluation of the displays, we asked the participants what purpose, in their perception, these displays served in the CASL. From their responses, we determined the purposes of displays in CASL as follows:

*Visual appeal*

Most participants were of the opinion the displays served an aesthetic purpose and made the environment visually appealing. Some were of the opinion that the presence of displays gives the impression of working in a "technological environment".

*Community awareness*

The displays enabled the viewers to get to know staff members of the CASL. They were able to associate names with faces of members in an effortless manner i.e. without browsing the CASL or UCD website and visiting the web page of individual members.

*Motivation*

The displays show the research system web pages of academic and research staff members in a repeated loop. Undergraduate students who arrived few weeks before on summer internship found it quite motivating and inspirational. Here is how an undergrad internee remarked:

*"I realized that it takes hard work and dedication to be on these displays."*

Most participants were of the opinion the displays provided a good "sight-seeing opportunity" but their potential was not being fully utilized. At present, they act as nothing more than a research poster and wall-clock. There were complaints from participants that the news ticker was hard to read and was also not updated regularly.

Table 4 summarizes the experiences of CASL members with the displays in CASL.

**Table 4: Summary of user experiences with displays in CASL**

| Issues | Findings |
|---|---|
| Memorable contents | • Photos of staff members (85%)<br>• Profile of staff member (83%) |
| Useful contents | Profiles (37%) |
| Most likely place to loot at the displays | Canteen (54%) |
| Purpose of displays | • Visual appeal<br>• Community awareness<br>• Motivation |

## SURVEY FINDINGS: EXPECTATIONS

The final part of the questionnaire consisted of open-ended questions designed to provoke the participants to divulge what changes they expected to be brought about with the displays in the CASL. These included the questions about the type of information to be shown on displays, positioning of displays in the CASL, and changes in interaction mode with displays. The results of this section of questionnaire are explained below.

### Content of displays

Participants in general were of the view that instead of profiles of staff members, news and events should be given more prominence on the display. They pointed out that the web-pages being were not tailored to public display. For example, it makes no sense to show the "Links" section of a web-page on a non-interactive public display.

Currently, news appear as a ticker at the bottom of the display. Many participants wanted this section of display to be made more prominent. Moreover, to their dismay, news displayed on display was quite static and not updated regularly.

Below are comments of some participants:

*"There is a lack of information on displays, plus unsuitable display -- web page has not been altered for public display".*

*"The display in the canteen can be used for entertainment and that in reception to welcome guests."*

*"Along with news about upcoming conferences and seminars, it would also be better to display auxiliary information such as weather forecast, intermittent traffic."*

### Change in Position of displays

Participants wanted displays to be placed in the areas of building where most people linger. Some comments from participants are given below:

*"2nd floor display should be outside the lift or besides the stairs. Most people currently do not pass or see the screen in its current location".*

*"It would be better in view of my desk or in places where people linger".*

*"Place them in more public areas e.g. seating areas."*

*"It would be better to have one in the elevator."*

*"Bring them all down to eye-level or for canteen, seated eye level."*

### Making the displays interactive

Most participants were apathetic to the possible option of making displays interactive and allowing participants to upload content of their choice. However, a few of them found the idea exciting. Although, they still preferred a moderated control over the user-uploaded content lest it undermine the professional look and feel of displays.

### Presence/leave information

As a way of enhancing collaboration, we proposed to the participants the option of displaying their presence/leave information. Most participants expressed strong opposition to the idea of displaying their presence/leave information on displays. They considered such information to be quite private and not something to be shared with other than their immediate colleagues. This proposal of displaying presence/leave information was inspired by applications such as In/Out Board [5] and Active Portrait [2]. However, in the case of aforementioned applications, the information was accessible to only the close colleagues rather than people from other research groups, not to mention non-academic staff e.g. human resource staff, as in the case of displays in the CASL.

Table 5 summarizes the expectations of CASL members with displays in CASL.

**Table 5: Summary of user expectations with displays in CASL**

| Issues | Findings |
|---|---|
| Content of displays | • Focused on events, rather than personal information<br>• Web pages to be tailored for public display |
| Positioning of displays | • Places where people linger<br>• Bring them to eye level |
| Making displays interactive | Moderated control on user uploaded content |
| Presence/leave information | Breach of privacy. Only immediate colleagues should get to know about that information. |

## UTILIZE THE POTENTIAL TO FULLEST: DESIGN GUIDELINES

Based on the collected experiences and expectations of participants about displays in the CASL, we offer some design guidelines to utilize the full potential of ambient displays in academic setting.

### Content type: "Core" and "Auxiliary" Contents

"Core contents" on ambient displays in academic setting should be focused on relevant event and news, rather than profiles of academic staff. It is more inspirational for the fellow colleagues to see events such as recent awards, patents and publications of members being shown on ambient displays.

*People seem more interested in looking at dynamic and up-to-date content rather than static ones*.

In addition to "core" contents, to further evoke the interest of viewers, some auxiliary contents may be added such as latest news about weather forecast, and intermittent traffic.

### Contextualization of Content

Ambient displays should display information relevant to the different audience in different settings. In our case, most participants were of the view that the content on the display near reception desk should be more general and appealing to visitors. One administration staff member who joined CASL a few weeks ago was puzzled to see that the content on the display near the reception desk did not give new-comers any idea about the vision and activities of the CASL.

### Positioning of Displays

Ambient displays should be placed considering the movement flow of people in the building. Before conducting the survey, we assumed that almost every member of CASL looked at the display near the reception desk. However, we found out that many people used the car park and entered the building using elevator from the underground basement to reach their floor, thus bypassing the reception desk on the ground floor.

Most people viewed the display in the canteen followed by the reception desk, and quite a few of them looked at them at the floor where their cubicles were. That indicates that 3 out of 5 displays in the building were hardly if ever being viewed by the occupants. Moreover, a place which was used by all members of CASL had no display i.e. the elevator.

Here is a comment from a participant:

*"I view them only when I'm using the photocopier on the 1st floor. Better put them over printers, water-coolers, and in elevators… anywhere people are waiting."*

Therefore, it is important to identify the *movement flow* of people and *congestion spots* within the building before positioning ambient displays.

### Privacy concerns

Information displayed should not infringe upon the privacy of members. Considering the strong opposition to the public display of presence/leave information we encountered in the survey, designers of ambient display systems must be sensitive to privacy concerns of viewers. This issue becomes critical when, unlike the cases [2, 5], many viewers do not happen to be their immediate colleagues.

Table 6 gives a summary of design guidelines for ambient displays in the CASL.

**Table 6: Summary of design guidelines for ambient displays in CASL**

| Issues | Guidelines |
|---|---|
| Content type | • Dynamic and up-to-date content<br>• Content be made event-centric rather than profile-centric |
| Contextualization of content | Different contents for visitors and members |
| Positioning of displays | • Identification of flow of movement<br>• Identification of congestion spots |
| Privacy concerns | Comprehension of privacy concerns in case information is viewed by the people other than immediate colleagues |

## CONCLUSIONS AND FUTURE WORKS

In this paper, we reported on the findings of a questionnaire-based survey of the current use of ambient displays in an indoor environment of a research lab. We collected the experiences and expectations of the viewers, along with highlighting the limitations of our survey methodology. Based on survey findings, we formulated some design principles to minimize the underutilization of ambient displays in indoor settings. We plan to implement the proposed changes in the design, layout and positioning of the displays in CASL and collect the subsequent feedback from the users.

## ACKNOWLEDGMENTS

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# A notification system for a landmine detector using distributed cognition

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**ABSTRACT**

This paper presents a design for a visual display to be added to mine detection equipment. It is an application of the tenets of calm computing to a safety-critical system by putting cognition outside the mind, aligning inputs within the centre of attention and along the periphery, and juxtaposing stimuli in close proximity to the source of the information, all with the aim of increasing safety.
The first iteration occurred in the redesign of a landmine detector is described, starting from a literature review of the related practices, concept design, mock-up production and, finally, heuristic evaluation and the brainstorming undertaken with experts in the field.

**Keywords**

Notification Systems, Calm Technologies, Landmines Detection, Distributed Cognition, Critical Activity Monitor, Humanitarian demining.

**INTRODUCTION**

This work is based on a study of the practice of landmine detection with the use of electromagnetic signals based detection technology [1]. The correct procedures for the identification, investigation and declaration of a buried object with a metal detector have been embodied in the device with the aim of distributing cognitive processing between the operator, the tools and the perceived and acted world. The basic idea was to face the issue of the cognitive load of the operator providing the landmine detector with a notification system display [2], [3] that could allow a presentation of the data in visual form, thus being isomorphic with respect to the target - the buried landmine - and at the same time to the surrounding environment - the soil, the topographical and geographical setting. The spatial proximity between the display and the most important contextual elements that the operator must consider were also design issues **[4].**

A prototype and a scenario in a video format were built and presented to three experts in the field of humanitarian demining. We requested them not only to evaluate the concepts but also to make proposals and offer design ideas in order to push the project forward.

**THE PRACTICE OF LANDMINE DETECTION**

A mine is a device designed to kill or injure anyone who comes into contact with it in general through direct pressure. There are many different types of mine, all essentially consisting of a container containing explosive and a fuse. The main characteristics of landmines are their simple, no-maintenance and economic technology, combined with their persistent threat throughout the years. There are smaller mines aimed at people (AP) or larger ones aimed at vehicles (AT). The production of metallic landmines has been progressively replaced by that of plastic landmines, which are harder to detect [7].
At present, the most widely-employed way of scanning a territory is by using metal detectors. Basically, these portable technologies are composed of a search head, a connecting rod, a handle and an audio signal transmission system.

We isolated the basic steps of the practice of landmine detection from the work of James Staszewski, which analysed the best practices of a number of expert users [1]. These steps are: (1) to sweep the surface suspected of hiding landmines (search); (2) on receiving a signal, to try to repeat it in order to obtain confirmation; (3) to investigate its shape by matching the auditory information with the images of known landmines (investigation); and (4) finally, to declare the suspected type of mine (decision).

The initial phase consists of searching for buried mines, while “sweeping” the ground surface and lightly moving the detector over an area of 1.5 metres (the “lane”) with a cross-lane trajectory; if there is no signal, the operator moves on 15 cm, repeating the procedure, and so on.

When a signal is perceived, the operator tries to reproduce it by moving the tool over the critical area; if the sound is repeated, the investigation phase begins. The operator must elicit the shape of the object on the basis of the sounds emitted by the detector.

The possible actions for investigating an auditory signal in order to elicit the corresponding shape (and classify it) depend on the halo produced by the buried object. The halo is precisely the visual pattern imagined by the operator on the basis of the sound emitted or not, as the landmine detector is moved over the critical area; the halo of a landmine is normally circular, and its dimensions can vary widely based on the amount of metal that composes the mine and its dimensions. Other innocuous objects that can produce a signal may have different, non-circular halos that are difficult to distinguish from a mine. These tend to cause false alarms, which slow down the demining process and tire the operators.

From the description of the landmines inspection practice, it is possible to focus on three coexisting elements producing cognitive load: the first is environmental information interpretation; the second is the rehearsal and situated application of the inspection procedures (with all the geographical, temporal, sensory and motor related components); and the third is the interpretation of the data coming from the device. As for metal detectors, the absence of isomorphism between the signal and what is signaled in the investigation phase can be considered as an added cause of cognitive load. Proof of this is found in the radiating movements that the operator executes over a halo in order to build up a mental image [1].

We considered these issues as design problems and imagined a display integrating auditory information and embodying the procedures of landmines inspection routines. The solutions proposed are: (1) creating isomorphism, homogeneity and consistency between the data from the different sources, allowing the operator to organise them. (2) juxtaposing the contextual information (geographical/physical/environmental); and (3) furnishing the user with information organised at the centre and at the periphery [5] in order to meet the cognitive principle of the dynamical partition between the foreground and background [6]. The results are a set of artefacts that allow the situated manipulation of visual data about the environment in a transparent way, and organize the user's attentive view [9].

A number of devices are provided for visualisation support, but they are mostly located separately from the body of the tool, thus violating the principle of juxtaposition and the spatial proximity of the data. Otherwise, when a display is mounted on the landmine detector (e.g. the ALIAS detection system [8]), it is located too close to the visual field, compromising the perception of the context which is crucial for the operator to achieve sensory-motor coordination and the analysis of the environmental factors.

**THE REDESIGN**

The main modification of the detection device is a circular display located over its main body with the aim of supporting the activity of the operator through instructions for sweeping and the visualisation of the halo (*fig.1*).

*Fig. 1 The circular display mounted over the main body of the landmine detector*

The basic idea is a system that takes a trace of the halo while the user moves the device, in order graphically to build it in progression while the user moves the detector; in this way, the auditory information will be grabbed and registered by the system in visual form.

As for the initial phase of the search (*fig. 2*), the arrows projected onto the screen will suggest to the user in which direction he/she should go. In this way, the user will not have to memorise the areas of the ground already scanned and those still to explore, but can simply follow the instructions of the system, that automatically calculate and display the trajectories.


*Fig. 2. The circular display prototype: the phase of sweeping the ground*

As for the investigation phase, when the operator has to decide the nature of the buried object individually, the system supports the detection of the halo by visualising it on the screen. *Figures 3* and *4* show the phases of inspection of a metallic and a plastic landmine respectively.

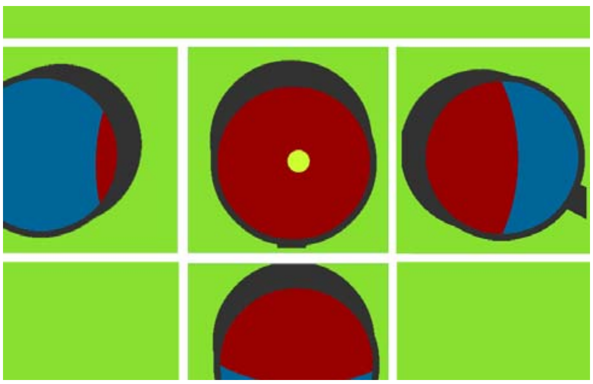

*Fig. 3. The circular display prototype: radiating inspection of a metallic landmine*

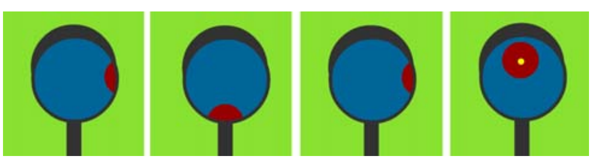

*Fig. 4. The circular display prototype: radiating inspection of a plastic landmine*

The benefits of the concept described lie in the tenets of distributed cognition. The working memory of the operator is partially relieved by switching between audio analysis, visual imagery, the recalling of the halos' classifications, sensory-motor and spatial cognition, the evaluation of the soil and the retention of the actions still to perform in order to complete the sub-procedures. Finally, the screen-based information would be sharable with the other components of the team, storable and thus available to others in different moments, to support the decision-making, training, and eventually, a second-time analysis.

After the concept design phase, video prototypes and a video scenario have been built in order to submit them to a group of experts in the field of humanitarian demining. They have been asked to perform a hybrid evaluation that would take into account not only the scenario produced, but also a review of an available solution for a dual sensor detector with a mounted display (ALIS) [8]. They have been solicited to express the opinions, ideas and visions raised by the exposition of these materials. A synthesis of their contributions is presented below:

*In the past, when addressing the operator interface with the metal detector, we tended to ask the designers/manufacturers only to provide the operator with an audible output when detecting a target. The idea was to prevent the operator from losing focus on the ground, which could contain hazardous objects that could be triggered physically by contact with the search head. Newer detectors have, over the past couple of years, among other indicators, successfully integrated an LED bar, giving the operator a visual reading of the strength of the signal. Visual displays as an added source of information, decreasing the amount of false alarms, and in general determining a reduction in the human factors affecting the whole process of detection. On the other hand, they tend to overhang the field of vision and thereby increase the risk of making mistakes. The system proposed in the scenario represents an overcoming of the existent problems in that the display mounted over the body of the device allows the operator to maintain an acceptable field of vision, and requires only a short training session. The use of a display represents, in general, a shift in the paradigms of the detection procedures, and there is the possibility that the next generation of deminers, being used for computer games equipped with display glasses, could improve the system proposed in the scenario.*

In sum, the experts' opinions were positive in that they acknowledged the improvement that visualisation can bring to the detection process, such as the importance of using a display mounted on a landmine detector in order to integrate the visual field unobtrusively. One of the experts envisioned a high tolerability of augmented environments in the near future, thanks to the diffusion of high technology computer games.

## DISCUSSION

We tried to work with both the paradigms of distributed cognition [10] and disappearing technologies [9], [5], [11] in different phases of the project. They revealed common themes derived from cultural-historical psychology, like the claim to amplify cognition by putting it outside the human brain [10],[11], or the intuition that an effective cognitive artefact tends to disappear from the attention of the user, as in the practice of writing.

The original contribution of the redesign described above lies in its attempt to locate the added source of information (the display) at the same level as the other elements of the visual field, with a spatial proximity to them, and with the same visual language. Moreover, the indexicality [2] of the information produced is pushed to a 1:1 scale, in order to furnish the user of a working landscape that tries to imitate a natural setting, and that allows the user to reason through manipulating information in a context-situated fashion.

The aim of employing a calm technology to the distributed cognition analysis of the operator's cognitive load is intended to allocate information in a dynamical and fluid partition between the periphery and the centre of attention. This is an organisational principle of perceptual stimuli (already recognised by Gestalt psychology [6]) that follows the human disposition to organise visual information as figures (central, in movement, affording action in a Gibsonian perspective) and background (peripheral, static, the Gibsonian visual invariants) that creates a mutable landscape produced by the attention of the perceiver [5], [12] . Hence, the proposed display, acting as a notification system [3], fades into the environment during routine sweeping and emerges at the centre of attention when a buried object is detected. So far, the design concept has exhibited a positive heuristic that allow us to proceed with the design process.

## CONCLUSIONS

This paper presents a design for a visual display to be added to mine detection equipment. It is an application of the tenets of calm computing to a safety-critical system by putting cognition outside the mind, aligning inputs within the centre of attention and along the periphery, and juxtaposing stimuli in close proximity to the source of the information, all of which are designed to increase safety.

The redesign of a landmines detection device started with an investigation of the activities in which it is involved. We analysed the procedures isolated from James Staszewsky for soil inspection with the metal detector PSS-12 in order to be taught to novices [1]. The attempt to embody these procedures into the system using well established psychological principles was the rationale that guided us in the redesign process. Then we asked three experts in the field of humanitarian demining equipment to provide hybrid evaluation/envisioning feedback which could the set requirements and constrain the following redesign iteration. Hitherto, we have individuated a spectrum composed of different elements in the analysed field: the sensory-motor activity and coordination, the landmine detector, working as a lens that disappears at the attention of the user, and the background environment. Ambient information systems can have, in this kind of configuration, a possible dimension, in which tools act as supports for creating relations and producing meaning from the heterogeneous stimuli available for the building of a perceptual experience.

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# Ubiquitous Sustainability: Citizen Science & Activism

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**ABSTRACT**

In this workshop we propose to explore new approaches to bring about real environmental change by looking at the success of empowering technologies that enable grassroots activism and bottom up community participation. Ubiquitous computing is transforming from being mostly about professional communication and social interaction to a sensor rich personal measurement platform that can empower individuals and groups to gain an awareness of their surroundings, engage in grassroots activism to promote environmental change, and enable a new social paradigm – *citizen science*. This workshop brings together fresh ideas and approaches to help elevate individuals to have a powerful voice in society, to act as citizen scientists, and collectively learn and lobby for change worldwide.

**Author Keywords**

sustainability; environmental monitoring; citizen science; sensor networks; slogs; climate change; urban informatics.

**ACM Classification Keywords**

H5.0. Information interfaces and presentation (e.g., HCI): General. K.4.2 Social Issues.

**PROPOSED URL OF SITE TO HOST PROGRAM**

http://www.urbaninformatics.net/green3/

**BACKGROUND**

As UbiComp researchers and practitioners we struggle to understand, test, and envision scenarios of our technological futures, but as humans we have a collective higher calling – an ethical responsibility to acknowledge, address, and improve our own health, the health of our environment, and promote more sustainable lifestyles. There exists both synergy and tension between the progress of UbiComp and environmental concerns. There is little doubt that technology is able to play a vital role in positive environmental transformations. As UbiComp practitioners in this evolving field of environmental awareness and sustainability, we find more questions than answers. What are the big challenges? Are there standard approaches we can share? What will really matter?

Environmental conservation and anthropogenic climate change are issues that can no longer be ignored by any government, industry or academic community. Compared to the rapid rate that technology has been developed and integrated into everyday life, applications of ubiquitous technology to improve the ecological situation have lagged behind. This workshop builds on the success of two prior important environmentally themed workshops: *Ubiquitous Sustainability: Technologies for Green Values* at UbiComp 2007 and *Pervasive Persuasive Technology and Environmental Sustainability* at Pervasive 2008. Our workshop shares the goals of these two previous workshops by bringing together a diverse range of practitioners from computer science, engineering, sociology, architecture, urban planning, design, art, and other related fields. It differs in its scoping to explicitly evoke concepts of activism and citizen science as a vocabulary for building techniques, tenets, and technologies to bare on the issues of

**TOPICS OF INTEREST**

Paulos [1] proposes *citizen science* as a way to enable a participatory urbanism: "We need to expand our perceptions of our mobile phone as simply a communication tool and celebrate them in their new role as personal measurement instruments capable of sensing our natural environment and empowering collective action through everyday grassroots citizen science across blocks, neighborhoods, cities, and nations." While sensor rich ubiquitous computing devices usher in a compelling series of new device usage models that place individuals in the position of influence and control over their urban life, there


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are a number of important barriers to the development and adoption of such systems. These research challenges form the topics of interest for this workshop and include:

**From Socialite to Citizen: Redefining Identity** – Ubiquitous devices such as mobile phones play a large part in helping the digital generation establish their sense of identity. We need only to look at marketing tactics to see how the mobile phone has become an iconic representative of 21st century lifestyle across geographical and cultural boundaries. How can the transformation of the mobile phone from a communications device to a 'personal instrument' that helps us measure and understand the world around us similarly encourage the user to embrace an active, environmentally conscious and responsible lifestyle?

**Feedback Loops** – What types of feedback loops provide information that allows users to see how their behavioral change is impacting on the environment?

**Privacy and Anonymity** – Users may desire to participate in public data collection but not at the expense of publicly disclosing their daily location traces and patterns. What mechanisms can ensure privacy and guarantee a level of anonymity for users and yet enable groups to make connections and foster open debates with their data?

**Calibration and DIY Culture** – Citizen science by definition explicitly enables the use of scientific data collection equipment by non-experts. The handling and usage of the sensors and measurement conditions will vary wildly – in and out of elevators, handbags, pockets, subway stations, etc. How can we reliably calibrate these sensors 'in the wild'? How can we create a common citizen science knowledge pool, lingo and nomenclature to identify, share and discuss measurement data?

**Sensor Selection** – What would be a reasonable set of sensors to use and what conditions make sense to measure? Where should the sensors be mounted and in what contexts and positions are they best sampled?

**Environmental Impact** – Finally, perhaps of greatest importance, while the vision is to provide millions of sensors to citizens to empower new collective action and inspire environmental awareness by sampling our world, the impact of the production, use, and discarding, of millions of ubiquitous sensors must be addressed. Does the overall benefit of citizen science enabled by these new devices offset their production, manufacturing, and environmental costs?

**Other Issues:** Authentication and trust, hardware extensibility, open platforms, software for sharing, and other technology that can support citizen science and grassroots activism such as wearables and carriables.

## SOUTH KOREA AND ENVIRONMENTAL ACTIVISM

South Korea has a long history of environmental activism and provides an ideal setting to explore a set of culturally specific environmental challenges and the efforts to solve them. For example, the *Citizen Movement for Environmental Justice* (CMEJ) founded by Seo Wang-jin in 1999, has since become one of Korea's fastest growing NGOs focusing on environmental justice and the fair distribution of national resources. Korean environmental civic groups are also involved in grassroots political activities. For example, the *Civil Action for the 2000 General Election* (CAGE) consisting of 423 civil organizations incl. a number of green groups successfully launched a 'blacklist' campaign in 2000. The blacklist campaign was established to single out politicians they felt were "not qualified to run" due to positions on environmental and social issues. Of 86 blacklisted candidates, more than 60% failed to win their election.

## WORKSHOP FORMAT AND ACTIVITIES

We want to actively engage and acknowledge the cultural history and landscape of Seoul in the workshop's interrogation, learning, and debate of UbiComp technology and strategies for environmental awareness, sustainability, and grassroots efforts. The workshop brings together passionate practitioners into a shared forum to debate important issues emerging in this rapidly evolving field. To that end the workshop format balances a small degree of individual presentations of work with a more involved series of collective brainstorming activities and design interventions. The workshop will serve as a 'safe place' to explore this design space away from the pressures of 'being right' and 'bad ideas' and leverage the location of Seoul as a palimpsest for active learning and exploration of this important topic. The overall outcome will be a series of new design sketches and approaches to guiding UbiComp research forward in harmony with the issues of the environment and sustainability.

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# Live Sustainability: A System for Persuading Users toward Environmental Sustainability

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## ABSTRACT
This paper presents an interdisciplinary study on social science and persuasive technology to build a novel human-centric sustainable system, Live Sustainability, which is aimed towards changing the harmful behavior of people on the environment. Three human factors are considered to motivate people to behave sustainably; these include: (1) awareness, (2) social networking, and (3) feedback with rewards. Live Sustainability is used to record a user's log with a sensing network through RFID embedded cell phones and to react in real-time according to the user's behavior. Additionally, a website with a ranking system and electronic pet for social influence is used to record the $CO_2$ emissions associated with consumption, transportation, and indoor activities. Preliminary studies have shown promising behavioral changes using Live Sustainability.

## Keywords
Persuasive technology, RFID, Sensing, Sustainable design

## 1. INTRODUCTION
Human behavior plays a key role in environmental sustainability. Technology, when used properly, can play an active role in persuading humans to adjust their habits in their daily lives to protect the environment. This paper is motivated by the aforementioned observation and aims to develop a human-centric persuasive system, Live Sustainability, which helps people, pursue environmentally sustainable habits.

In the following paper, we will demonstrate how a wireless sensor network in conjunction with mobile technology and embedded radio frequency identification (RFID) sensors are used to enable Live Sustainability to track $CO_2$ emissions at the individual level. Furthermore, Live Sustainability calculates the personal energy consumption in real-time, and reminds the user the instant they make an inappropriate decision. The Sustainable Index, collected from the sensor network, measures a user's degree of eco-awareness. The index is transferred to the web server and the mobile device instantaneously updates this information. Lastly, a website is also utilized for peer assessment.


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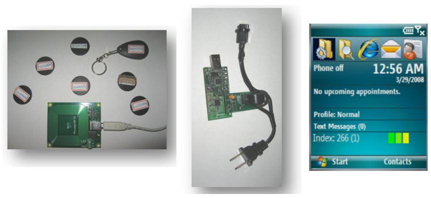
## 2. RELATED WORK
Systems associated with sustainability have raised much interest recently. For example, EcoIsland [[1]] is a system aimed at reducing $CO_2$ emissions by changing the lifestyle of a family. It provides a connected social network for a family and their neighbors. These families were more aware of environmental issues after using EcoIsland; with most of them reducing their $CO_2$ emissions. However, the lack of real-time monitoring in EcoIsland prevented just-in-time reminders and the resulting immediate behavioral changes. TerraPed [[2]] motivates users to change their behaviors that may harm the earth by reminding them of the wastes they produce. However, it only provides feedback on air quality while $CO_2$ emissions by individuals are not considered. The users may not get direct feedback.

The social network method has been used widely to motivate users to improve their habits. For example, Khan and Canny [[3]] applied social marketing to persuade users to engage in environmentally sustainable behavior. In their work, social influence plays an important role in the reduction of consumption. However, they only used comparisons between friends to persuade users. Virtual Polar Bear is another social network example [[4]]. By showing a polar bear on broken ice, it shows the user the direct connection of their behavior to the effects of global warming. However, the polar bear is only a photo and does not interact with the user.

# 3. HUMAN FACTORS

## 3.1 Awareness: Promoting an environmental conscience



**(a) (b) (c)**

**Figure 1. Sensors (a) RFID reader and tags (b) current sensor (c) screenshot of the cell phone**

Awareness of one's surroundings has a strong influence on one's lifestyle. Sustainable management leads to more eco-friendly decisions and thus a better world. In general, people are habitual in their daily lives. They choose the same road when they go to school or office in the morning; eat similar foods; buy similar groceries from the same stores; and instinctively turn on the TV at home. All these routines are due to human habitual behavior. However, these habits may, to different degrees, be harmful to the environment. To this end, the persuasive technology can be used to instill an environmental conscience in people. This is achieved through real-time reminders using RFID sensor networks and mobile technology. The system is installed into a cell phone with an embedded RFID tag (see Figure 1(a)) which is integrated into a current sensor network (see Figure 1(b)) and a web-based user interface. The platform of a system with Windows Mobile 6.0 Standard in a smart phone reveals the Sustainable Index with a color bar at the bottom of the screen (see Figure 1(c)) whilst the red color bar and phone vibration shows the $CO_2$ emissions rate. The number in quotation besides the Sustainable Index shows the increasing $CO_2$ emissions of users. These pre-emptive indicators are used to remind users to change their behavior.

## 3.2 Social Network: Magical Social Power of Cohesiveness in Groups

Social networks that exhibit group cohesiveness and peer assessment have been studied [[5]]. The cohesiveness of groups is an interesting issue. The obvious example is the social influence between teenagers. Their friends, in certain circumstances have a stronger influence on them than their parents. Online social network site now has been one of popular destinations on internet such as MySpace and Facebook in United States, Cyworld in Korea, and Mixi in Japan [6]. Most of users register online social network for friend relationship, data storage and sharing [7]. The Live Sustainability service utilizes these group mindsets to motivate people in correcting their bad habits to form a new lifestyle. When one person of influence changes his or her habits, the others imitate them. Consequently, a chain reaction of life style alteration occurs.

Another interesting topic is peer assessment. Using the same example, teenagers engage in self-gratification through comparison with each other. When one person performs better than the others and is rewarded, it is likely to spark competition within the group. In Live Sustainability, the eagerness to be at the top of the hit parade speeds up this social effect. Our web-based application associated with this system is developed with the aid of ASP.NET. The Sustainable Index and Bonus are received from the server.

## 3.3 Feedback: Emissions Trading Scheme

Proper feedback and rewards are important to motivate users to maintain a responsible attitude towards the environment. In Live Sustainability, the origin of the feedback comes from the Sustainable Bonus supplied from the $CO_2$ Bank. The concept of Sustainable Bonus is inspired by the well-known Kyoto protocol [8]. According to the protocol, the member countries have to reduce greenhouse gas emissions. The countries or companies that do not achieve their targets are required to buy emissions credits from other countries or companies. Sustainability thus becomes a measurable and tradable product.

A possible business model is described below. Governments who sell emissions credits can give a part of this revenue to the $CO_2$ Bank to operate the Sustainable Bonus system. This Bank then uses the Sustainable Index as its base unit for trading. This index is the inverse of $CO_2$ emissions. Furthermore, this system converts the Sustainable Index to the Sustainable Bonus as opportunity cost in that it is generated from the opportunity cost of the resources people save through behavioral changes. Thus, the Sustainable Bonus is directly proportion to the Sustainable Index. The Sustainable Bonus can be converted into real currency for purchasing commodities in the real world or into support of tree planting by a Non-Government Organization (NGO), such as Acción Ecológica [9], I Plant Trees [10], and Tree-planter.com [11]. In this way, a three-way win situation is built by the cooperation between the users of the Sustainable Bonus system, the CO2 Bank, and the government. People create a better world through changing their habits and saving resources. Moreover, these savings could be converted into tree planting that leads to a more sustainable future.

# 4. PROTOTYPING

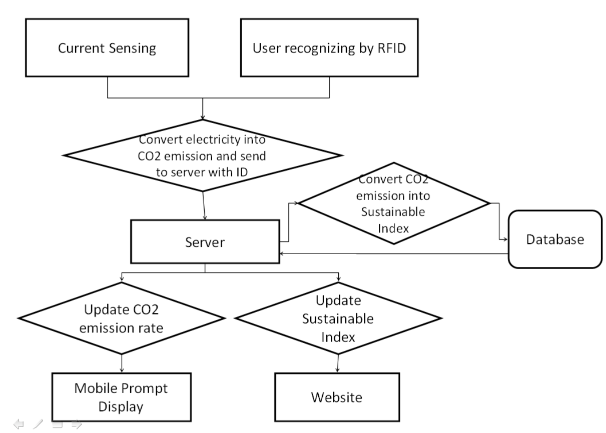
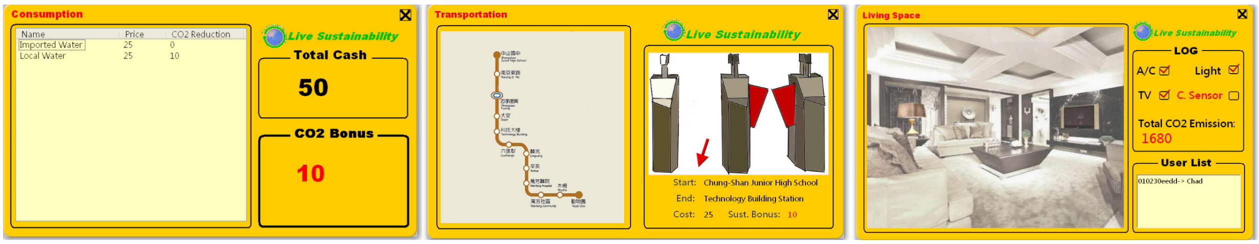



**Figure 2. System architecture**

The system architecture is shown in Figure 2. Current sensors measure real-time electricity usage, and RFIDs detect the user's ID. Electricity usage is converted into $CO_2$ emissions and then sent with the user's ID to server. The server converts these $CO_2$ emissions into the Sustainable Index and synchronizes simultaneously with the cell phone and website. Prototyping of Live Sustainability is performed. Three categories which lead to server $CO_2$ emissions are targeted. These are associated with




(a) (b) (c)

**Figure 3. Screenshot for simulation (a) Consumption (b) Transportation (c) Indoor activity.**

consumption, transportation, indoor activity, and Live Sustainability Website as described below.

## 4.1 Consumption

According to [12], consumption is the major emissions producing activity in peoples' daily lives. There are many kinds of products but they come from all over the world. For reducing $CO_2$ emissions, Live Sustainability encourages users to buy local products with the immediate reward in the form of Sustainable Index (see Figure 3(a)). Conversely, when the user buys imported products, they do not receive any rewards.

## 4.2 Transportation

Transportation is the second major activity of people. Live Sustainability tries to reduce $CO_2$ emissions by notifying the user (in the form of a message to their cell phone) of the environmental impact of their chosen transport, such as the higher $CO_2$ emissions of driving a car instead of taking public transportation (see Figure 3(b)). The user may then change their decision due to the increased awareness of the harmful nature of their activity to the environment.

## 4.3 Indoor Activities

The third major source of $CO_2$ emission is the range of activities that take place indoors. When the user enters into an indoor space, Live Sustainability calculates the $CO_2$ emissions associated with turning on electronic appliances such as air conditioning, a television, a computer, etc. When other users come in, all of the users share the $CO_2$ emissions (see Figure 3(c)). For this reason, the operation of Live Sustainability encourages users to utilize this space in a more sustainable manner.

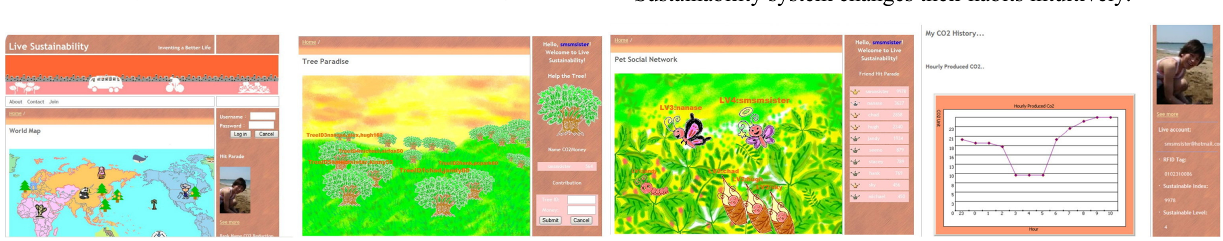
## 4.4 Live Sustainability Website

The *World Map* shows a global view of people's sustainable behavior on earth (see Figure 4(a)). The system uses tree ranks based on the Sustainable Index to indicate the level of sustainability in the region. A tree with more flowers represents more behavioral changes in a country. In *Social Network*, a top-10 rank of Sustainable Index with a personal photo is used for reinforcing a strong eco-awareness. Take MakeMeSustainable [13] for example, they provide users to achieve sustainable goal by tracking users' energy consumption and using blog to share sustainable strategies. In Our system, the users compete with their friends and feel satisfaction and pride in their rank. The members of the group are formed from the user's friends in MSN, AOL, Yahoo massager, etc. Electronic pets are used to encourage behavioral change. The electronic pet simulates the molt of a caterpillar to various kinds of butterflies (see Figure 4(b)). Moreover, the environment where the electronic pet lives changes with their grades. The higher the level of a user's Sustainable Index, the more luxurious an environment is generated. With this peer competition, the user will try to decrease $CO_2$ emissions in order to reach a higher ranking in a group. *Tree Paradise* provides a public call to encourage users to donate their Sustainable Bonus for tree planting (see Figure 4(c)). A tree map shows how many trees are contributed by a user in an area by donating their Sustainable Bonus. Each tree on the map appended with the donators' names for publicity encourages the feedback of other users. In addition, a sapling indicates an area which is closest to receiving a complete donation. It encourages users to donate their bonus immediately so that they feel that they are a key figure in the tree's birth.

Finally, the Personal Log helps users to visualize the history of CO2 emissions in their lives daily, weekly, and even yearly (see Figure 4(d)). Through the log, the users can identify the pattern of their CO2 emissions and the activities behind this pattern.

## 4.5 Experiment

We aim to build and demonstrate a working Live Sustainability system in Taipei at the end of 2007 to the middle of 2008. The proposed test site is the Smart Home, in OpenLab, NTU. In addition there are opportunities to engage some of the other field laboratories in the demonstration such as the Image and Vision Lab, Intelligent Robotics and Automation Lab. We propose to tie in access to some of these laboratories campus WiFi networks, as well as populating the area with our own test network and provide some of the graduate students with user devices that they can loan to the laboratories to test the system. In this way we intend from the beginning to test not only the technical proficiency, but the life and social context too. The feedback from the tested students is positive that the Live Sustainability system changes their habits intuitively.



(a) (b) (c) (d)

**Figure 4. Screenshot of web services (a) World trees map (b) Social network (c) Tree paradise (d) Personal log**

## 4.6 Scenario

### *Before Live Sustainability*

Bob is a graduate student. He goes to lab by car every day. Upon getting to the lab, he always turns on all the lights and the air conditioning. As many people do, due to high temperature in the lab, he usually turns the air conditioning to the coldest setting. At noon, Bob goes out for lunch with his friends, but he sometimes leaves the air conditioning on. At the end of the day, he goes back home and surfs the internet.

### *After Live Sustainability*

One day Bob finds many of his good friends using Live Sustainability so he immediately creates an account to keep in fashion.

Next morning, Bob prepares to drive his car to the lab as usual. When he is at the door, the phone vibrates. He finds out the Live Sustainability bar becomes red and the message shows, "High $CO_2$ emission action, please take public transportation". After reading the message, Bob decides to take the subway to go to school. By avoiding heavy road traffic, Bob even reaches school earlier than he would when driving.

After getting to the lab, Bob switches on the lights and the air conditioning as usual. His phone vibrates again. He realizes that the temperature he just set was too low, so he turns up the temperature.

At noon Bob goes for lunch. In the middle of lunch, his phone vibrates again; the message shows that the air conditioning is turned on without anyone being in the lab. He turns off the air conditioning remotely.

On the way home, Bob stops by a grocery store to buy cooking oil. In front of the oil section, there are many kinds of oils. He picks up two different oils: one is a local product and the other one is imported. He notices that there is a $CO_2$ reduction mark on the bottle of the local oil. He decides to buy the local one.

After dinner at home, he surfs on the internet as usual. He logs on to the Live Sustainability website. On the website, he finds many of his MSN friends on the top-10 rank. He selects the "Social Network" page and finds out that one of his friends, Mary, has an electronic pet that is still in the pupa level, whilst his own pet has already turned into a caterpillar. He shows this off to Mary. After that, he clicks on the Tree Paradise icon. He finds a tree that can be planted after his donation, so he donates his bonus for the tree to be planted. Right after his donation, his photo appears on the tree. He feels proud of himself.

## 5. CONCLUSIONS

A human-centric sustainable system is designed by considering awareness, social network and feedback. A persuasive system named Live Sustainability is developed. The system tracks the $CO_2$ emissions of people to generate a personal Sustainable Index. Pre-emptive reminders are issued to promote behavioral change to improve sustainability. A business model involving the government, the $CO_2$ bank and the users is proposed to realize the system in future.

## 6. BIOGRAPHY

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# Motivating Sustainable Behavior

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### ABSTRACT

Personal resource consumption is a major issue in sustainability. Consequently it has attracted a great deal of attention in the research community across domains including psychology, design and, more recently, HCI. Extending this body of work, this paper proposes the theoretical basis and general design of a system intended to enable users to understand the effect of their resource consumption practices and the direct influence that changes in their behavior patterns will have. The system has not yet been constructed. The design is motivated by the desire to enable users to experiment with, draw conclusions on and personally optimize their personal energy consumption. This vision is fundamentally one of citizen scientists, empowered to take responsibility for and reason about the consequences of their own actions. A further key element in this paper is to support communities of users as they develop, share and promote these sustainable conclusions and best practices, essentially aiding activists to spread their local message about this key global issue.

### Author Keywords
Motivation, sustainability, resource consumption

### ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

### INTRODUCTION

In the face of environmental scares, rising costs for fuel and food and diminishing availability of these resources [14], sustainability and the environment have become prominent economic and political issues across the globe, literally becoming make or break issues in elections [e.g. 3]. In spite of this, the level of change individuals enact in their own behavior remains worryingly low. This matters: resource consumption in the home and commercial sector is reported to be almost 20% percent of overall consumption in the USA [15], and up to 20 times per head greater than that in the third world. Europe and developed Asia fare little better with multipliers of 12 and 10. This paper explores the issues underlying this discrepancy: why do vote green, but not act it? And, more importantly, it offers a theoretical understanding of how we as technologists and interaction designers can influence this trend.

It achieves by reviewing the literature on theories of motivation and linking the conclusions of this discussion into a framework of activism supported by technological systems and services which allow individuals to capture, understand and communicate not only the impact of their behaviors but also the impact of their changes in behavior. By designing infrastructures that facilitate citizens in understanding and acting in their everyday energy consumption practice, we hope to promote a positive vision of accepting personal responsibility for the resources we consume and foster the image (and reality) of achieving a better quality of life through the adoption of sustainable practices [9]. We also anticipate that providing users with these kinds of tool will support the grassroots development of products and service solutions [10] tackling sustainable issues.



### MOTIVATING SUSTAINABILITY

This position paper suggests the fundamental factor underlying our unwillingness to integrate sustainable practices into our everyday lives is one of motivation. Introducing DOTT 2007, John Thackara illustrates this suggestion vividly [13]:

*"The house is cold, someone keeps turning the lights off, and the grey water toilet is blocked again. As a way of life, sustainability often sounds grim. The media don't help: they tell us we have to consume our way to redemption. The shopping pages are filled with hideous hessian bags; and ads that used to be placed by double-glazing cowboys now feature wind turbines, and solar roofs. Adding mental discomfort to the mix, politicians scold our bad behavior as if we were children dropping litter. And preachy environmentalists expect us to feel guilty when we fail to embrace their hair-shirted future with joy. Could one planet living be made desirable, better than what we have now?"*

Indeed, this is a theme which has long been examined in the design community (in, for example, the SusHouse project in the late 90s [18]). It is concisely expressed by Manzini [9]:

*"the action of consuming less has to be combined with a perception of living better".*

However, how this objective can be realized remains a topic of some debate and this paper turns to psychological theories of motivation for insight. Although some of these have been explored in the context of computer science under the general banner of captology [5], this paper provides a brief review specifically focusing on how they can be used to explain the lack of adoption of sustainable practices in the developed world.

In particular, we highlight goal-setting theory [7]. This framework identifies three major factors of an end state that contribute to how motivated an individual is to attain it: proximity (the length of time it will take), difficulty (how hard it is) and specificity (how well defined success is). It suggests that people are most motivated to achieve goal states which are clearly defined and not too challenging or long-haul. Unfortunately, most goals in sustainability do not take this form. For example, reducing a home energy bill is a task which will take several months, may involve arduous efforts to enforce good practices on other family members and the influence of any given action (say using less of an appliance) does not have a clearly observable impact on the final result. Goal-setting theory predicts that motivating oneself to achieve a task of this nature would be extremely difficult.

Another key concept is the distinction between intrinsic and extrinsic motivations [11]. The latter term refers to motivations related to the achievement of external goals such as avoiding an unpleasant circumstance, impressing another person or attaining a particular prize or status. In contrast, intrinsic motivations (which have generally been studied by educational psychologists) lack obvious external incentives but are generally thought to be more powerful. They have been linked to an individual's belief that affecting the desired outcome is within their control and a high internal level of interest (as in the pursuit of a hobby). Although sustainability concerns are often couched exclusively in terms of extrinsic motivations such as saving money or attaining respect, combining these with appeals to intrinsic, self-driven motivations might make a more effective approach. Thackara hints at this issue in the quote given earlier: why is sustainability something we must be compelled to embrace? A better approach would surely be to make it more internally desirable, frame it as something people might actually want to do.

## CITIZEN SCIENCE AS SELF STUDY

This paper proposes to embody the motivational factors reviewed above into a framework of citizen science. To ground this discussion, it deals with a specific example of the use of electricity in the home, although we believe the concepts discussed can apply more generally: to water, fuel use and transportation. One key component of this system is a diverse set of devices to measure, display and control resource usage and the efficiency of that usage. In the electrical domain, this includes a network of power meters attached to individual sockets, room activity sensors, ambient displays and on/off device controllers. Although numerous, these kinds of device are generally small and consume relatively little power. They have been studied in the context of sustainability by many previous researchers (see [2] or [12] for brief reviews) and some commercial products are already available.

The novel aspect of the approach proposed in this paper is to focus on collating data from these devices with more normal diary and activity logs in an on-line social networking site. The main goal of this site will be to allow users to visualize and understand their own resource usage over time through encouraging and supporting them in asking meaningful questions about it. These questions might relate to the current state of their energy consumption, to some change they have enacted in their habits, to outcomes of future changes they might adopt or to a comparison between their usage data and that of one or more other users of the system. By supporting this kind of sophisticated hypothesis generation and test, people will be able to better understand the consequences of their own actions and therefore to adjust their behavior in full knowledge of its effects.

This represents a fundamental shift in motivational strategy with the objective of demonstrating to users how small changes in their behavior can have clear significant effects in their consumption. For example, many people may find it hard to connect the use of the lights in their kitchen and restroom with their monthly electricity bill. Rephrasing this as a percentage change in usage based on improved behavior acted out over the course of a single day or week and then projecting that forward on to a period of weeks or months will make the impact clearer. Goal setting theory predicts this simpler, more immediate and precise expression of goal states will increase people's levels of motivation. Similarly, by empowering users with the ability to understand the impact of their actions, we can appeal to intrinsic internal motivators. The value of setting achievable goals has been stated previously in this domain [e.g. 16]. The system proposed in this paper extends this concept with its focus on user experimentation in goal setting and goal achievement strategies.

This approach also appeals to the concepts outlined in Democratizing Innovation [6] which suggest that users themselves represent the most informed and aware experts and innovators in many domains. This kind of tool we propose in this paper will act to leverage this contextual knowledge and insight, and may lead to user generation of novel products, services and sustainable solutions tailored to their specific context. Such outcomes could be used to promote local community change, start businesses or in dialog with policy makers and service providers. This concept is expanded upon in the following section discussing activism.

However, practically realizing such a system will be a challenging task. Bridging the gap between the kinds of questions and answers that otherwise untrained users might make and understand and those which an essentially analytic computational system might reason on and resolve is a formidable problem. This paper indentifies developing such systems as a key research challenge and suggests that the solution will lie in harnessing the power of a community of users. By enabling the sharing, searching and exploration of data, questions and results from many users, the knowledge and expertise available throughout the community will be made available. Although there will never be a one size fits all solution, many users in a given physical location will face common problems and difficulties but some will be more able and willing to tackle these than others. By leveraging the enthusiasm and skills of these essentially activist users, a community system could promote their results and best-practices widely.

Another key aspect of the system would be to enable users to control and configure the infrastructure installed in their homes. This is a key element in the model of community problem solving: if one citizen solves a problem, another must be easily able to replicate that same fix in their own lives and homes, including automatically configuring any equipment installed there. Furthermore, customizable input, control and display infrastructure is essential to the concept of the citizen scientist asking and answering questions about the impact of his or her own behaviors, practices and environment on resource consumption. For example, noting a high level of usage from a home entertainment system, a user might choose to connect up an ambient display to show this information live and later explore whether this had any effect. Alternatively, a user might experiment with how his or her behavior (and overall usage) changes when deploying automatically controlled lights linked to an activity sensor in the kitchen.

A final benefit of this kind of community system has been highlighted by other authors, in particular Mankoff et al. [8] on the topic of sustainability. Grounded on a thorough review of the literature they propose exploring whether social networking technologies can enable behavior change relating to resource consumption by tapping into factors such as group goal setting and competition. Mankoff's approach is clearly relevant to the one put forward in this paper.

## ACTIVISM

Generally, activism is used to refer to directed action to instigate social or political change in relation to controversial issues. Activists are often motivated by intrinsic factors, reinforcing the importance of rephrasing sustainability in these terms. Borshuk [1] enumerates motivating factors as: self-concept, socialization, the search for meaning and identity, values, personality attributes, political consciousness, a quest to join community life and a need for status. On-line activism has also received attention. Vegh [17] describes three distinct categories: awareness/advocacy, organization/mobilization and action/reaction. Respectively, these refer to the use of information technology to distribute or promote a message, to organize events in the real world and to engage in "hackivism", a term for virtual attacks such as denial of service.

The concept of the activist as someone who engages in direct action, in the form of asking and answering questions about behavior and consumption in order to determine best practices, is central to the vision proposed in this paper. Equally, Vegh's concept of using the internet as a means to spread awareness of issues and advocate for change is central. Highly motivated activists are a critical component of how the system proposed here might work in an actual community. Realistically, not all individuals will want to undertake the kind of hands-on investigations outlined in this paper. So by providing enhanced tools to support those who do to communicate to and influence those who do not, we may be able to increase the rate at which new, sustainable practices are adopted. Furthermore, the empirical, numerical data that the system we propose can capture may be able to create compelling, supported arguments which citizens can present to other energy stakeholders such as providers, policy makers and regulatory bodies. This kind of lobbying is a core part of activism and this proposed system has the potential to enhance it.

## EVALUATION APPROACH

A multi-faceted evaluation of the approach outlined in this paper is important. The simplest metric would be to assess the ability of the system to effect changes in an individual's behavior. This is relatively easy to achieve by empirically logging resources consumed and qualitatively observing how habits and practices develop. However, the social context in which activism and community change takes place calls for a broader mandate. The overall goal of the framework described in this paper is to promote best practices of resource consumption and energy efficiency more effectively across a whole community. Correspondingly, any comprehensive evaluation needs to answer the question of whether the approach described here accelerates the rate of social change compared to that achieved with existing activist and top-down policy structures. This can only be realized by detailed, post-project comparative case studies contrasting the overall social and physical environment of a community which has been using the system against one which has not. Although ambitious and large scale, only through such in depth qualitative study can the true worth of the approach proposed in this paper be validated.

## CONCLUSIONS

This position paper has proposed a vision of motivated citizen scientists equipped with specialized tools which enable them to capture and understand their resource consumption practices and in the role of activists, seamlessly communicate the most optimal ones to other system users and large-scale policy makers. These concepts are in the preliminary stage of development, but we firmly believe they represent an empowering way in which citizens can take concrete action to generate novel solutions on sustainability issues and communicate these to their peers. It has been suggested that to achieve a sustainable level of resource consumption, a reduction of up to 90% from current levels may be called for [9]. Supporting users in the generation of grass-roots solutions to their local problems will be an important mechanism by which such radical change can be achieved and this paper outlines one way this activity can be supported.

## MADEIRA AND MUSE 2008

This position paper is one result of MUSE 2008, a two week brainstorming workshop held in early July by Lab:USE, a research group at the University of Madeira in Portugal. The theme of the workshop was “Interaction for Sustainability”. Madeira is an isolated island (Morocco is the closest continental country) with an increasingly affluent local population (of 270,000) and a large tourist industry. It has developed very rapidly in recent years. Beyond the common moral imperative to behave sustainably, these factors combine to place heavy demands on existing resource infrastructures. Sustainability is a critical issue for Madeira and the goal of this workshop was to generate research proposals to address how interactive technologies could serve this need. Although its work on this topic is at an early stage, Lab:USE is committed to pursuing innovative research in the area of interaction for sustainability.

Other concepts explored at MUSE 2008 included the generation of new services for tourism, a series of awareness, educational and motivational games related to recycling and rubbish disposal and the requirements for a community and social networking site which would offer citizens a canvas on which to express their concerns relating to environmental issues and development projects.

## AUTHOR BIOGRAPHIES

Ian Oakley is an assistant professor at the University of Madeira and an adjunct assistant professor at CMU under the CMU|Portugal agreement. His research interests are in the psychology of interaction: the perceptual and cognitive human issues that underlie and affect how people adopt, use and relate to computational systems. Under this broad banner, sustainability is an emerging topic of interest and he sees attending this Ubicomp workshop as an important opportunity to get in touch with the community which is forming around this topic. He has recently spent two years doing R&D in Korea (split between positions at GIST in Gwangju and ETRI in Daejeon) and as a Scot shares Paul Dourish’s affection for haggis.

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# Carbon Metric Collection and Analysis with the Personal Environmental Tracker

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**ABSTRACT**
The Personal Environmental Tracker (PET) is a proposed system for helping people to track their impact on the environment, and to make changes to reduce that impact, creating a personal feedback loop. PET consists of sensors that collect data such as home electricity or gasoline usage and send it to a database for analysis and presentation to the user. By collecting data from diverse sources, PET can help users decide what aspect of their lives they should make changes in first to maximize their reduction in environmental impact. PET's open architecture will allow other ubiquitous sustainability researchers to leverage the infrastructure for research in sensors, data analysis, or presentation of data.

**Author Keywords**
Ubiquitous computing, sensors, environmental change, mobile devices, social networking, feedback loop.

**ACM Classification Keywords**
H5.0. Information interfaces and presentation (e.g., HCI): General. K4.2 Social Issues.

## INTRODUCTION

It is widely recognized that the global climate is warming due to anthropogenic sources [7]. There are an increasing number of people interested in making personal changes to reduce their contribution to climate change. We focus our efforts on these people who are actively seeking to reduce their carbon footprint. These users have questions about how best to direct their efforts, such as "how much additional electricity does increasing the thermostat on the air conditioner by one degree consume?" or "how much less carbon is released by carpooling with someone who lives nearby rather than driving alone?" We need to provide a system that allows users to perform informal experiments related to their daily lives and provide rapid feedback on the results of those experiments.

Another important question these users face is "what are the relative contributions of different activities to my carbon footprint (driving, air travel, heating/cooling home, entertainment, food, consumer purchases)?" While tracking usage in individual areas (home electricity usage, automobile gasoline consumption) is important, the comparative contributions to the user's carbon footprint must be determined for rational decision–making. This approach allows users to prioritize among the many possible ways they can reduce their environmental impact.

## SYSTEM DESCRIPTION

Our proposed system, the Personal Environmental Tracker or PET, will help users reduce their footprint in three steps: collecting data about their daily activities, converting the raw data into a carbon footprint, and embedding the results in social networks, forming a feedback loop for environmental change.

### Sensors

PET will collect data about users' lives through a constellation of sensor inputs. While our target users are already motivated, it is critical that the effort required to collect data is kept as low as possible. Many people live busy lives, and excessive overhead for data collection may convince users that collection is not worth the effort, especially when the environmental results might not be seen for decades. We see several ways to collect data: physical sensors, information sensors, and manual sensors.

Acquiring data from physical sensors is a commonly used method. For example, systems for tracking electricity usage for a whole house [4], or a single device [9, 8] already exist. Positional data from GPS units (such as those in some smartphones) can allow estimation of carbon output based on mode of transportation such as the Carbon Hero system [5]. One could even imagine a tailpipe sensor attached to an automobile that directly tracked greenhouse gas emission.

The disadvantage of physical sensors for data acquisition is that it often requires the purchase and installation of equipment to collect the data or extract it in digital format. The exceptions are sensors that piggyback on an existing device, such as the GPS capabilities of a mobile phone already carried by the user.

Calibration of the sensor data is an important topic to address because data can be collected from number of different types of physical sensors under varying circumstances. Because PET will have raw data collected from users with different sensors, the accuracy of sensors can be compared for users performing similar activities. Users with access to different sensors of the same type (such as whole-home electrical usage) could use both sensors simultaneously to gauge their accuracy and compare them to the values provided in the bill from the utility company. For sensors where each instance has a variable degree of error, users could be directed to a standardized trial (such as walking between two points for calibrating a location sensor) and the results compared to results from other users.

An increasing amount of relevant data is already available online; it merely needs to be mined and processed to be useful to PET. We call these sensors that gather data from digital sources *information sensors*. One area with abundant data is credit or debit card transactions. Those users who make most purchases with credit cards possess a wealth of information that can provide data on environmental impact, such as buying gasoline, food, or consumer products. Personal finance web applications such as Wesabe (http://www.wesabe.com/) have demonstrated that it is possible to securely make use of credit and debit card transaction information to aid users in tracking their finances. Retrieving electricity usage data from utility websites is another source of data already being used by systems such as Personal Kyoto (http://personal-kyoto.org/). PET can also leverage the data users are voluntarily maintaining online, such as travel itineraries in the TripIt web application (http://www.tripit.com/).

To reduce overhead for users, automation is generally preferable to manual data entry. In some cases, however, users will need to take explicit action to record data for PET. We believe mobile devices can significantly reduce the effort required for manual entry, and allow the data capture to happen at the time and place of event being recorded. For example, mobile phones can scan RFID tags containing the carbon footprint of products that manufacturers may embed in the future [1]. Cameras in mobile devices can capture the ubiquitous barcodes on products, or scan receipts for later analysis by optical character recognition. Speech-to-text services such as Jott (http://jott.com/) can provide for hands-free data entry, and of course, users can always fall back to typing into their mobile device.

#### Analysis

As data are collected, PET can provide a variety of analyses. One particularly useful analysis would be to condense the data down to a single number representing the user's carbon footprint. A single value would allow the user to easily see how their behavior is impacting the environment, and allow comparison with other people and groups.

It is important that the feedback and analysis of the user activity be as immediate as possible. For effective behavior modification, the delay between action and understanding its impact should be short, measured in minutes or hours, not days and weeks as most utility bills are.

Calculating the carbon footprint of activities requires the use of estimates and averages for some factors. Because the best guesses for these values may change over time, or there might be differences of opinion on how best to compute the footprint, we propose making the analysis methods user–modifiable, further permitting users to participate in the scientific process. To permit comparison and aggregation of footprint data, there will be a canonical calculation formula that will be updated over time as better techniques become available. Users can modify the canonical formula to perform "what if" calculations on their own data, and share their formulas with other users for discussion.

PET only displays the results and analyses of users' actions, and does not prescribe how users should modify their behaviors. The aggregation of sensor data from multiple aspects of users' lives ensures that they can see what behavior changes make most sense for them.

#### Social networks

Allowing users to go beyond just looking at their own footprint, to see it in context with other users' can be an important way to motivate change in the long term. Comparisons with friends, neighbors, and others around the world can give users the motivation to continue to or redouble their efforts. Friendly competition can be helpful, but it's important that the desire to improve one's standing through manipulation of sensor data not get in the way of the underlying goal of reduced environmental impact.

Integration into social networks can facilitate users sharing knowledge about how to reduce consumption, and emotional support from like-minded individuals.

### SYSTEM ARCHITECTURE

To support the range of functionality described above, we envision the architecture of PET as a multi-tiered system using HTTP and representational state transfer (REST) [6] to tie the components together. Figure 1 shows a block diagram of the system architecture. Sensors are device or service-specific plugins that collect data and send them to a

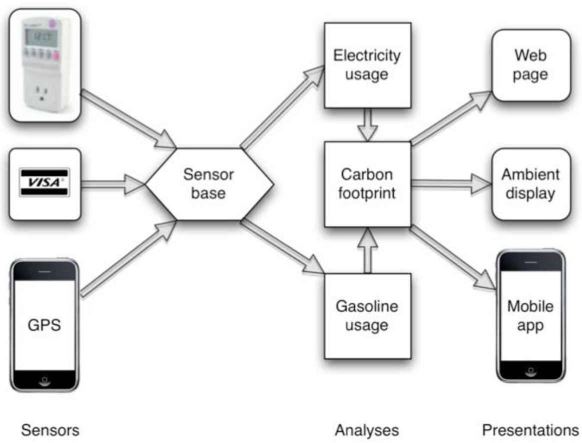


**Figure 1: PET system architecture**

sensor database. The sensor base component simply stores data for later recall by analysis tools. Analysis tools retrieve sensor data from the sensor base, and in some cases, pass their results to higher-level analysis tools. For example, sensor data about gasoline usage in the sensor base might be converted to an estimate of greenhouse gas emissions, which could then be used to compute the relative contribution of gasoline usage to the user's carbon footprint. Presentation tools can take up the results of these analyses for display as web pages, to virtual polar bears [3], or interactive games [11]. In fact, the social network functionality discussed earlier could be built as an application for existing social network systems (such as Facebook or Orkut) that is just another presentation tool for data in the sensor base.

PET strives to be as open as possible. The use of HTTP and REST allows sensors, analyses, and presentation tools to be implemented in any language. Standardized formats for sensor data will allow easy implementation of new sensors, and decouple sensor development from analysis and presentation. Tracking a new type of activity only requires the creation of a new sensor that talks to the existing sensor base. All the existing analyses can be applied to the new data source. Experiments on new persuasive computing techniques to change user behavior can be structured as new analysis and presentation tools on top of the raw sensor data or lower-level analyses.

The system will be open source, enabling a broad development community to take shape. In particular, having an open source sensor base allows organizations that wish to collect data but do not want it to be public, to set up their own servers for internal use.

Most users would send their data to a centralized default server open to the public. In PET, users will own their data: they should be able to download their data, move it elsewhere, or remove it from the system entirely. The personal finance site Wesabe was a pioneer in this area with their users' "data bill of rights"[1], which applies equally well to the environmental data we intend users to collect.

The spectrum of data that PET collects on the user's environmental impact is potentially quite private (location traces, travel history, etc.) and some users may not wish to share their data. The raw data are required for accurate analysis; however, for discussion and sharing among the user's social network, only the aggregated values resulting from the analysis are required. A public PET server can collect data from all users, but it only allows users access to their own raw data. The server can distribute aggregated data and the results of analyses among users without unduly intruding into users' privacy. For those users who are unwilling to entrust their raw data to a public server, an option to create a personal analysis system that runs on the user's computer can be considered, optionally sending the results of the analyses to the public server for aggregation.

## INITIAL IMPLEMENTATION

The initial implementation of PET should provide the entire workflow from data collection to analysis and presentation for two different types of sensor data. The APIs and data formats used by the sensors and the sensor base need to be well defined to support additional development by external developers. This infrastructure would allow an initial evaluation of our claims about the utility of having sensor data from different aspects of daily life merged into a single presentation.

Once the initial implementation is complete, we would seek to build an open source community around the system to support more sensor input types and more analysis and presentation tools.

## CONTRIBUTIONS

The idea of recording data about people's lives and tracking trends to help reduce their environmental impact has been thought of before [10]. PET differs from previous work in this area by offering a comprehensive open framework for this endeavor. PET would provide infrastructure for other researchers in both data collection and analysis, potentially speeding progress. Researchers working on new analyses or persuasive presentations of data could focus on the analyses rather than having to also spend their time constructing a system for collecting sensor data. Researchers developing new sensor inputs would have a natural destination for their data that allowed them to perform useful analyses.

Since PET will collect data in multiple aspects of users' lives (electricity usage, gasoline usage, etc), it can provide useful information on the meta question of what area a user should focus his or her efforts to reduce environmental impact. This approach differs from most systems that focus on only one area such as home electricity usage or carbon released from personal transportation usage.

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[1] https://www.wesabe.com/page/security

In order to be useful, PET requires data input from sensors and analysis by computers, each of which create their own environmental impact. As described earlier, PET accepts data not only from physical sensors, but also information sensors and technology-assisted manual data entry. The sensors seek to leverage existing devices (such as mobile phones) and existing behaviors (such as personal financial tracking), which significantly limits the additional impact of data collection. A survey of studies on usage feedback systems in energy consumption found that savings on the order of 10% or more was quite achievable [2]. If PET can enable users to make a comparable reduction in environmental impact, the additional costs of data collection, analysis, and social collaboration will be quite small in comparison.

While we have focused on the issue of climate change, PET could easily be extended to track other sustainability topics such as water usage, habitat loss, and social justice through the creation of new sensor inputs and new analysis and presentation tools.

PET will provide its users with insight into their own environmental impact, and the impact of others in their social network. That foundation of understanding, based on hard data, provides the platform for advocacy and activism in their jobs and communities. PET users can speak from direct experience on how environmental impact can be reduced, and demand those reductions from their employers and their elected officials.

In the broader context, the data collected and experimentation with analyses could provide more accurate models for calculating carbon footprints when fine-grained data are not available. The results could feed back into policy decisions, which could be based on data gathered about how people actually live. Finally, users positive behavior modifications would have a direct impact on climate change.

## BIOGRAPHY

Robert Brewer is a research assistant on the Ubiquitous Wireless applications team in the Laboratory for Interactive Learning Technology (LILT) at the University of Hawaii at Manoa. He is pursuing a PhD in the Information and Computer Sciences (ICS) department with a focus on ubiquitous computing and environmental awareness.

Robert graduated from Reed College in Portland, Oregon in 1992 with a Bachelor of Arts degree in Physics. In 2000, he received a Master of Science degree from the ICS department at the University of Hawaii at Manoa. His thesis research focused on improving mailing list archives.

Robert also has experience in industry. As one of the founders of LavaNet (a Hawaii-based Internet Service Provider), Robert also took an active management role as vice president and technical manager for the first three years of LavaNet's existence. Over LavaNet's 14-year history, he worked as a senior technical specialist on a variety of Internet infrastructure projects.

## MOTIVATION

The Ubiquitous Sustainability workshop is closely aligned with the research area for my dissertation. Feedback from this workshop can further shape my ideas as I prepare my dissertation proposal. Learning the latest research directions from like-minded individuals will grow my knowledge of related work in this area.

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# GreenSweeper: A Persuasive Mobile Game for Environmental Awareness

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## ABSTRACT

In this paper, we discuss *GreenSweeper*, a collaborative, mixed-reality, photo-based mobile game aimed at promoting environmental awareness. By collectively sensing the environmental landscape through photographs and text descriptions of surrounding artefacts, GreenSweeper is designed to be more than just fun, to deliver environmental messages and provoke reflection. In this paper, we briefly discuss the design and implementation of GreenSweeper, followed by a brief discussion on the value of persuasion and mixed realities in promoting environmental awareness.

## Categories and Subject Descriptors

D.3.3 H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces. K.4.2.Social Issues

## Keywords

Mobile games, Sustainability, Urban computing, Persuasive technologies, Serious games

## INTRODUCTION

The urban landscape is constantly negotiated and re-appropriated through informal urbanities, signage, hoardings, and housing or industrial developments. However, in the midst of these urban spaces, we rarely stop to think about the damage to surrounding environmental landscape. Environmental sustainability is often treated as resulting from making conscious, environmental-friendly decisions. This form of separation from our everyday interactions posits environmental sustainability as a complex, disconnected notion. However, weaving environmental awareness into our lifestyles, by reflecting on our local surroundings and the artefacts that we use regularly, could help us better understand the world around us.

A characterising feature of infrastructures is that they are sunk into and inside of other structures, social arrangements, and technologies, adopting Star's description [6]. Urban infrastructures are fraught with issues such as increasing damage to flora and fauna, energy depletion, pollution, garbage, and toxic wastes. The embeddedness of urban infrastructures results in greater cumulative damage, which goes unnoticed until it manifests itself as a colossal catastrophe. The problem here is that we do not take notice of the surrounding environmental landscape on a day-to-day basis.



In a parallel vein, the advent of mobile devices has spurred a slew of mobile applications supporting environmental sustainability, such as the usage of mobile sensors to create maps representing environmental damage [7], and the generation of environmental data for consumer products [5]. We extend the notion of Participatory Urbanism and citizens acting as agents of change [4]. We briefly present *GreenSweeper,* a mobile, mixed reality, photo-based game designed to promote environmental awareness. By collaboratively marking out the greenness of the infrastructure, our goal is to raise awareness of surrounding environmental sustainability issues that deem further action. *GreenSweeper* makes use of photographs and text descriptions of artefacts to qualitatively define the environmental landscape. In the following sections, we will provide descriptions of the game design and technical implementation of *GreenSweeper.*

## GAME DESIGN

Our motivation for *GreenSweeper* is to promote a new delivery of environmental awareness by combining game play with reflection. GreenSweeper differs from typical handset games like Snake, Tetris, or Bejweled, by layering meaning through combining elements of the real world with the virtual. It is designed to be played by pedestrians or cyclists within bounded urban grids. As a serious game, GreenSweeper informs users about the greenness of the surrounding infrastructure, by which we hope to shed light on environmental damage and impact. We initially prototyped our system to work on the UCI campus, but it could be scaled to any map. *GreenSweeper* works both indoors and outdoors, as long as a network connection is available.

*GreenSweeper* is motivated by Minesweeper, in that the prime goal is detecting and avoiding mines on a grid. In our game, the presence or absence of mines is determined by the level of greenness. The user first selects a square on the map, then shoots a picture of the most green/non-green object within an area, and provides a relevant description and green/non-green tag. The map can be programmed to be any geographical map. This tag serves as input for the learning algorithm which determines whether or not there is a mine in the area. Initially the mines are chosen at random, but on reaching a convergence point with increased input from users, the algorithm thresholds out areas with more non-green tags as mines. The pictures, descriptions, and tags are sent to a public account on Flickr, which are later randomly displayed at the end of each game session, along with the user's picture history. By displaying pictures, we provide compelling visual feedback of environmental impact.

The GreenSweeper system architecture is composed of Nokia N800s connecting to Flickr photo sharing web application and an AMP (Apache, MySQL, and PHP) web server. The Nokia N800 is the front end of the system, running the GreenSweeper application that consists of the graphical user interface and game logic. The front end of the system communicates with both Flickr, to store photos, and the web server, for processing. The back end of the system consists of Flickr and GreenSweeper's web server. The web server serves the content to the Nokia N800 device and also gathers information from the user's data stored on Flickr.

We do not employ any automatic location-detection techniques; rather we gather location data from the user input. The rationale behind this design decision is to allow the device to theoretically work smoothly in any wirelessly-connected area, but by by-passing problems of General Positioning Systems (GPS) within closed doors and Wi-Fi based positioning in areas without access points. Wi-Fi based positioning is attractive, however, along with the issue of not having enough access points to cover most areas [2], there is the issue of the variance of Wi-Fi signals. In addition, due to our large environmental landscape, surveying Wi-Fi access points will be an issue. The larger variance of Wi-Fi signals seen by moving users [3] may present problematic data to *GreenSweeper's* server, for example, a location can be mistakenly reported as another.

# 3. SYSTEM ARCHITECTURE

## Back-end:

GreenSweeper offers a game play that reflects the environmental sustainability of the area that surrounds the users by placing mines in areas that are less environmentally friendly than others. In addition, we wanted to support many users accessing the system and a system that can support a large user base and user generated data. Our goal for the backend was to create a system that allowed for scalability, reliability, security, minimal latency, and have a good performance to allow for a multiple users. To support this, we implemented a system that allowed for growth and easy integration to future development. The developed system uses various technologies to collect and generated data from and to the users.

GreenSweeper's backend is build upon an AMP (Apache, MySQL, and PHP) web server along with Flickr for photo storage. The web server provides GreenSweeper the map of mines, collect information generated by the user's game play, and display information on area's environmental sustainability. The Flickr account allows a large storage area for users to submit their photos along with meta-data that is relevant to the study, including meta-data on the game played, general location, and the greenness according to the user. The Flickr album is made public so users of the game can view the pictures of the area played to gain more information on what other users perceives as environmentally friendly/un-friendly.

The mines in GreenSweeper are generated through an algorithm using the weight based on an area's greenness. We were able to determine the area's greenness by applying a small weight to every user's photo submission. The photo submissions include meta-data on the game played, general location, and the greenness according to the user. This user generated data is stored within Flickr until a nightly update is activated on GreenSweeper's web server, in which it parses the information and updates the data accordingly. Using this data, we can effectively generating an approximation of the greenness of an area by allowing the user generated location weights within the algorithm. An area that is persistently non-green will have a higher percentage of having a mine than a location that is greener according to the users. Over a period of time, we predict the user-generated data will reach a convergence point in which the data will accurately present a map with locations of environmental friendly/un-friendly locations.

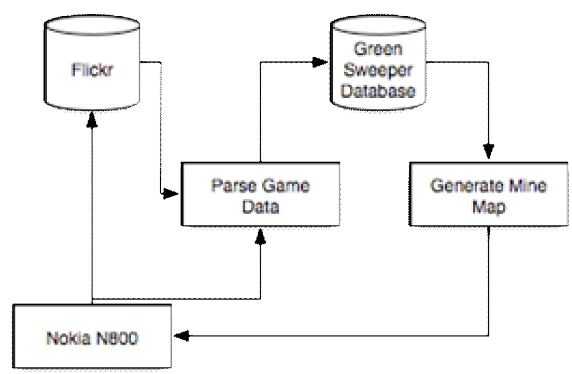


Figure 1 – High level architecture of GreenSweeper with flow of information within the system.

## Front-end:

The Nokia N800 tablet was chosen for its large screen, built-in camera, and ability to connect to wi-fi networks. The user interface is written in Python using the PyGTK framework, a set of wrapper classes for the GTK+ library. The application runs on the default Maemo development platform and Hildon framework. The camera programme is written using Python bindings for the Gstreamer library, a multimedia framework.

The game logic of GreenSweeper includes network connection and mine determination. We query the mine map from the server for the particular grid, which has a total of 4 mines in 3X3 sub-grids, through Python urllib connection. Then, we notify the sever, through urllib protocol, to check photos on the Flickr album when the game session is over. Pictures taken by the user to Flickr are uploaded by emailing contents through SMTP protocol directly to the unique address of the Flickr account. Based on the mine map retrieved from the server, the user can see how many of the square's neighbours are mines. All mines explode if the square is a mine, ending the game. Also, the user can flag the square, which is equivalent to right-clicking the square and marking it as a suspected mine.

## 4. DISCUSSION

In this section, we will discuss aspects of GreenSweeper relevant to the theme of the workshop.

***Value of Mixed Reality in Environmental Sustainability:*** GreenSweeper seamlessly combines elements of the real world with the virtual game play. Environmental degradation is a physical issue – it concerns changes in air quality, level of contaminants in water, amount of CFCs released by auto-mobiles, and so on. Solutions to monitor sustainability should be as close tied to the real world as possible. By creating a non-immersive environment, that mandates the player to devote equal amounts of attention to the physical and the virtual worlds, actions in GreenSweeper directly translate to and result from meaning-making in the real world.

Figure 2 – Various pictures shot using GreenSweeper

***GreenSweeper as a*** *Persuasive* ***Game:*** GreenSweeper supports existing cultural and social positions by allowing the player to document artefacts, but also contributes to influencing the position, leading to a change. When these changes are significant, the player will be motivated to act on the issue. [1] The immediate outcome of GreenSweeper is not as important as the understanding of the world. The implications of players' actions serve more than the purpose of momentary recreation or competition. The game has function and outcome, both while playing the game and outside of it.

***Raising environmental awareness:*** Awareness of environmental issues is the first step towards building a sustainable environment. GreenSweeper underscores artefacts that are typically ignored, by forcing the user to find an artefact and evaluate its greenness. Moreover, the player has to move around the grid to advance further in the game, inherently exploring different areas. By tightly integrating data collection with recreation, we hope to highlight problems in the surrounding environment. By collective qualitative sensing, we hope to gather a range of opinions on urban infrastructures.

***Deductive and Descriptive:*** We construct a space for two experiences – deductive, that allows game play and competition, and descriptive, that allows exploration of the area and contribution to information content. They are mutually inclusive, since the user has to describe the artefact in order to play the game. By encouraging deductive playfulness and modelling on a familiar game, we hope to sustain the interest of the player, while implicitly sampling the world.

***Reflection and reflection:*** We speak of two kinds of reflection here – mirroring and cogitation. By displaying the player's picture history, GreenSweeper mirrors the player's pictures to reveal the import and meaning of hir actions. By displaying other players' pictures and descriptions, unpredictable, intersection/non-intersecting decisions and artefacts captured by other players are shown. This may lead to cogitation, surprise, amusement, disagreement, or approval. The game aims to bring meaning to rituals of walking, waiting, or boredom.

***Protecting privacy:*** GreenSweeper protects privacy of the players through anonymity. Only a unique ID for every player is generated to distinguish on Flickr and for the processing, but player information is not collected. Although this does not establish reputation of the other players, we are only concerned with the information contained within the pictures and descriptions.

***Ubiquity***: Our motivation in making *GreenSweeper* a mobile game is to incorporate environmental awareness into the everyday practices of the user, without requiring additional infrastructure. In addition, it permits unrestricted movement of the user, hence covering a greater range of artefacts. Furthermore, it encourages pedestrian activity in tagging and covering squares of the grid.

The above pictures and descriptions were gathered informally from 5 users to rapidly evaluate our system. We are currently conducting large-scale user studies to evaluate and improve our system design. Of particular importance is the question of the impact of the size of the play grid and the population density of artefacts on the motivation of the player. Parking lots, parks, and other open areas tend to be visited rarely, so the statistics in that area affect the convergence of overall sustainability analysis. The nature of tags and descriptions and its relation to the pictures will also be evaluated. Above all, we seek to understand the value of games in promoting environmental awareness.

## 5. ACKNOWLEDGEMENTS

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## 6. BIOGRAPHY

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# Sensonomy: Envisioning folksonomic urban sensing

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**ABSTRACT**

Sensing urban environment with covering extensive area in a precise quality is important issue for sensor network approaches. This paper describes a system called "Parasitic Ambient Logger" which is attachable to mobile devices in order to sense ambient air environment. Unlike the conventional sensor network approaches, the system can build environmental sensing infrastructure in a cost effective way because it has less limitations of installation cost. Mobile sensor nodes should be able to know its location information for practical applications. Our method employs Wi-Fi based positioning technology which can get one's location even in daily urban environment. This grassroots style sensing environment helps to gain awareness of our surroundings. By aggregating the data, large dataset of ambient logging can be used to analyze long-term and city-wide urban environment.

**Author Keywords**

urban sensing, sensor network, folksonomy, mobile device

**INTRODUCTION**

Environmental sensing using ubiquitous sensor networks is going to be remarkable research fields in these days[1]. A common research topics in ubiquitous sensor networks has been the development of sensing infrastructure using low power static sensor nodes that are connected through wireless networks with flexible topologies. Although these approaches work well in a controlled environment, there are difficulties to install sensing infrastructure in a real-world to investigate city-wide activities[5]. For example, having to deploy large numbers of sensor nodes everywhere in our daily life is a most significant problem. Even if the enormous numbers of nodes could be prepared, getting property rights to install every nodes is almost impossible. Moreover, there are a lot of problems to overcome caused by its battery life, storage size, network access and initial location registration. Thus conventional style of sensor networks can not scale to the city.

One of the practical solutions for this problem, covering everywhere that we live with sensing infrastructure, is using a mobile platform[2][4]. If the sensors are embedded to the device that everyone already has (e.g. mobile phones, music players, portable digital assistants (PDA) and laptop computers), some kinds of limitation will dissolve. Sensors can get longer battery life and larger storage size derived from that of the mobile devices.


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**Figure 1. Appearance of "Parasitic Ambient Logger" System. (sensor modules attached to an iPod touch and a laptop computer)**

We propose "Sensonomy" which is real world folksonomy based on various sensing technology and peer production. As folksonomy develop in Internet-mediated social indexing, "Sensonomy" is a bottom up style of mobile sensor networking by citizens in a real world. There are possibilities to realize various kinds of application under this concept (e.g. weather forecasting, pollution investigation, environmental sensing, etc.)

Most significant transition from static to mobile sensor nodes is location registration problem. Although the problem is even simpler for static sensors, mobile sensor nodes should know its location somehow by itself. In order to get location information of sensor node, one of the most applied technology is global positioning system (GPS). Although GPS device is widely used in static sensor network system in outdoor environment, it is not usable to detect one's location continuously in our daily life because performance of GPS declines significantly in indoor environment. Even in outdoor environment, the accuracy of GPS often getting worth in urban area due to buildings reflection. This problem also makes effective urban sensing systems difficult.

In our ambient logging system, we employ Wi-Fi based positioning technology[6][7] to enable each mobile sensor nodes to detect the location by oneself. By making use of densely installed Wi-Fi access points at urban areas, every Wi-Fi installed mobile devices get ability to detect its location in daily situation.

In this paper, we introduce our first proof-of-concept prototype, "Parasitic Ambient Logger", that is composed of common mobile devices that are easily available today and attachable tiny sensor device. Figure 1 shows working appearance of the system in two style, sensor module attached to music player (Apple iPod touch) and laptop computer. Using these kind of easily available devices and parasitically attaching sensors to get the help of computational and network resource, grassroots style sensor networks using mobile sensor nodes can be built in a realistic cost.

Following sections consist from the concept of proposed approach, system architectures, our proof-of-concept implementation of "Parasitic Ambient Logger" and its application examples. Our proof-of-concept implementation demonstrated that the system actually works effectively in a city environment.

## PROPOSED APPROACH

In this section, we describe a concept of "Parasitic Ambient Logging" that can be alternate style of practical sensor networking model.

### Mobile urban sensing

Environmental sensing in urban area is getting more important because of growing concern about investigating drastic change of climate or surveying air pollution over large scale.

Apart from conventional static sensor network infrastructure under controlled situation, sensing nodes in the form of mobile phone like devices are strongly needed to achieve this object[5][3]. Because deploying large numbers of sensor nodes everywhere in our daily life is impossible.

One of the practical solutions for this problem, covering everywhere that we live with sensing infrastructure, is using a mobile platform as seen in [2][4]. If the sensors are embedded to the device that everyone already has (e.g. mobile phones, music players, portable digital assistants (PDA) and laptop computers), mobile urban sensing can be realized

Most significant change between previous work and mobile urban sensing is how to tell the location information of sensor nodes itself. In case of that the node does not move, it is enough to tell location of the installed device manually at initial setting up process. On the other hand, it is essential for mobile sensor nodes to detect its current location somehow.

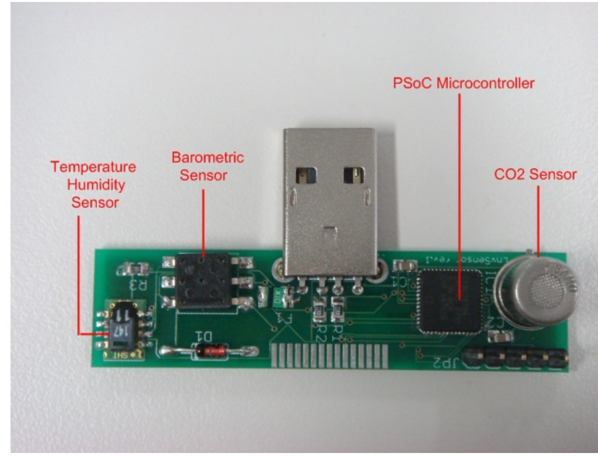


**Figure 2. Top view of the sensor module (with USB connector).**

### Parasitic logger

There are some other kinds of problems to overcome that is specific to mobile urban sensing. Because of portability of sensor nodes, it is not easy for the primitive sensor nodes that have only lower functionalities to work properly in mobile context. For example requirement of battery life, storage size, network access are also becomes problems in this mobile urban sensing. Some kinds of computational abilities or network accessibilities is strongly needed.

It is ideal that embedding necessary sensors into mobile cell phones that already have longer battery life and storage size that can go through all day long and network accessibilities to share the sensor data, but it is hard to implement environmental sensors into today's cell phones because of its limited programmabilities.

Our approach employs keeping sensor module simple and resigning these capabilities to common Wi-Fi installed mobile devices which is available today (e.g. music players, PDAs and laptop computers). Parasitically attaching as simple as possible sensor module to, it can make the most of abilities from these mobile devices.

### Ambient logging and location information

Urban sensing is a technology that records various low-level environmental information continuously and massively from our daily living space. It is important to sense location information where the data is captured and store time series of contextual information from environment. Such archived information can be used for analyzing working environment of a particular person, enhance the communication modality using contextual information around the users and surveying environmental information from geographical mappings of the data for city-wide scale. To provide such a statistical information in geographical views, most important information is "location" of where the data is captured.

Usually, GPS is used for location sensing as well known. However, GPS is not enough for location sensing, because

**Figure 3. Wi-Fi access point locations estimation (Tokyo metropolitan area).**

People's living space is mostly indoors and GPS does not work properly in indoor environments, and also GPS does not estimates building floor or room level location, which is important for mobile sensor nodes. Wi-Fi based positioning has a characteristic that it can estimate indoor location or building floor location. Thus we employ this technology.

## SYSTEMS

In our "Parasitic Ambient Logger" system, each of sensor nodes is a set of common mobile devices with attached sensor module that is easily portable in one's daily life.

Our sensor module is composed of multiple single functional sensors and microcontroller (shown in Figure 2). Carbon dioxide, Barometer, Temperature and Humidity sensors are included in this module in order to measure ambient air condition and low level context information of the environment.

This sensor module has low-level sensors (carbon dioxide, barometer, temperature and humidity) and a microcontroller to sense ambient air condition. Derived sensor data from module is transferred to mobile devices via USB or serial port.

### Wi-Fi based positioning

For Wi-Fi based positioning technology, we use "PlaceEngine" which is previously proposed by Rekimoto et al[7]. PlaceEngine maintains a Wi-Fi access point location database based on the estimation algorithm. The current database contains more than half million access point information that covers major cities in Japan (Figure 3). It also supports floor and room estimation based on Wi-Fi Signal fingerprint similarity. Using this technology, it becomes possible to record precise location log both indoors and outdoors.

### Hardware details

We developed first implementation of our "Parasitic Ambient Logger" using some kind of low-level ambient air sensors and a microcontroller. To explore the idea of sensor modules this implementation keeps flexibilities in communication method between the mobile devices. An detail list of components is shown in table1. We use Cypress PSoC microcontroller to make use of its analog amplification and conversion capabilities for capturing the data from sensors.

| Function | Components |
|---|---|
| Microcontroller | PSoC CY8C24794-24LFXI (Cypress) |
| Carbon dioxide | TGS4161 (Figaro) |
| Barometer | FPM-15PASR (Fujikura) |
| Temperature/Humidity | SHT15 (Sensirion) |

**Table 1. Component list of sensor module**

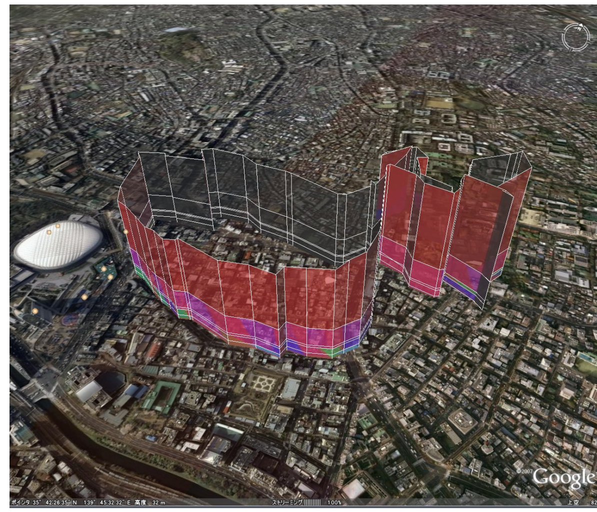


**Figure 4. Visualization example of ambient logging. Sensor output data (CO2, barometer, temperature and humidity) is overlaid to its location.**

## APPLICATION

Given the continuous ambient logs with location information are available, a lot of applications can go through. Figure 4 shows the plot of the sensor output to a map. This kind of geographical representation is easily applied not only time-based plotting of the sensor output data.

## DISCUSSION

For applications described above, most important thing is data and how to aggregate it, not a particular device. Hence heterogeneous sensor devices and its connection styles are possible. Figure 5 shows the possible variations of "Parasitic Ambient Logger" system configurations. There are many kinds of mobile devices in the world, so that one and only configuration of sensor module is not enough to achieve real-world sensor networks. For example, (a) shows simple and ideal one. At this moment, it is difficult to embed environmental sensors to mobile phones, because of size and energy consumption problems. (b) is more realistic one at now. sensor modules are connected to mobile phones via bluetooth. (c) and (d) are example configurations demonstrated in this paper. Thus various kinds of configurations are possible.

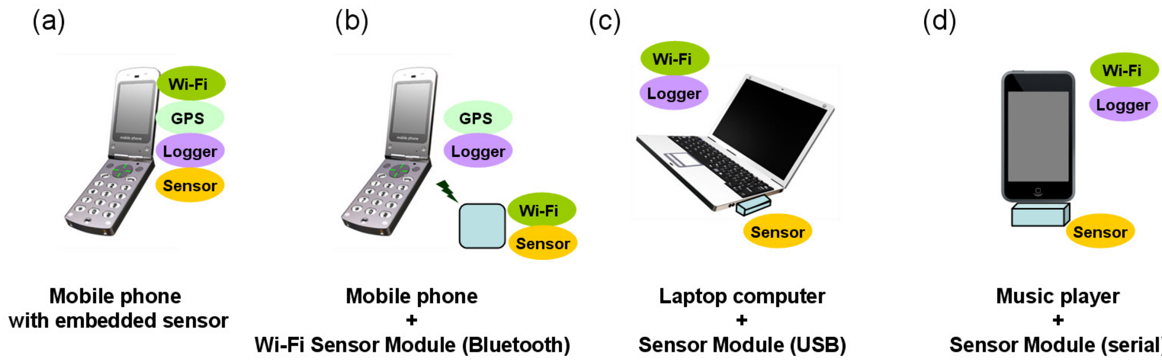


**Figure 5. Variations of "Parasitic Ambient Logger" system configurations: (a) Mobile phone with embedded sensors, (b) Mobile phone and Wi-Fi ready sensor module (connected via Bluetooth), (c) Laptop computer and sensor module (connected via USB), (d) Music player and sensor module (connected via serial)**

## CONCLUSION

In this paper, we introduced the main concept of "Parasitic Ambient Logger" that employs mobile sensor nodes to sense large-scale urban environment, its practical implementation and its application examples in urban area. This can be alternative approach against conventional sensor network infrastructure with static sensor nodes. Major characteristics of this technologies is using single function sensor modules attached to commonly available mobile Wi-Fi devices. Simple time based matching of sensor data and location information from Wi-Fi positioning techniques make mobile ambient logger possible. Compared with GPS, Wi-Fi based positioning can detect one's location with high accuracy in most urban daily situations. Thus a mobile sensor node approach in urban environment fits to an application area of Wi-Fi positioning system. Our proof-of-concept prototypes are demonstrated that the mobile sensing platforms works effectively in urban environment.

## BIOGRAPHY

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He suggests "Sensonomy" which is real world folksonomy using various kind of sensors.

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# Fresh: Cell-ID based Mobile Forum for Community Environmental Awareness

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#### ABSTRACT

This paper describes our mobile framework *Fresh* which engages the public in location sensitive experiences and in municipal monitoring of their environment, available both on users' mobile phones, and online.

This mobile forum is based on Cell-ID positioning and GPRS communications. It stores and receives information from a remote server which analyses and processes the scientific data received from a scalable mobile sensing framework called *MobSens* and makes it available to local communities through *Fresh*.

#### Author Keywords

Mobile sensing, environmental monitoring, pervasive computing, location based applications, Urban computing, Social Network.

#### INTRODUCTION

Mobile phones provide us with sounds and imagery from our homes and neighbourhoods, and the wireless capability of these phones will allow us to search, publish or share environmental data easily and immediately. People will have access to a great diversity of sensors, allowing them to make even more detailed observations of their environments [2][3][4]. They will be able to cross-reference publicly available spatially and temporally data - traffic, weather, air quality, -within their vicinity and feel rhythms of their community.

In this paper we describe our work in developing a mobile based social network called *Fresh* which utilise mobile and sensor networks power for the benefit of the environment.

#### Fresh

*Fresh* is a Mobile interface that utilizes GPRS networking and positioning using the cell-IDs from peoples' phones to allow people to discuss issues related to their local environment. This mobile utility (forum) will encourage users to interact at different locations and times to build a picture of their area and to reduce the carbon footprint in their environment by getting some advises from more experienced users.

This mobile forum can quickly help users to discover whether anyone within the surrounding area is interested in environmental issues. In addition, users will be able to access environmental data such as pollution, noise, weather Using prompts to trigger information from users, the interface is a mobile phone tool to engage and encourage participation over time from multiple locations (Figure 1). and traffic information which are generated by a real-time and scalable mobile sensing system [2].

MobSens system is being developed by MESSAGE project [1] which enables individuals to monitor their local environment and their private spaces (e.g. activities and health) by using mobile phones in their day to day life. The MobSens is a combination of software components that facilitates the phone's internal sensing devices (e.g. Microphone and camera) and external wireless sensors (e.g. data loggers and GPS receivers) for data collection. It also adds a new dimension of spatial localization to the data collection process and provides the user with both textual and spatial cartographic displays. While collecting the data, individuals can interactively add annotations and photos which are automatically transferred to a remote server (over GPRS connection). This makes it easy to visualize the data, photos and annotations on a spatial and temporal visualization tool and web interface.

#### Fresh User Interface

In Fresh, initially the world is empty but as the interaction is started the phone cell-ids fill with questions and answers which are asked by users who are trying to make their way across the city. Users can search their current location for any information about their local environment such as pollution level and weather information. Also they can look at a tagged questions and answers related to this location. They can choose to answer the question with a short text response. If they don't find what they are looking for they could start a new discussion by dropping a question for others to answer.

Finally, the on-line website allows users to look up information about any specific area they have been to. They



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can view where it has been, who answered their questions, the answers and any related discussion.

Whenever a user starts the application they are prompted with a number of options:

- to ask a variety of environmentally based questions regarding:
  - Traffic
  - Pollution
  - Weather information
  - Health problems
- to answer a variety of environmentally based questions which has been asked in this particular area (Cell-ID);
- to give advice regarding how to alter their behaviour and reduce their environmental footprint,;
- to view in their current physical area the latest (or latest maximum) measured pollution level tagged with location;
- to give a personalised user name (nick name) which they could use later to look up their input on the online interface.

All their inputs are automatically associated with their current cell-IDs. Here are an example of some typical questions and answers of Fresh system:

Q. <u>*Is there heavy traffic round here.*</u>

*A. Yes, many use this road to get to M11*

Q. <u>*Is Girton very noisy?*</u>

*A. Yes, it is surrounded by A14*

Q. <u>*Is bee population declining in this area?*</u>

*A. May be, farmers use insecticides excessively*

*A. Yes, genetically modified crops can harm bees*

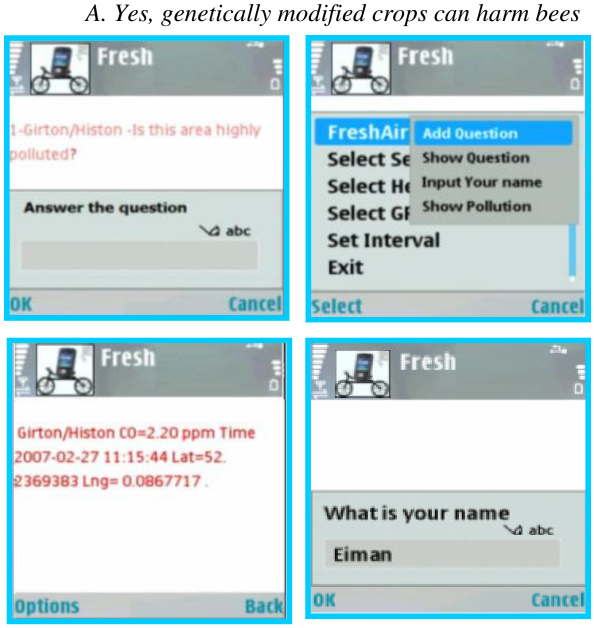


**Figure 1 Screenshots of the phone software.**

**Implementing Fresh**

Fresh employs standard client-server architecture (Figure 2). The software application runs on a mobile phone, which is currently any of the Nokia Series 60 phones 3rd generation, it is written in Native Symbian C++ which is capable of the following:

- logging the phone's current Cell-ID;
- Providing user interface;
- Connecting to the server in real-time.

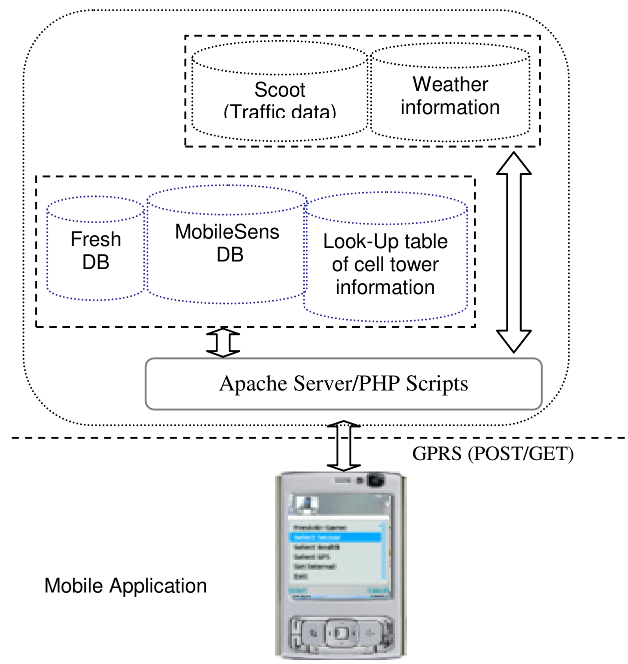


**Figure 2 Fresh System Architecture.**

The server component of the system runs on a standard Apache server with PHP and PostGreSql database. PHP is used to script the logic on the server with PostGreSql being used for persistent storage. Also the PostGIS plugin-tool of PostGreSql is used for spatial queries.

As most mobile phone networks do not provide mobile phones with routable IP addresses, all communications requests must be initiated from the client side. These calls are sent from the client to the server over HTTP using POST and GET requests, with the parameters being passed within the data of the POST request. The reply is then used to update the state of the client application. POST is used to send information to the server such as users new questions and GET is used to obtain information from the server such as local traffic information.

Information including user IDs, questions, answers, current location (cell-ID) and look-up table of cell-IDs data including Latitude and Longitude of each cell-tower (provided by O2) stored in the database along with the history of all previous answers and locations (Figure 3,3,4).

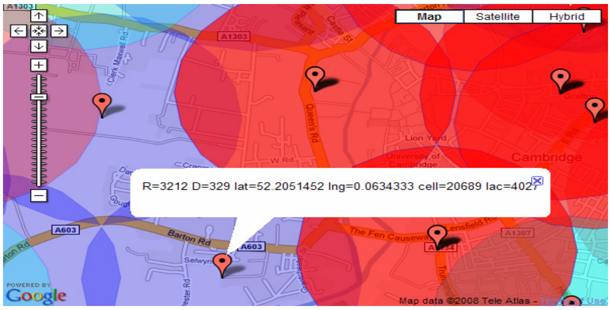


**Figure 3 Overlay of O2 cell-IDs (in Cambridge) on Googlemaps**

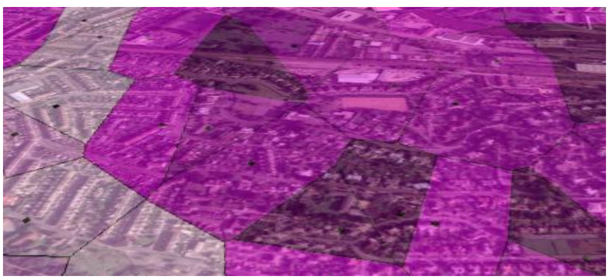

**Figure 4 Pollution map (Cambridge) based on Cell-IDs**

| CLat | CLng | CCel | CRadius | CDirection | CName |
|---|---|---|---|---|---|
| 52.xxxxxxx | 0.xxxxxxx | 19085 | 3212 | 90 | West Cam,cl |
| 52.xxxxxxx | 0.xxxxxxx | 19681 | 3212 | 60 | M11 Junction (12) |
| 52.xxxxxxx | 0.xxxxxxx | 50105 | 3212 | 270 | Lensfield Road |
| 52.xxxxxxx | 0.xxxxxxx | 55104 | 3212 | 299 | AddenBrook Hosp, Mowbray Rd |

**Figure 5 O2 Cell-IDs around Cambridge are labelled with friendly names.**

The database is also linked to real-time pollution, noise, traffic, weather and environmental information stored in MobSens database which is part of MESSAGE project [1].

### Future work and conclusion

Future developments will focus on the following:

- evaluate where, when, and why people participate;
- examine user behaviour and attitudes toward such systems;
- build context-based and interactive visualisation to draw a picture of this social network;
- allow users to interact with the system using media contents such as sound, image and video;
- extend Fresh to reward the users for their activities such as answering large number of question;
- investigate how to develop and deploy large-scale, mass-participatory pervasive systems;

We also hope to further improve the web interface to allow users (or local authorities such as city council) to look up information about any questions and answered that they have encountered, whether created by themselves or by others. They can view where it has been, who has created a particular question or answer, and can continue to follow its progress as the interaction continues.

By participating in this forum, we hope local communities will change their environmental behaviour toward sustainability, using the information that the system provides, and have an engaging, and enjoyable experience.

### ACKNOWLEDGMENTS

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### Author Biography

Dr Eiman Kanjo is a Researcher at the Computer Laboratory and Mathematical Sciences Centre at the University of Cambridge. She is also a member of Cambridge eScience Centre (CeSC). Her main research interest is in mobile and pervasive sensing.

Prior to joining Cambridge University, Eiman worked at the MRL (Mixed Reality Lab), Computer Science, University of Nottingham in the area of Pervasive Computing, location based games and mobile development.

She has also worked as a researcher and developer at the ICCAVE (the International Centre for Computer Games and Virtual Entertainment, Dundee) carrying out research work in the Interactive Toys and board Games project which is sponsored by the Scottish Enterprise under the Proof of Concept Programme.

She earned her PhD from the Computer Science department, University of Abertay Dundee, UK, in the area of Pervasive and Tangible interfaces based on Computer Vision and Interactive TableTops in 2005. She is an ACM Professional Member, a reviewer to a number of conferences and journals and holds the patent “Object Tracking System”.

# Nevermind Ubiquity

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## ABSTRACT
Systems-level innovation in many fields is reactionary. It responds to the emergence of new components, materials, and processes with new ideas for their use. Despite the benefits of this lure of the new, it can risk undervaluing the role of already deployed technologies in addressing unmet needs. This position paper draws analogies to the tension between new construction and adaptive reuse of buildings to discuss alternative design strategies in ubiquitous computing for citizen science, activism, and resource stewardship.

## Categories and Subject Descriptors
K.4.1 [**Computers and Society**]: Public Policy Issues – *ethics, regulation, use/abuse of power.*

## General Terms
Design, Economics, Experimentation, Human Factors, Legal Aspects.

## Keywords
Ubiquitous computing, pervasive computing, sustainability.

## 1. INTRODUCTION
Ubiquity is a quality, not a reason. "Everyone will have a car," automobile boosters told Southern California. Fifty years later, most of our innovation and hope comes from goals of less, or at least better, driving—not more.

Many *reasons* for information technology to be embedded everywhere are intensely attractive: More communication at less cost; more data available to more people; linkages of the physical and digital yielding deeper understanding of the world; perhaps even increased participation and personal empowerment. Yet the current model of everywhere computing, achieved through billions of mass produced, semi-disposable devices, which many of us turn over yearly for incremental improvements, cannot be applied to sustainability without some irony and, hopefully, some revision.



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## 2. WHAT WE ALREADY HAVE
Market pressures and increased corporate accountability are pushing manufacturers to reduce the impact of what they build, and as users we are more and more aware of the importance of recycling, reusability, and—sometimes—parsimony. Inside this workshop, though, imagine something extreme. Consider what it would be like to never get another mobile phone, a faster internet connection, a better laptop. Take all of our current technological capacity, and freeze it. We have a sort of ubiquity in our workshop room, even embarrassingly so. Now imagine growing old with those devices that we have, the way one might with a grandmother's watch or a treasured, vintage car.[1] What would we be forced to do? Be lucky to have? Imagine the current, amazing scope of the internet and mobile communications, also frozen.

Pacala and Socolow wrote "humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century." [2] They list fifteen "stabilization wedges" that could be used to meet the world's energy needs while limiting the trajectory of atmospheric $CO_2$, essentially orienting fifteen fields around performance goals needed by 2054. More than just know-how, do we already possess the *technologies* to address significant goals of citizen science and activism around the challenges of environmental stewardship? As designers, would facing a lifetime with our current technologies force us to act more effectively towards these goals? What would we do if we weren't focusing on the next semi-disposable device or dawning capability? These questions aren't about design requirements for sustainable ubiquitous technology.[2] They are about how sustainability means understanding and working with what we have, as much as dreaming of something more.

In architecture, there is a similar drive to create new designs with fresh aesthetics and modern materials, and to build spaces that address the unmet needs of groups of people. New buildings are considered cheaper to build, easier to expand and maintain,

---

1 In a recent talk, Saul Griffith mentioned another's quip that people should be assigned a Mont Blanc and a Rolex at birth, pass them on at death, and never buy another disposable watch or pen in their entire life. Current class implications notwithstanding, it's a provocative point.

2 Though that would be an interesting workshop. For our "frozen" technology, let's assume that the technology was built to be longer-lasting to begin with, perhaps consistent with the design principles of Danny Hillis' *Clock of the Long Now*: longevity, maintainability, transparency, evolvability, scalability. [1]

and more efficient. In fact, many older buildings have the potential to be more energy efficient than all but the most modern construction. [3] Additionally, in old buildings, we can find craftsmanship most could never afford today, and materials that would now be very expensive: stone, wood, and copper, for example. In some cases, that combination of materials and craftsmanship, along with the cultural context, create places that wear well, are appealing, and are part of our identities. To knock down an old building and create a new one with lower "total cost of ownership," higher "efficiency," and more "features" seems easier than fixing the old one. But these are buildings that we may never be able to make again, and they may resonate as part of people's identities, something which is not duplicated or quickly regenerated. In the long view, they may be sturdier and possible to maintain quite well, given some human ingenuity and effort. Ubiquitous electronics are of a different scale, and rarely does any single device contribute to our sense of group identity or resonate with us like a physical place. We can still take inspiration from (the admittedly more difficult) building practices that mix historical and modern structures, from adaptive reuse, from the acknowledgement of the extensive visible and invisible value in what we already possess.

Given a charge for "adaptive reuse" of the technologies and know-how that, hypothetically, our workshop now must live with forever, we would need to translate our aspirations for activism, citizen science, and sustainability into innovations that fit within the capabilities of the communications technologies we already have. And they are not lacking! Like working with classic buildings, it may require thinking that's not off-the-shelf conventional tech wisdom. In our workshop room, we at least have access to wireless devices, local and remote computation and storage; displays and perhaps a projector; connectivity of various kinds; local sensing of images, audio and location—and maybe more, depending on what people bring to demonstrate. We have stylus, keyboard and touch interfaces for data entry and probably many other capabilities. We even have access to existing online systems that facilitate self-report, mapping, data publishing and analysis, and media sharing. Surprisingly, we may need to spend some time on a real asset inventory of what we already have. Not only will we need to assess what our now-lifelong technological capacities are, but what assumptions about them we may have made "before the freeze" that needn't apply if we really have to make what we have work. We will need to create the pieces that fit between the old and the new, rather than waiting for everything to be "new." (Written down, the latter doesn't seem very logical—but I find myself doing it all the time.)

But work to do what? Next comes the question of where to apply our tools first, on what topics and towards what combination of discovering new knowledge, promoting awareness, or directly affecting change. As I understand it, sustainability takes the long view. Activism focuses on the urgent and significant. These are qualities and reasons in a productive tension. We can re-evaluate our existing technological capacity by asking how it can be applied to the significant, the urgent, and—this is what the long view means—what is *not for us*. It is a view that asks can we meet our needs today in ways that give others in the future the capacity to meet theirs?

Given an understanding of technology (and our design effort) as limited resources like any other, and the horizon of innovation as just that, there seems little choice but to turn what we have towards where we might learn the most and have the most impact. Our *current* technologies might follow the before-and-after of major urban development or interventions; they could provide insight into the longitudinal effects of significant legislation, new medications or sources of food. They could provide data on changes in the environment. They could reflect the contributions of microscale cultural and social decisions into the larger scale state of the world. They might contribute fundamentally to neighborhoods and communities documenting and expressing their lives in a way that promotes a new stewardship of diversity and existing resources. What do we find significant? Should it change as our tools do?

## 3. THE CONTEXT FOR DESIGN

To some extent, these applications and questions are being explored in the ubicomp and sensing systems communities using both current and near-future technologies. There is related work by UCLA, MIT, Dartmouth, Columbia, Carnegie Mellon, Intel, Nokia, and many others in the "urban sensing", "people-centric sensing", "participatory urbanism", and similar areas. [6-12] These approaches could be applied within the proposed technological time capsule of our workshop. The significant challenge facing us is how to move from early research to more significant and active contributions, both locally and internationally.

For this workshop, perhaps this thought experiment can help uncover assumptions underneath our current design practices and the status quo of academic research. To continue the earlier analogy, many supporters of the "green building movement" promote the idea that we can make our building approaches more "sustainable" or energy-efficient while benefiting the bottom-line of the organizations and people that build them. While this is a reasonable goal and often helps such projects find traction enough to get built, it can encourage assumptions and qualifications to our analyses that do not take into account other social goals, cultural values, or attempt full consideration of the economics or consumption practices involved.

For example, Emily Wadhams of the National Trust for Historic Preservation makes the argument that to recover the energy put into the creation of an older building, after it is demolished and replaced with a new energy efficient one, can take decades. [3] Similar assumptions to this one—that new buildings with expensive eco-materials necessarily reduce overall energy use, that a zero-sum economic result is a minimum criteria for success, or that the commercial market offers the only opportunity for significant contributions of technology—represent only one set of possible contexts for our decision-making or for answering the questions above. We should consider possible public policy mechanisms to bring new capacity to communities or to support sustainable approaches to meeting people's needs. These might include not just regulatory enforcement, as in California's Title 24 Building Energy Efficiency Standards, [4] but stimulation of expression and innovation in the communication channels created by new technologies, such as the U.S. Public Broadcasting Act of 1967 [5]. (Perhaps it is time to consider publically programmed services in the rest of the wireless spectrum, and not just television and radio.)

As designers, we could start by creating better explanations of what we think is possible *now* to others whose expertise could help us relate to it to both local and global challenges. We might embark on our own investigations with the tools that we have. If our technology was frozen, we would have unfamiliar advantage:

innovating within existing capacity will not be passé or underfunded. We needn't worry about our technology being superseded, or having to move to a new platform, or feeling the familiar stasis of waiting for the right technology to arrive. The active use of current internet and mobile technologies in ad-hoc crisis response and more generally in developing regions illustrate that this is possible and productive.

## 4. CONCLUSION

The concepts of sustainability and stewardship challenge us to value the existing as well as the new, and not to mistake the availability of a means for the motivation to use it. Perhaps the position is obvious. It also feels like unfamiliar territory for both technology and pop culture. To leverage the scale of ubiquitous computing towards sustainability—to make ubiquity matter—we have to be willing forget it as a motivation. Sustainability demands by definition that we focus on *what already exists out in the world*, and only then on what we will expend energy to build anew. Hybrids of the two may be some of the most interesting, humane, and challenging solutions we will find. The larger the scale we look at, the bigger variety of devices we will see in use, the older many of them might be, and the more we will have to work with. In this workshop, like Pacala and Socolow, let's look at what we already have, and make a similar analysis of ubiquitous computing around what we feel is significant, urgent, and not-for-us.

## 5. ACKNOWLEDGMENTS

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# Semantics-based urban sensing for Sustainability

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## ABSTRACT

The paper presents a brief discussion to sustainability in urban areas, a critique of existing definitions of sustainability and critizes the over-abundance of these definitions which renders the concept itself almost unusable. For a participative and local rooted involvement of the citizens in questions and policies for sustainable development in urban areas “sustainability” needs to be substantiated to the specific place, time and people in question.

In the connection of individual perspectives and shared global knowledge in real-world sitations the substantiation can happen as a discursive process and sets the topic in a certain place. This raises the question how to connect the particular knowledge of a citizen, a local or simply the user of a place with the knowledge of others (researchers, politicians, activitsts, other citizens) in a common field of action to help them to develop “their “ concept of sustainability for this time, this place and their problems.

To bring the people in power and increase their motivation to participate in environmental policies on a local level, great potential can be seen in serious gaming and alternate reality games to involve people and translates the invisible social and global processes to individual experience and spatial knowledge.

## Categories and Subject Descriptors

J.4 [**Social and Behavioral Scienes**]: Sociology

## General Terms

Design, Experimentation, Human Factors, Theory

## Keywords

Urban computing, Sustainable development, serious gaming, real-world experiments



## 1. Introduction

In an ongoing research project the Authors explore the conditions and potential of gaming like applications to support sustainable development in urban areas.

This paper summarizes the reflections on sustainable development and appropriate models of space conceptions as theoretical fundament for serious games situated in the everyday environment. With the conceptual framework of real-world experiments, small applications for mobile phones as everyday technology can ground abstract descriptions and qualities to specific real-world situations

## 2. Organizing Sustainability

If “Sustainability” is supposed to be not just a mere vision or phenomena, but a concrete path of human development the question arises how to perceive, manage and plan such trajectories.

Of course, sustainable development can’t be reduced to a pure management issue with clear defined goals, strategies and appropriate instruments to control the process efficiently. More than that, we must understand that a sustainable development in a holistic sense is a future-orientated set of learning, exploring and designing processes on a societal scale. The inherent characteristics are uncertainty, agnosticism and conflicts on various levels (Minsch 1998).

To complicate the development of methods to organize and monitor sustainability, the scope and range of a sustainable development itself transforms rapidly and continuously and is highly context-related. The ubiquitous ambiguity of “Sustainability” is a vague term and unveils under the lens of the practitioner and the practical researcher families of widely varying concepts systematized in a kind of generations. Metaphorically it’s the same like with culture: Everything is culture, but not everything is the appropriate culture for a certain task or situation. Analogous, sustainable development has to be attributed to discussion and continued exploration for the appropriate, far more than to the deployment of a certain concept.

## 3. The gallery of definitions

In the history of sustainability concepts since the beginning in the 18th century somewhere in the woods of East Germany, the Brundtland-commision mark the beginning of the modern understanding to “meet the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland 1991).

Since the Brundlandt report a series of different definitions has evolved and rendered the term "sustainable" almost unusable. The debate for the "right" definition of sustainability goes on for decades now and throws up new concepts and definitions in the same pace. David Pearce has called this continous flow the "gallery of definitions" (Pearce 1898) at a UNCED conference in 1989. In a survey to regional sustainability (DIEFENBACH 2001), the economist Hans Diefenbacher pinned down the outcome in a preliminary summary of the debate:

- None of the many variations was powerful enough to become widely accepted
- The genuine basic definition rooted in the forest agriculture has been adopted by the "mainstream" of the economical theories and transformed to complete new concept not compatible with the original definition
- New trajectorial understandings focusing on the ecological limits of economies incorporate meanings from the original concept of forestry again (sustainable yield, sustainable growth)
- The conflicts are solved in dialectical abstract and vague definitions

In a earlier study examining the sustainable economy on a regional level he states, that the achieved consensus on the understanding of sustainable development dissolves already when questioning the scope of the concept. Ecology, culture, economics, society, politics – a wide variety of understandings to include and exclude these fields appeared in his research. (Diefenbach 1997)

In a very strict understanding just the ecological aspects are covered and as such the term works as an analytical frame for a environmental management of resources as the economical base of human activity.

A group of wider definitions agree on the extension of the scope not merely compromising just the ecological conditions but also other aspects of the former mentioned fields. More or less most of these definitions can be retraced to the basic model of a "triangle of sustainable development". In this model the societal, economical and ecological dimension circumscribes the sustainability and possible conflicts between these dimensions are to be conciliated within the hierarchy of goals derived from the three dimensions. As in the former strict definition the environment and the natural resources are the preliminary condition for the human activity and the existence of later generations.

Other authors extend the scope to a much wider definition by incorporating the cultural and political sphere – the development of democratic institutions, the activity of NGO's, the emergence of participative structures etc. Charles Strong formulated in 1976 already a first concept for such a wide definition as

"…a path of development designed to help people define their real goals for growth and to utilize their own available natural resources and human skills to achieve these goals with patterns of growth that are sustainable, that will not destroy either the natural resource base upon which continued development depends or the traditions and value systems of the people concerned." (Glaeser 1984)

This approach puts it in the realm of ideas similar to the self-reliancy theory and some concepts developed for the Third World.

This point is essentially helpful on the local level of sustainability processes as it can be seen in a – unfortunately not very successful - crucial element of the Agenda21.[1]

In the conference in Rio it became clear to support the efforts for a more sustainable world on the global level with a local strategy to address individual action and behavior as the individual way of life. The "local agenda 21" was this local strategy. Thought as a participative process it represents a way to involve the citizens in environmental issues. The local agenda 21 tries to raise awareness on the potentials and problems of their community as "their" politics, to engage the citiziens in that and to encourage them to extend the scope of action and field of engagement.

Despite all implementation problems these goals are still present and it raises the question how to connect the particular knowledge of a citizen, a local or simply the user of a place with the knowledge of others (researchers, politicians, activitsts, other citizens) in a common field of action to help them to develop "their " concept of sustainability for this time, this place and their problems.

This is primarily a problem of learning processes in a real world which poses two questions: what are the appropriate space conceptions and how can we annotate concrete situations with environmentally relevant knowledge.

## 4. New spaces and space conceptions

Sustainable development is a spatial term, focused on the activities of different stakeholders and their impact on the environment. But the different stakeholder do not share the same perception of space. Planning institutions are looking at plans. Plain, rational, abstract documents of a Cartesian space, defined by describable borders. Individuals perceive space as sequences of subjective impressions. Thus, describing their space as narratives and linked rows of situations (Certeau 2007) which is rather a produced category than an a-priori existing entity. Linking and creating environmental relevant knowledge to space has to bridge the gap between these different perceptions and find appropriate models of space matching the user experience.

The theoretical perception of „space" has changed from the ancient conception as a stable, physical constellation of spatial elements to a dynamic, culturally and socially produced entity and the symbolic and medial level of the city gains significance, topological relations replaces topographical ones  and the „city "as spatial continuum is increasingly perceived as dynamic, process orientated structure.  "(Maresch 2002)

Beside the cultural sciences social sciences and the literature and media science discovered the space as a methodologically

[1] As follow-up of the Brundtland Commission the General Assembly of the U.N. at the Earth Summit, held in Rio de Janeiro in 1992, came up with the Agenda 21. The programme compiled a comprehensive blueprint of action to be taken by groups and institutions on a global, national and local level to support sustainable development (ref: Rio Declaration of Environment and Development).

necessary term (Löw 2001, Dünne 2006 , Sturm 2000, Thrift 1996, etc.). and interesting models evolved.

But also the genuinely space-based disciplines such as geography, architecture, landscape planning and city and spatial planning embraced their original reference system once again after a phase of time and temporalization (Virilio 1980, Castells 1996, Läpple 1992, etc) in the reverberation of the digital revolution. With the Renaissance of space new and existing theoretical approaches to the phenomena space were rediscovered and evaluated in their ability to solve the problems on the new battlefields of a temporal AND spatial signed society.

When embedding sustainable development processes in the city with ubicomp technologies the consequences are manifold.

The complex social, economic and ecological system called the „city“ forms areas, which consist of individual perspectives and social, technical, economic and ecological elements in different variations. Space theories developed by the social and cultural sciences try to illustrate this. Usually the acceptance of a socially constituted area presupposes however a perceptive space owner. The originating point of our discussion, the ‚purely objective observation of space', is insufficient on the level of the modern urban structure and requires a theoretical founding on the level of the individual (i.e. the space owner).

Fundamental for the development of a appropriate concept of sustainability for a specific site, a specific group of people as a common field of action is a understanding of "space" as a socially produced fluid structure. Such a concept of space, most appropriate developed by Martina Löw, bases on a relational concept of space and place initially developed earlier (Certau 2007, Foucault 1982, Lefebvre 1991).. Spacing uses not a metric classical space but the images and pictures which occur by perceiving the metric space (Löw 2001). The constitution of space happens in two processes: spacing as placed social commodities and the synthesis by individual perceiving these commodities. Place and location itself develops through both processes – spacing and the synthesis / combination by each individual. By this concept a complete social space is constructed as a context for learning processes of a heterogenous group of stakeholders. And can be the fundament for applications of learning, seeing, discussing individual and mutual knowledge in the city.

## 5. Individual knowledge for planners and citizens

For the post-fossil urban development under the impression of the climate change former planning, land-use and educational concepts of the industrial era are unsuitable. Concepts like „the intelligent house ", virtual power stations or the "Ubiquitous city" aim to new possibilities to interact with our environment, but they remain to a large extent technology-based. i-environments open up potentials for a trend-setting urban environmental and resource management. For citizens, but also for planning experts tools for the genesis of urgently necessary sustainable urban areas are missing.

With techniques based on an appropriate space concept refering to the construction of space through acting in the understanding of social construction of space and the possibility for customization of describing categories by individual semantic category building (ontologies) and - in semantically weaker form - as Folksonomien, information skeletons of urban situations are possible and can be integrated in a broader view shared by a group of people, the milieu, the city population etc. Thus new perceptions of urban areas are possible, which supplement on the one hand the traditional environmental information systems, on the other hand raise new awareness for environmental issues by the participative character of such a system. In particular the support of community-building and the experience in situ affect increasingly the motivation to discuss and reflect this topic.

## 6. Experiments and the real world

The characteristic of urban areas as elements of highly complex systems and the situatedness of all social processes – the contextual location of social facts in space and time – outlines the preconditions for application related research in this field. Accepting the fact that all social behaviour und thus the implementation of sustainable development concepts is situational, the regular methodologies of natural scienes are unsatisfying. A methodological research design could be more productive, to avoid the scientific separation of world and laboratory, theory and reality. Rooted in the ideas of the Chicage School the concept of "real-world experiments" of "Public Experiments" seems suitable. The general 'model' is both ecological and evolutionist: urban social life could best be understood as embedded in geographic and material environments. Fieldwork is preferred to laboratory, in fact the world is the lab.

The field carries with it an idea of unadulterated reality, just now come upon. Certain field-sites become unique windows on the universe, revealing only at this place something that cannot be moved or replicated in the laboratory. In such instances, 'being there' becomes an essential part of claiming authority for an observation or discovery. (Gieryn 2006)

Realexperimente are experimentation processes, which take place not in the special world of the scientific laboratories, but in the society itself. Experiments out of the scientific laboratory do not represent a deficitary form of the scientific experiments in laboratories in principle. However some preconditions must be fulfilled in a" Realexperimente Design ".Realexperimente are twosided: as in traditional experiments purposeful interferences creates measurable results and thus produce new knowledge, but not just for research and the academical world. While laboratory experiments are those procedures, in which scientists can test their ideas freely, Realexperimente are embedded into social, ecological and technical organization processes, which are usually carried out by many participants. (Gross 2005).

Substantial characteristics of the concept by Gross and Hoffmann-Riem is the simultaneousness of application of knowledge and generation of knowledge and something called openness to surprise. In Realexperimenten the production of new knowledge evolves if the experiment does not behave as foreseen. This „surprise "represents the actual knowledge progress. Therefore the Design of the experiment must be open to surprise, able to integrate the unforeseeable in a constructive way.

## 7. Possible outcome / Two projects

The aforementioned positions towards space, knowledge representation and experimental approaches to address issues of a sustainable urban development process on a local level, are part of our current research in mobile gaming as tool to enable citizens in understanding, creating and sharing knowledge. The paper is less a normal research report, but more a position paper to show three important focal points for applications to embed sustainable development processes in the urban with the help of ubicomp technologies.

To sum up these positions and illustrate the underlying thoughts, two small applications act in place of the typical conclusion.

„Can you see energy?"

Based on technologies like mobile phones and Multiplayer Games small games were developed (Pervasive Gaming/Alternate Reality Games) as serious games, which present themselves as outriders for new interactions in material environments, concepts and technologies. These games have been developed to support a space and an environmental perception in the context of urban sensing. How can we see energy consumption and does it create a different view on the environment when compared with the energy released by your walking? What visual phenomena and situations do you mark as being "natural"? And what is the quality of this facet "natural"? The spatial-temporal fixation of all of these collections in space, time and ontological description as an annotated interactive map creates a new opinion to the respective environment as community gererated content. The ontologies for the description of such situations can be provided beforehand by experts or developed or extended within the application by the user. The generated description language, categories of tag clouds can be shared with other users (the community).

"Urban space fixations and natural phenomena"

Picturing natural phenomena in the urban structure, tagged with the geographical position and the recording time with mobile phones as side-track to the everyday activities creates a collection of stream of photographs picturing aspects of processes regarded as being natural.

The collected results of the photographs of specific situation cannot only be regarded in maps, but also over time and describing terms to be sorted („which natural phenomena of the category X documented Y in the periphery of the place Z in the period N"). The information here are the the documented situations with the abilities of modern Smartphones (GPS for place, clock for time, camera for visual documents, microphone for audio documents and ontology based description lists). Additional information such as weather or traffic conditions can be integrated as information available in the Internet into the system, in order to make further semantic lists of new maps available. In the playful generation of these maps the city surfaces as a dynamic network of various natural facets.

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# Automated Journeys

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## ABSTRACT

Computing technology now pervades those moments of our day when we move through our cities. Mobile phones, music players, vending machines, contact-less payment systems and RFID-enabled turnstiles are *de rigueur* on our daily journeys. This workshop aims to examine these augmented journeys, to reflect on the public, semi-public and private technologies available to us in them, and to speculate on what innovations might be to come. Taking as our starting point cities such as Seoul, we aim to take seriously the developments in mobile technology as well as the advancements in autonomous machinery and how these mesh with our urban journeys. The workshop's empirical focus will be directed at producing 4 envisagements that either speculate and/or critically reflect on technological futures.

### ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

Weiser's vision of computation moving off the desktop and into the everyday world is now a reality in many ways. However, while there has been much study on how this has affected the household, the workplace and, to some degree, what Oldenburg calls "third places" [4], we are only beginning to understand how it is changing the way we experience the cities we live in. The authors have previously explored, through a series of workshops, how this has affected specific urban contexts [1,3] and, through an ethnographic study, how we might begin to talk about the urban experience in terms of the journeys we take [2]. With this workshop, then, we will bring these topics together and directly address how the public, semi-public and private technologies that we encounter and bring with us into the city shape our urban journeys. Here, the focus will be on the ways in which our interactions with the city become increasingly automated and how an awareness of the technological impacts on our daily journeys might inspire future designs.

## THEMES

During the workshop we will address five interrelated themes concerning technology's role in transforming our urban journeys. By examining how these themes are borne out specifically in the city of Seoul, we will attempt to understand what broader implications they might have as well.

**Automation and public interactions.** In our cities, automation is becoming more and more prevalent. Fast food is becoming even faster – now one can buy a hamburger in Seoul at McDonalds without having to hand over any cash or even a credit card; contact-less mobile phone payments are now a reality. Additionally, humans are disappearing even more from building security with robots in Korean schools replacing more traditional guards. We can ask, then, with the increasing uptake of automated machines, have urban journeys in Seoul become more individualistic? Does automating technology decrease the level of social interaction or instead give rise to new forms?

**Efficiency vs aesthetics.** All sorts of activities are being technologized, often under the guise of efficiency. Stopping off at the toilet while on your way to work once was a straight-forward affair, but now toilet users in Seoul are confronted by toilets with control panels offering heated seats, jets of water, and the sounds of chirping birds. Even cleaning one's mobile phone has become a public service; kiosks that allow you to subject your phone to a sanitizing blast while on the go are popping up all over Seoul. But are all of the technologies found in our cities making our journeys more efficient, or is it just the opposite? Must one choose between a pleasant experience or a fast one, or do urban technologies represent a new form of aesthetic?

**Automated identities.** Seoul's T-Money system allows for contact-less payments in city shops as well as on the subway. With a range of options from RFID cards to mobile phone upgrades to tiny plush characters (that can have their credit recharged using USB), there are myriad ways to take advantage of the system. However, such innovations also raise issues around how we are identified in and through our movements. Do e-money technologies such as T-Money make us more or less anonymous now that we can be uniquely identified by our RFID train passes, our mobile phones, our credit cards, and so on? And, more fundamentally, does the presence of this automation in our everyday urban lives offer new ways to present our selves? Are we becoming, in the words of Vertesi, technomorphized [5]?

**Layers of mediation and interaction.** We can no longer conceive only of human-computer interactions as defined by a single person using a technology. A person can interact with a public technology (e.g. a ticket machine) *through* a more personal one (e.g. a mobile phone). Likewise several people can use the same public technology simultaneously, or a person can interact with others through the technologies around them. Even technologies themselves are beginning to interact on their own. In Seoul it is now possible to have robots park your car or to ride in trains that have no human conductor. How then, we might ask, are these various and complex layers of mediation and interaction manifest as we move through our cities? Moreover, with these layerings, what are the ways in we might come to change our relations with technology and ultimately each other?

**The hybrid of technology and tradition.** With talk of technology transforming our lives it is easy to overlook the cultural traditions in daily life. But in a city like Seoul technology and tradition exist side by side. In the streets old-style food vendors proliferate, and puffed rice isn't something you make at home with a high-tech cooking device, rather it is something you go out on to the street to purchase from an "old fashioned" *no-jeom sang* (street seller). At the same time, however, *sticker sa-jin* (photo sticker) machines are ubiquitous in those same public spaces, allowing people to go out and purchase something made on the fly in a considerably more hi-tech fashion. This begs the question, then, how are, or how could, the technologies we encounter in our everyday journeys intertwine with older low-tech traditions. Is one replacing the other? Is technology introducing new traditions or ones simply re-shaping old ones?

## ORGNIZATION

The authors all possess ample experience in workshop organization. Drawing on previous successes, we plan to promote this workshop through the www.inbetweeness.org website, as well as through related mailing lists. The call will be targeted towards a range of participants from fields including computer science, interaction design, architecture, social science and the arts. Position papers of 2-4 pages will be invited about the design, implementation or study of technologies for automated journeys, and from these submissions we will select approximately 16. Accepted submissions will be published on the website prior to the workshop and a mailing list will be created to foster a dialogue of ideas amongst the participants. The workshop itself will take place over the course of a single day and include guided fieldwork, group discussion and design brainstorming. After brief introductions, the participants will be divided into 4 groups. Each group will join a local guide who will take them on a typical daily journey through Seoul. The guides will draw group members' attention to the automated systems and help them, where possible, to use the systems first-hand. After their morning excursions, the groups will return to the conference center and create short presentations about the automating technologies and types of interactions which they observed. They will then be asked to create a design envisagement that speculates and/or critically reflects on the future of urban technology. These designs will be presented and discussed, with discussions encouraged around the relevance of their ideas to UbiComp as a whole. All of the fieldwork material, design envisagements, and discussion themes will be collected and published on the inbetweeness website in an archival format for the entire community to access. Furthermore, as we have conducted several workshops exploring technology in urban settings, we will gauge the interest in a journal special issue at the conclusion of the workshop.

## ABOUT THE ORGANIZERS

*Arianna Bassoli* is a PhD student in the Information Systems and Innovation Group at the London School of Economics. Her interests lie in interaction design research, urban computing and how it can be informed by a situated understanding of people's everyday life. She has experience in the design of proximity-based and mobile applications that allow people to exchange digital resources in various everyday occasions.

*Johanna Brewer* is a PhD student in the Informatics department at the University of California, Irvine working with Paul Dourish. Her thesis is focused on urban computing, particularly in the design of social technologies. Her research centers around how an examination of mobility in urban spaces, specifically the London Underground and the Orange County bus, might help to inform these designs.

*Alex Taylor* is a member of the Socio-Digital Systems Group at Microsoft Research, Cambridge. He has undertaken investigations into a range of routine aspects of everyday life. For instance, he's had an unhealthy preoccupation with hoarding, dirt, clutter and similar seemingly banal subject matter. Most recently he has begun obsessing over robots and other curious 'thinking' machines.

## ACKNOWLEDGMENTS

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# Make Me Happy: In Situ Data Collection for Urban Sync

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**ABSTRACT**
This paper gives a short overview of *Urban Sync*. The underlying research theme of this project is about the matter of personal interaction and relationship building in urban environments. It starts with a storytelling approach to motivate the research questions and challenges. Furthermore it describes a technical setup to perform in situ ethnographic research by the author to collect multimodal data about the context of the urban environment and the physiological responses of the subject when performing everyday life activities.

**Author Keywords**
Affective computing, cultural hacking, urban journeys, urban planning, physiological data, emotions

**ACM Classification Keywords**
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

**EXCERPT OF MY DAILY DIARY**
„... damn, missed to recharge the iPod! What about the scooter? hopefully working, I am in a rush to our weekly meeting to discuss the work of the research group, although my head is filled with ideas for some urban art projects, anyway I need to be happy first! So, what' s missing? Latte + Twitter! My scooter is nice and brings me in 10 minutes from the suburbs to downtown where I head to the one and only coffee shop being located in a traditional cosy building with nice chicks around and a perfect italian coffee machine from the late 60ties. WiFi is free, WiFi is fast. Yes this makes me happy! Checking replies and direct messages at Twitter and wondering why people post so much crap ... on other days when I am alone in a new place, a different urban setting, knowing nobody, like 2 weeks before in Paris, I ended up at McDonalds for free WiFi and I was so damn happy about these silly postings of my „socioborgs", thats how I call myself and all these nerdy people twittering as hell. Although the music in the coffeeshop is not such bad it could be better by exploring the playlists of all the other people sitting around and doodling their MP3s on shiny iPods or being in isolation behind their earplugs, at least half of them look interesting enough to get rid of my digital chitchat and get into some real conversation, that would make me feel really happy! I wonder if there will be once in a time a happy machine, a personal companion who knows about emotions, who has been part of my life tracking all my interactions with people and things and places, logging my implicit and explicit reactions and having enough computing power, AI algorithms, connectedness to other machines, people, cities to resolve from all these constraints to 1 solely thing for me, his master: More Happiness! ..."

**SCIENTIFIC CHALLENGES**
As a trained computer scientist and musician, holding a Ph.D in music information retrieval and AI, my research has been shifting from pure number crunching to ethnographic techno-sociological prototyping. The underlying theme gets meanwhile a little bit clearer than it was in the beginning. Any kind of interaction (man-man, man- mobile device, machine-machine, etc.) which is taking place in my personal habits when encountering cities, people and technical artefacts seems to resonate with my most inner search for balance and happiness. There have been devices (e.g. the iPOD touch for doing dualmode twittering over WiFI and listening to my favorite music) and even applications (our prototype *BluetunA* for sharing music taste) that made me feel better, but the same way a lot of the things around have been time-consuming, frustrating and separating. Ending up in 2008 indeed urban places act like the main mediator for my personal well-being being connected to people and devices on different ranges. The mixture of instantaneous, near-field, city-wide and global interaction has to be in perfect balance to optimize my daily journeys thru the city and life.

Therefore the research rationale I will follow has been blueprinted partially as a short term scientific mission entitled *Urban Sync*. It will investigate the matter of happiness and how it relates to aesthetics vs. efficiency, the hybrid of tradition and technology and the complexity of mediating layers of diverse granularity and scale in urban environments. As a starting point I will conduct an ethnographic study by gathering realtime audio, physiological data, and network activities in the GHz range in different european capitals. By using a portable GPS datalogger the data will be underpinned by an according spatial representation. The setting of the research is difficult since the well-known problems of in situ data collections which are aimed at studying emotional responses and human behaviour will encounter. The technical setup consists of a portable digital audio recording device, a prototypical smartband which records heart rate and skin conductance and a scanner to track activities in the HF range. In combination with the time-stamped GPS data complete trails of my personal experiences will be recorded and stored for subsequent post-processing. This latter stage will seek for correlates between the individual data channels by using machine learning techniques and information visualization techniques.

## ACKNOWLEDGMENTS

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# Difficulties in Skill Acquisition and Pervasive Environments

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## ABSTRACT

Pervasive computing implies new application opportunity as a result of technology integrated into everday environments. Whether considering the sophistication of emerging mobile platforms, or the automation of routine tasks in service provision, technology mediated interaction is woven into the time between home, work and leisure. Two recently emerging areas of innovation regarding mobile and pervasive applications pertain to health and learning. However, where recent findings in these areas seem to indicate the potential for ubiquitous applications in everyday environments, there are caveats presented by the nature of interactions between traditional work, home and leisure environments. The paper introduces the opportunities, challenges and potential solutions to integrating robust health and training applications into automated journeys.

### Author Keywords

Novel user experiences, outdoor applications, pervasive application design, interaction design

### ACM Classification Keywords

H.5.m [Information Interfaces and Presentation]: Miscellaneous

## INTRODUCTION

With an ever-growing cohort of individuals getting older, health care and social systems are struggling to redefine what it means to consume resources and remain engaged during the later stages of life. In tandem with this demographic based need, aging is one of many areas to have had a renaissance of sorts, in response to recent findings regarding brain plasticity. The brain is malleable, positively reshaping itself in response to many different forms of learning. In contrast, as we get older the brain undergoes characteristic degenerative changes[13]. Somewhere between these two processes, it has been found that maintaining a rich intellectual life, learning new skills throughout life, and adhering to a minimum of physical activity not only maintains a higher general level of cognitive function, but also staves off disease processes such as Alzheimers disease[12, 7].

It becomes possible to envision applications that utilize multimedia rich mobile platforms to engage skill acquisition at diverse moments in our daily lives towards positive health. However, several key considerations of movement through cities contradict concerted skill acquisition during these transient moments. When mobile, is it possible to consolidate information? Secondly, as one can expect a modicum of passivity in transitional environments, does learning require active engagement? Lastly, how can training systems compete with the interface of the environment to support any attention from a user?

## CONSOLIDATION

Efficiency requires downtime. An interesting area that highlights this fact is sleep research[11]. It has long been understood that sleep is necessary for optimal cognitive function, as it is reflected in the behavior of sleep-deprived individuals. Sleep deprived individuals are worse-off. However, recent neuroscience studies have been providing insight into the process of consolidation, in which many different types of memory require a cascade of brain changes that only happen during sleep. Our understanding of these processes is at the cellular level of detail. For example, researchers Gais, Rasch, et al. [6], with a placebo controlled crossover design, have shown a visual task where, if a certain neurotransmitter is inhibited during sleep, improvement in the measured visual skill simply does not take place the following morning. Neural cellular processes also support time-course sensitive procedural learning while awake[1], as explored by mechanisms such as long-term potentiation[8] and long-term depression[2] (a kind of sensitivity of activated cells to prime for subsequent information from the same stream in the future). The point is that consolidation and downtime is critical to learning.

Turning to everyday environments, the contradiction of integrating skill acquisition tools into our everyday environment is that efficiency is not monotonically related to the amount of time engaged. Potentially, the time in between work, home and leisure is required to support cellular mechanisms of consolidation. A potential solution is to build systems that explore learning with sensitivity away from sheer repetition. By oscillating between moments where users are being exposed to information they are required to engage with to learn, and moments where the users are allowed to simply exist in the everyday environment devoid of direct engagement, technologies will mutually support skill acquisition while recognizing the biological limits reinforced by non-engaged movement through the city.

## PASSIVE VERSUS ACTIVE LEARNING

Constructionism is a dominant theory of education in which learning is proposed as part of an active process in which mental models of the world are tested, and tested best while users build in their environments[10]. This directly contradicts the idea that significant learning can take place passively. Moreover, as an individual passes between active environments, whether home, work or leisure activity, the transient everyday environment may be the exact opposite of what constructinists have shown to be the type of environment that supports active learning.

A potential solution once again lies along the time-course of information presentation. All moments in passing from one environment to another are not created equal. Some moments warrant attention, mediating any technology driven learning task to the passive background, and other moments do not. When a user reads a book on a subway train, they mediate their own give-and-take between activity and passivity of the reading endeavor. Technologies to support skill acquisition need to similarly allow for this give-and-take. To do so, repetition of key moments in the learning process, or during the presentation of information, distribute the pressure for a user to acquire the information across a larger period of time, supporting their external requirement to be able to be, at some moments, actively engaged, and at other moments, not. This doesn't address the lack of building opportunity in the everyday movement through the city, but such detail would need to be addressed given the nature of the skill to be acquired or the information to be learned.

### Multi-sensory Interfaces

Similarly, purely from an interface perspective, the sensory domains in which a user is engaged at any given time during transition in their environment are disproportionately visual, tactile, or auditory, based on the task at hand. The train is loud. Driving is visually exhausting. Exchanging cash for services has a user in a tactile exchange. As human-computer interaction begins to examine assistive devices and universal access[5, 9], as well as multiple domains of input for novel systems[3, 4], these research agendas can teach us how to actively engage users across sensory disciplines. If a mobile learning tool, in parallel, presents information to multiple sensory domains, diverse competitive environments to the learning tool can be compensated for. If the environment in one moment demands disproportionate visual attention, or tactile, the other domains can compensate.

## CONCLUSION

At the interface of pervasive computing and our desire to acquire intellectually fulfilling, and subsequently healthy lives, new interfaces that introduce skill acquisition and learning into our everyday environments are on the horizon. These interfaces have the challenge of existing in the transition between environments that are perhaps more suited to concerted study and learning - those of the home, work, or leisure environments. However, that does not discount the opportunity to combat where the environment is adverse to skill acquisition. We have shown that a better understanding of the biological limits of information consolidation, the nature of different types of learning, and drawing from ongoing research into multisensory interfaces can provide research based strategies to begin to develop learning applications for the automated journey.

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# Automation as a very familiar place

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**ABSTRACT**
We propose that the constraints set by the infrastructures supporting our journey through spaces we create are a strong determinant of how we experience those spaces and their places. We argue that rigidity of infrastructural constraints causes familiarity, and that familiarity breeds the automatic experience.

**Author Keywords**
Automation, qualitative experience, infrastructure.

**ACM Classification Keywords**
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

*The train came out of the long tunnel into the snow country. The earth lay white under the night sky. The train pulled up at a signal stop.*

*A girl who had been sitting on the other side of the car came over and opened the window in front of Shimamura. The snowy cold poured in. Leaning far out the window, the girl called to the station master as though he were a great distance away.*

—*Yasunari Kawabata, Snow Country*

The infrastructure making our journeys through spaces possible have also always shaped our experience of those spaces. We wish to propose that the constraints of infrastructure are an important though certainly not the only factor in producing our experience of the journeys they support.

We are interested in the qualitative attributes of infrastructure and consider their consequences for the automatic experience. The choice of the wording "qualitative attribute" rather than the software engineering term "quality attribute" is intentional—we want to allude to the richness of meanings that are determined through qualitative studies rather than the more restricted notion of quality used in software engineering, which intend to capture what, when talking about software, is meant by a 'quality product'. At the same time, we take note of the experience in software architecture that the structure or structures of a system are strong determinants for that system's quality attributes [1], including usability [2]. We hypothesize therefore that the architecture of our technological infrastructures is similarly important to the ways in which we experience the places and spaces they support.

The quotation chosen to initiate this paper illustrates how difference in landscape as evident to a train passenger can be used to evoke a feeling of place to readers. In the hands of a nobel-prize winning author, the familiar features of train cars and a winter landscape are used to reconstruct for readers a sense of place. Arguably, much of the power in these concepts as used here lies in their familiarity. They are familiar because they are stable across a variety of contexts—a journey by train in Scandinavia now compared with one in Japan some hundred years ago, while not exactly the same, has some stable and defining features: the passive traveler situated in the train car, observing the landscape passing by the window.

What is more, the stability across many contexts of how train travel is experienced enables a shared understanding between people. Much of this stability is due to the technically necessary features of rail infrastructure. It by nature defines one or more fixed and non-negotiable routes through landscape, and the passenger is necessarily confined to "their" place in the train car for much of the journey. Certainly the passenger can get up and go to another car, but the practical circumstances given in the train car is a strong force for most passengers to surrender and remain passive in the place defined by others, the train car.

What happens to our experience of journeys such as train travel if it is infested/blessed with the wave of technologies ubicomp represents—enabling people to increasingly personalize their surroundings? Personalize, we must note, is justified precisely because it allows people's preferences to direct more aspects of their own experience, enabling them to make places their own. When people make places their own, by e.g. choosing the soundtrack to their journey, they are simultaneously avoiding the alternative. That alternative, the place that could have been or the displaced place, is what we currently have a diminishing opportunity to study. It is rich and important precisely because people cannot choose and personalize ad infinity, because it brings out the frequently collaborative behaviour of appropriation that, in de Certau's [3] terms, are the *tactics of the weak*. Personalizing ones experience rather than producing it collaboratively would seem particularly likely during transportation, as the people one happens to be co-located with are often strangers.

Opportunities for personalization, of course, are never unbounded. Infrastructure always constrains behaviour, and anyone who has tried to reuse software will know that is no less true for digital technology. What is the relationship between the constraints set for us by technological infrastructures supporting mobility and the ways in which we experience journeys? Will the digital infrastructures of tomorrow enable future authors to draw on experiences it frames with the same richness that Kawabata does for train travel? Or will an unprecedented opportunity for personalization mask the influence of infrastructure's constraints, making them too subtle, localized and personal to allow analysis?

Tailoring of technology to the preferences of the individual is to a degree orthogonal to the question of control—who is doing the personalization. On the one hand authors such as Aarts et al. [4] envision environments saturated with AI technology that are able to artfully adapt to the desires of the individual. On the other hand, initiatives such as PalCom [5] emphasize the necessity of people remaining in control. We take the position, along with Barad[7], that distinctions are always local, including the of distinction between humans and digital agents as pointed out by Suchman[6]. In some contexts this distinction matter, in others it does not. To designers it often matter a great deal, because designers must try to match technology with use. For users they may not be important—how many of us are aware of when the trains we travel in are steered by a human an when by a computer?

The position that the distinction between human and digital agents is localized—important in some contexts and not in others—enable us to ask the question: in what contexts is it meaningful to talk about automation as a distinct mode of control ? Perhaps it is not meaningful in general. Automation does not always mean external to a human body. Psychologists know that a large part of our everyday behaviour is automatic in the sense that we are not consciously aware of it [8]. The ways in which often repeated patterns of behaviour become automatic is familiar to most people. Distinguishing between what we do unconsciously and what is done for us that we are not conscious about may not be significant in every context. Thus the employee who bicycles to work following the same route as he or she has for twenty years may have an experience that is every bit as automatic as that of the person who for twenty years have been going to work on the same computer-steered train. Yet if we instead look at the means available to them for handling contingencies, the distinction between automation-in-the-body and automation-in-the-computer becomes significant. If a need arises en route to change the destination, the person in the train is left with fewer options—those designed for him or her—than the person who drives a bicycle. This example shows that the force causing automation can be of different magnitudes—automation-in-the-body is easily changed or overruled by the individual, whereas automation in which control is situated in infrastructure is much more rigid. This, interestingly, is true for digital infrastructures as well—any software architect will agree that changing the architecture of a system has far-reaching consequences, and is often very costly.

## CONCLUSION

We have suggested that the rigidity of constraints set by infrastructures, digital or otherwise, is a key factor in producing the automatic experience. Digital technologies that increase the opportunity for personalization may change the ways in which infrastructure influence our experiences. In particular, we raised the question of whether it makes the meaning of our experiences more personal and therefore less shared. Further we suggested that the notion of automation can usefully be analyzed in terms of where control is situated and in terms of the rigidity of its implementation.

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# Connectability in Automated Journeys

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## ABSTRACT
Automated journeys are intimately intertwined with technologies that capture, transfer, store, process, and display information. Analyzing the impact of such complex environments on urban experiences is a challenging task. As a first step towards understanding automated journeys, we focus on the connections among people, things and places, and introduce the notion of *connectability* in relation to the active human process of establishing meaningful relationships. By rethinking existing technologies in a city from the perspective of *connectability*, we can begin to identify key dimensions of the design space of technologies for meaningful relationships.

## INTRODUCTION
In a city like Seoul, pedestrians use digital technologies such as mobile phones, RFID transportation tickets/gates, and contactless payment systems. While these technologies are being proven to make our journeys efficient, their impact can go beyond the narrow concerns of efficiency. Indeed, they can enable us to encounter everyday spaces in new ways, creating *"alternative spatialities"* (Dourish, 2006).

We can begin to understand automatic journeys' broader impact by analyzing how people, things and spaces encounter one another in such journeys. To closely examine the process in which people establish connections, we distinguish *connectability* and real connections.

*Connectability* arises when there is perceivable relevance of people, things and spaces. People can selectively externalize and/or internalize it as a real connection such as a friendship, a Familiar Stranger (Paulos and Goodman, 2004), and a 'location bookmark.' Technologies could automatically generate connections (e.g., food traceability systems.) Alternatively, they can generate *connectability* through the provision of information resources, which people can interpret and use in order to actively establish meaningful connections.

Information media play a key role in communicating *connectability* and thereby influence real connections. For example, the rise of the popular print culture may have changed the connections of geographical spaces in the head of the public[1]. More recently, social networking websites reflect and influence the connections among people. Embedded devices in a city could similarly influence the connections that we make in everyday spaces.

[1] Ikegami (2005, p.371) carefully suggests that this could have been the case in pre-modern Japan.

## CONNECTABILITY IN A CITY
Ubicomp technologies had begun to fill urban spaces with various kinds of connections and *connectability*. 2D barcodes printed on food packages digitally connect the food items and relevant information about farmers, shipping dates, and agricultural chemicals. People use mobile phone-based navigation systems (e.g., *NAVITIME* (Arikawa, Konomi and Ohnishi, 2007)) not only for wayfinding but also for proximity search and geographical 'bookmarking.' RFID transport tickets (e.g., Japan Railway's *SUICA*) store tens of train-ride records in their read/write memory. These records can be displayed or printed for personal reviewing and reflection. *NaviTa* [www.poster.suica.jp/navita.html] extends the interactive poster *SuiPo* (Tsunoda et al., 2007), enabling travelers to easily fetch a local map and a directory of nearby stores/services on their phones (see Figure 1). Systems like this could influence the way we associate one space with another, and the traces we leave (e.g., through RFID scanning and wireless web access) influence the way we present ourselves to the world, possibly influencing the *connectability* about us.


**Figure 1.** The *NaviTa* system at Tokyo Station. People can fetch a local map and store/service directory by touching their RFID-chipped mobile phones on the green "touch area."

## *LOVEGETY*: LESSONS LEARNED
*Lovegety* (see Figure 2) is a commercial matchmaking device that uses short-range radio. It is an extremely simple device, having only two push buttons. One is the power button and the other is the mode button for selecting one of the *Talk*, *Karaoke* and *Get* modes. (The three small LEDs

below the mode button indicate the current mode.) LED$_1$ blinks if peer devices exist in proximity (about 5m) and LED$_2$ blinks when the modes of the colocated devices match. The slide switch on the left is used to turn on/off the sound that accompanies blinking.

The device is not on the market anymore, but we can still learn from relevant popular writings such as the book "*Lovegety* Perfect Manual" (Gety Study Group, 1998). This book has 151 pages, including 40 short anecdotes from users, 7 "basic laws" for hooking up smartly, 16 pieces of "expert advice," and 30 maps of popular downtown spots across Japan together with short descriptions of how *Lovegety* could be used in these spots.

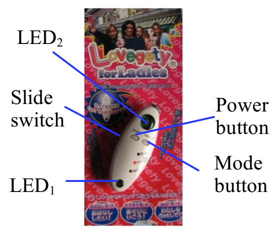


**Figure 2:** Lovegety

Due to the author's anonymity and the writing style that resembles the ones in lowbrow entertainment magazines, it may be wise to be cautious about the credibility of what the book says. Yet, the book seems revealing about the subtlety and delicateness of the social space in which the device is embedded. For example, it is *not* recommended to simply turn on the device:

> "If you find someone who you think might have *Lovegety*, first off, just quietly walk in front of the person, and, at that moment, cast a quick look and make eye contact. Then, turn on the mode of your Lovegety after one or two minutes. It is said that the talk will go smoothly in this way." (p.20)

Acknowledging such subtlety around *connectability*, we can carefully examine how things are in today's automated journeys and how things could be in the future.

## TOWARDS SUPPORTING CONNECTABILITY

Since *connectability* is a highly general concept, it may be useful to consider various kinds of *connectability* in relation to the following 6 dimensions:

| | |
|---|---|
| (1) People - things - spaces | Connections can be made within and across the following categories: people, things and spaces. |
| (2) Digital - physical | Connectability can be represented by using digital, physical, as well as 'hybrid' media. |
| (3) Explicit - implicit | Connectability can suggest connections explicitly or implicitly. Connectability can be *ambiguous*. |
| (4) Real time - batch | Connectability can be identified in real time (e.g., Lovegety) or through batch processing (e.g., post hoc analysis of GPS traces) |
| (5) One Time - repeated | Some opportunities to connect arise only once. Others arise multiple times and even repeatedly. This dimension is also relevant to *serendipity*. |
| (6) Ignorability | Connectability can/cannot be ignored without causing negative effects (cf. *"plausible ignorability"*) |

**Table 1.** Dimensions of *connectability*.

We would like to explore the design space of technologies for supporting *connectability*, based on these 6 dimensions. In doing so, we can consider social networks (Konomi et al., 2006; Konomi, Sezaki and Kitsuregawa, 2009), relationships of spaces, and *ecology of objects* (Brewer, Mainwaring and Dourish, 2008).

## CONCLUSION

We discussed *connectability* as a first step towards understanding automatic journeys' broader impact beyond efficiency. Ubicomp technologies can enable new forms of *connectability* in a city, and technologies for supporting *connectability* need to be integrated into subtle human processes. We then introduced the 6 dimensions that could be used to explore the design space for supporting connectability. In a related research project, we have quantitatively examined pedestrian movements and proximity patterns in a train station (Konomi et al., 2008), and we plan to qualitatively examine pedestrian experiences as a next step. We feel our discussions are most related to the theme *"Layers of Mediation and Interaction"* although we touched upon the issue of *"Automated Identities."*

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# Liminal, Spiritual, and Ritual: Fabrication and Evasion in Urban Journeys through Portable Devices

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## ABSTRACT
In this paper, we briefly discuss our ongoing research on the morphing role of portable device ecologies in urban journeys. Specifically, we discuss spirituality and liminality, socialities that emerge from the hybridities of devices and people, and the inevitable intrusiveness caused by perpetual possession of devices.

## Categories and Subject Descriptors
D.3.3 H5.2 [Information interfaces and presentation]: User Interfaces.

## Keywords
Non-use, Urban computing, device ensembles, mobile devices, camouflaging, spirituality, liminality

## 1. INTRODUCTION
With the increased ubiquity and decreased prices of wireless technologies, mobile technologies have merged into the practices of everyday life. Carrying these technologies almost everywhere one goes has become a common phenomenon in urban environments [2]. These device ensembles, or arrays of portable devices, include mobile phones, gaming devices, music players, and thumb drives [7]. The computation in these devices is not just physically embedded, but also socially and procedurally embedded. So much so, that we continually use these devices without thinking of them as computational [1]. However, as much as understandings of the use of device ensembles are important, non-use is traditionally neglected.

The portability of information and informational objects has resulted in blurred boundaries between different spheres of life - namely work, home, and play, unrestricted by geography. This leads us to raise pertinent questions on the nature of interactions shaped and mediated by these portable devices in our urban journeys. We speak here of journeys of everyday life, augmented by technology, between first, second, and third places [5]. The transformative power of these devices lies not only in participating in different spaces, but also in creating them wherever we go. They aid in temporarily appropriating public spaces for personal use [3] [4] to escape the surrounding physical space. In our on-going research we find that in the presence of strange or insignificant spaces, people, or practices, these device ensembles can play an important role in providing the individual with a link to their private world, and intensify their personal and emotional relationship with the technology.

In this paper, we reflect on our ongoing research on the role of portable technologies in our day-to-day lives. We question the role of device ecologies in daily routines, the marriage of technological spaces with physical spaces, and the practices surrounding non-use of portable technologies.

## 2. METHODOLOGY
We conducted a round of interviews with 12 graduate students in the University of California, Irvine campus. The informant pool ranged from 23 to 35 years of age, with 7 male and 5 female. Each interview lasted approximately 60 minutes. Compensation was provided. The interviews were preceded by a questionnaire structured on features and processes that affect personal relationships with mobile devices, such as memories, personalization, routine, adaptation, and mobility. The interview questions themselves explored a typical day with portable devices, transition of spaces, the tasks and contexts of use of devices, offline and device intrusiveness, play, and liminality.

## 3. FINDINGS
In this section, we introduce a subset of our salient findings relevant to the theme of this workshop.

***Liminality and spirituality**:* By spirituality, we differ from the conventional discourse on technology use for religious practices [8]. We broadly speak here of doing something “higher” as opposed to material or physical things [6]. Our findings show that technology can have good as well as bad impact on spiritual lives, and one has to be highly selective when dealing with technology for spirituality. Two forms of practices are worth noting here: the *use of portable technologies in supporting spiritual practices* and the liminal *shutting down of devices to achieve a state of spirituality*. The former involves emotional engagement with the technology, directly factored by intrusiveness, context, and worth. For example, mobile phones are considered spiritual when they helped in reaching a loved one, and portable music players in playing the right track at the right time on shuffle. The latter involves escaping technologies while doing something of greater importance, such as switching off mobile phones on weekends or while spending time with family during a vacation, or relaxing n Sundays, away from computers. Consider the following quote by P4, a female: *''Once a year (at least!) I take a vacation with my family and I purposely vote for really remote locations or international destinations so that nobody can reach me."*

We propose that in addition to the variables of efficiency and aesthetics, emotional engagement should also be considered in the design of portable devices. User experiences should be designed with and without technology. Portable devices are prone to battery deaths in addition to manual occlusion. How should the device handle incoming requests when turned off, in addition to Voicemail?

***Masquerades and armours:*** Portable devices were also appropriated for avoidance and concealment, by creating an impression of technological engagement. Camouflaging into the environment or indicating absent presence through subterfuge mechanisms such as putting on headphones or using the mobile phone while passing a group of people was quite common. For example, P10 uses her iPod and Voicemail to escape potential socialities: *''Basically, if I am like avoiding certain people, in certain situations, because our office is like so far, you have to pass so many people. Not that people bother me by saying 'Hi', but I don't want to be obligated to talk to anyone. I take the time to check my Voicemail, even though they are messages that I have already addressed. Other times I play a game or pretend to do something. My MP3 player, I really do listen to it, so I use it as a social signal than to camouflage. Sometimes when I see someone I'll just use my mobile phone''*

In addition, portable devices were also used a defence shields to indicate non-availability. Social presence, which indicates social availability, is mediated by devices. According to P3, a male informant, *''People keep bugging me, like if I want to work and someone wants to come and talk to me. I put the headphones on my iPod and ignore people. If people come and poke me then I talk to them. I mean I do have peripheral vision. But people seem to get the idea that if you have headphones on, you don't want to talk to them. I really hate when people keep talking to me and assume I am listening things.''* These defence shields were also used in times of anticipated danger, such as walking down a dark street at late night or crime-prone areas.

***Intrusiveness:*** On the subject of intrusiveness caused by people versus portable devices, our data shows that people were accused of causing intrusiveness, not the devices. It was commonly held that devices have no minds of their own and are under the user's control, barring exceptions of technological inappropriateness such as alarms going off during meetings and so on. From our analysis, three forms of intrusiveness emerged: *intrusiveness caused by others*, such as peeping to look at monitors and unanticipated intrusion into a private space, *intrusiveness caused to others*, such as talking over the phone amidst public and the subsequent neglect, and *socially-accepted intrusiveness,* such as phones going off during class and meetings.

## 4. DISCUSSION

The hybridity of digital ecologies, that support a myriad interactions, and physical spaces in urban journeys results in new social and symbolic meanings. We see that some of these technology-mediated socialities, such as the evasion of technologies as well as people, are deliberate. The layerings of portable devices come to the rescue in de-personalizing interactions in these urban journeys, that are increasingly surrounded by people. Technological masquerades and armours aid in automatising identities. In turn, the personal relationships with the device ecologies are strengthened. On the other hand, being perpetually surrounded by these devices, in journeys of all kinds, results in escapisms from technology during spiritual and emotional experiences. As designers we should g*ive the user the liberty to control a device.* Designing more engaging interactive experiences may not always be the right solution, especially when the user wishes to dissociate from the device. *Devices that will form a part of ensembles should be designed with other devices in the ensemble*. Portable devices are rarely used in isolation. In a device ensemble, each portable device serves a different principal purpose. They should be evaluated for various contexts, such as home, airport, gym, subway, and street, noise and illumination levels in the environment, models of shared usage, and social acceptability.

To help reify the findings, we are currently conducting in-depth interviews, diary studies, and focus groups in Finland and India, to provide a comparative lens across different cultures. Finland's categorical recreational activities, such as sauna, hiking, and weekend summer cottage getaways, and 100% mobile phone penetration provide an interesting background for our questions on spirituality and hybridity. Our interest in choosing India as the other backdrop is partly due to India's rapidly growing mobile devices base, but also due to the sedimentation of age-old practices combined with those trickled from a history of repeated colonisation and current infusion of western ideals, to provide a heterogeneous comparison.

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# The Everyday Collector

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## ABSTRACT

This paper presents the conceptualization of the Everyday Collector as a bridge between the traditional physical collection and the growing digital one. This work supports a reflection on the collection impulse and the impact that digital technologies have on the physical act of collection.

### Author Keywords

Collection, video, mobile phones, environment, storytelling.

### ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## INTRODUCTION

I gather artifacts. They recall my experience. They are a proof that something existed. This sense of appropriateness of my history through the act of collecting allows me to realize that my past is not gone, and exists in part through the process of recollection. I discover someone else's history when I play with antique toys. The pleasure is immense in reading, witnessing, guessing another person's life, her struggle and hope invested into objects. I create a story for the existence of each object that has one day been possessed and cherished.

Objects gone from their context can be reinserted through memories. Integrated or abandoned from their original surroundings, they can be organized, labeled, reinserted in their period through analysis. The collector looks for cues in the world to witness a story or to make sense of one. The collector visualizes, records, and plays back moments from her or someone else's history to reflect on it and be immersed in experience.

The scope of the digital is growing and fundamentally transforms our lives. Materiality is being technically extended. The digital offers another variety of artifacts that impact remembrance. The experience of digitally capturing the everyday and making sense of it through the physical act of collection could be combined. The digital could inform the physical, the physical could ground us deeper in our surroundings, and they both could exist independently from one another.

## THE EVERYDAY COLLECTOR

I propose the conceptualization of the Everyday Collector as a bridge between the traditional physical collection and the growing digital one. This work supports my reflection on the collection impulse and the impact that digital technologies have on the physical act of collection. The key to bind the physical act of collection and the digital opportunity of representation is metadata. Imagine a scenario where the object discovered grows references beyond the thing held, and the thing seen. The digital world can tie to an infinite number of features of the object, only limited by the technologies used to analyze and link the data. However, even simple features gain new meaning through tagging to the collected object. I investigate metadata such as location, temperature, and personal tagging on gathered objects.

As an example, the Everyday Collector allows users to collect temperatures - from the heat of the sun to the cold of the ice, invited to capture more complex temperature such as the soil that is associated with metadata, visuals and auditory samples. The participants retrieve the data per gathered items in their physical and digital laboratory.

The system encompasses the experience of the collector and invites the creation of an associative memory of textures, smells, temperatures, locations, places and objects. Value is to be found in both the collection of the object-digital relationships, as well as the unique opportunity to re-visit the world represented by this type of tagging and exploration. Individuals collect samples from their environment and connect them to their digital collection. The digital metadata of the collected elements is retrieved in association with the physical keepsakes.

## DESIGN

The Everyday Collector is envisioned as a valise that offers the carrying of technical devices that I develop for encoding the context of collected objects. From the frequency analysis of an object to a sound amplifier for an insect: a sound recorder's amplifier specifically captures the sound of the most minuscule creature encountered, the analyzed features of collected objects are translated into a digital collection of features to accompany the physical object.

In addition to collection, the story of gathered elements is retrieved through its digital relationships, queued by features such as the weight of an object. Self contained, the valise allows both the capture of digital media and objects in context with one another and the audio-visualization of these media, driving the explorer into an experience without separation between physical and digital opportunities.

The workshop will allow me to observe how urban elements are captured, gathered and collected both physically and digitally.

## DISCUSSION

"I was on the beach recently and saw a woman walking with her Scottie dog and he had a rock in his mouth. And I said, "That's so nice that your dog is bringing a rock back from the beach for you.". She said, "oh, this is not for us. This dog collects rocks." And she said he would spend fifteen of twenty minutes on the beach looking around for a rock that resembled the ones he already had, which were roughly hamburger shaped, and put them under the bed. – Charles Randall Dean *In The sensibility of the collector.* 2006. Philoctetes".

The impact of this work is to challenge the exclusivity of digital and physical opportunities of interaction, and rather, provide an experience where the physical process of collection is completely married to contextualization via digital means. I plan on documenting how this physical and digital opportunity leads to new processes of discovery and wonder in the primitive act of collection.

# UbiWORK: Design and Evaluation of Smart Environments in the Workplace

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## ABSTRACT
This workshop is the fourth in a series of UbiComp workshops on smart environment technologies and applications for the workplace. It offers a unique window into the state of the art through the participation of a range of researchers, designers and builders who exchange both basic research and real-world case experiences; and invites participants to share ideas about them. This year we focus on understanding appropriate design processes and creating valid evaluation metrics for smart environments (a recurrent request from previous workshop participants). What design processes allow integration of new ubicomp-style systems with existing technologies in a room that is in daily use? What evaluation methods and metrics give us an accurate picture, and how can that information best be applied in an iterative design process?

### Author Keywords
Meeting support, smart conference rooms, design process, evaluation, augmented environments, multimedia, teleconferencing, user centered design, interactive furniture.

### ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

## INTRODUCTION
The workplace, and in particular the smart conference room, is one of the places where real-world applications of ubiquitous computing are most highly developed. We believe that what is learned there in the domain of design for usability is relevant for the whole community. This year we focus on design issues for such augmented environments, and on the metrics of use and evaluation; a topic that participants in previous workshops agreed is crucial and where the evolution of a common set of guidelines is urgently needed to enable wider adoption and use of smart environment technologies.

### Design processes for smart environments
*Discovery:* First, it is necessary to understand and describe work context and activity (meeting types, solo or collaborative work, decision making, idea creation, and so forth). What methods are effective, and what existing research is of particular value? How do we categorize activity? [2] Different activities may call for different built systems; can we effectively set up common guidelines for the community? How do people know what to expect when they walk into a smart environment?

*Design processes:* The design of ubicomp for the workplace requires integrating devices, systems, and rules of practice. How do design processes change with the technologies for smart environments? Workplaces use a mesh of continuously evolving technologies: How can we design for continuous updates, devices from multiple vendors, as well as compatibility issues? What design methods can account for these and similar constraints?

### Evaluating smart meeting environments
A smart meeting environment requires investment. It is important, then, to perform evaluations in order to understand their everyday use as well as how they impact specific groups as well as the organization at large. Evaluation is also a critical first step in integrating the design of a smart environment. However, several barriers can stand in the way of effective evaluations. As work on metrics for ubicomp evaluations has shown [1,3], standard effectiveness, efficiency, and satisfaction metrics are important., but many other issues loom large. It is important also that users are not too distracted by all of the capabilities of a smart environment that they find it difficult to complete simple tasks. It can also be problematic to measure the effectiveness of collaborative interactions. Furthermore, it is necessary to understand the extent to which users feel in control of their environment and how well the space responds to their actions? Users also need to understand how the space adapts to their customization preferences. Finally, understanding impact is important: Is the new space accepted, and to what extent does it change users' behaviors or even the behaviors of the entire organization?

### Workshop format, activities, goals, scope
*Format:* Focus will be on discussion and idea sharing, rather than presentation. We will start with a round-robin introductory session (a couple of minutes per participant),

immediately followed by a subset of invited panels, demonstrations and/or short talks on workshop sub-topics, which will serve as provocations and points of departure for later discussion.

*Activities:* We will begin with brief reviews of and remarks on salient research; a few lightning demos; discussions (alternating between breakout teams to identify and classify areas of interest, and larger whole-group discussions) and finally proceed to a collation of ideas. The session will also provide a quick “state of the art” overview to participants.

*Goals:* We will focus on the recurring theme of design process and evaluation metrics for smart environments, with the goal of better understanding the iterative relationship between these. By beginning to develop a conceptual framework for commonalities in these areas, we may outline a set of guidelines or standards for designing and evaluating smart environments, particularly next-generation conference rooms.

*Scope:* The scope of interest includes but is not limited to (in no particular order): design processes for augmented environments and smart conference rooms, integrating mobile devices into smart environments, tools and applications to support augmented environment design, the roles of sensing and context awareness (particularly in metrics), and evaluation metrics and methodologies for conference rooms and other smart environments.

### Organizers of the workshop

We are a deliberately diverse group, drawing from several disciplines (computer science, electrical engineering, business systems, smart room hardware/software design, social science, and interactive architecture/design) and cultures (Japan, US, France, Canada). All of us have been working in aspects of ubiquitous computing, and smart meeting rooms in particular, for many years in both academia and industry.

**Maribeth Back** is a senior research scientist at FXPAL, and heads the Immersive Collaboration Environments project, focused on mixed-reality workplaces. She has worked on a number of smart environment systems as well as mixed reality projects at Xerox PARC, MIT Media Lab and Harvard Graduate School of Design. **Saadi Lahlou** is a social psychologist who heads the Laboratory of Design for Cognition at EDF R&D, a user laboratory in a large end-user organization that pushes the state of the art and fosters dissemination. He is the coordinator of the rufae (research on user-friendly augmented environments) network. **Masatomi Inagaki**, is a technology planner who heads the smart environment design team in Fuji Xerox’s ubiquitous technology area. Currently, his work is focused on designing next-generation workplaces for effective and creative collaboration. **Kazunori Horikiri**, is a senior architect at Fuji Xerox with expertise in ubiquitous computing and distributed computing. Currently, his work is focused on designing computing-embedded workplaces that enable knowledge workers to achieve effective and creative collaboration. **Scott Carter** is a research scientist at FXPAL. He has developed several ubicomp technologies, including peripheral displays and capture and access systems. **Gerald Morrison** is Director of External Research for SMART Technologies. Previously he was a Senior Development Engineer and Manager – Image Processing for SMART.

### Soliciting Participation

We will strive to attract diverse viewpoints, including people from different cultures, research areas, and disciplines, while maintaining a cohesive line of inquiry throughout the workshop. We hope to engage people with expertise in smart environments for the workplace, multimedia communication, ubiquitous display systems, user-centered design, evaluation methods, and mobile and ubicomp applications; and to draw engineers, researchers, and designers from both industry and academia.

We will post a web site at http://www.fxpal.com/UbiComp2008/ to describe the workshop. The site will be linked from each of our organizations' web sites. We will also distribute flyers at appropriate related sites, post to email lists, and directly solicit potential attendees.

**Selection of workshop participants and presentations** will be based on refereed submissions. Authors are invited to submit a 1-2 page position statement describing their interest, experience or ongoing research in the field, and including a brief biography. Position statements should have only one author, and admission to the workshop will be for that person only. Position statements should be sent directly to back@fxpal.com and will be published on the website. We would like to cap the workshop at about 20 participants (including organizers). Both the number of informal queries we’ve already received about a workshop this year and the depth of response to previous workshops reveal considerable continued interest in the topic, and we believe that entry will be competitive.

### Expected outcome of the workshop

One objective of this workshop is to form an ongoing framework for smart environment evaluation metrics. This includes writing a collective paper proposing metrics for understanding the use of augmented rooms, with the aim of publication in a major journal. We are also considering a special issue focused on this topic, pulling "best of" work from all four years of the workshop.

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# Illustration of the Intelligent Workload Balancing Principle in Distributed Data Storage Systems

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*Abstract* — **This paper introduces the intelligent workload balancing algorithm which applies stochastic approximation method, in particular conditional density propagation [bootstrap], to estimate the importance weights of the tracked "content codewords" inside of local and external workloads and by observing weights to forecast the future accesses to those "content codewords". As add-on the "content codewords" locality can be estimated.**

***Keywords: Intelligent workload balancing; distributed storage.***

## I. Introduction

The paper discusses workload balancing issues and provides a novel mechanism of intelligent workload balancing for highly constrained devices in heterogeneous networks.

Within scope of the proposed system architecture any type of the generated content which is necessary to store is analyzed by means of granular cache mechanism, sliced by information dispersal mechanism and propagated through the network. To undertake such activities a form of network transport abstraction, dispersed content codewords distribution and routing layers are usually utilised. The data codewords distribution tracking and propagation control approach are based on conditional density propagation mechanism (for more information see bootstrap filtering techniques and sequential Monte-Carlo methods).

Since any system, by means of a certain channel, is fetching and delivering particular information the workload is generated. Which usually produces impacts to the overall performance, reliability, and, energy consumption at the corresponding endpoints. Thus, the mechanism of workload management is considered as the most important part of any system, especially if such system is distributed one.

Workload balancing is the most challengeable capability of any distributed system that is targeted in data storage, back-up or archival operations. This feature becomes especially essential when the provided storage space is located on the energy and computationally constraint devices. There are several research studies [2]–[6] that address the problem by applying different methodologies. However, the question of non-uniform or skewed load and/or external workload detection and balancing is still on the hype and any sustainable solution is strongly appreciated by the research community.

## II. Definition of the Optimization Criteria

The presented approach addresses problem of intelligent workload management where the workflow estimation and tracking are spatially correlated with a certain cost function. Traditionally, a distributed storage management is based on certain set of rules or policies which are predetermined by benchmarking and testing beforehand. It is rare the case, when such solution can be applied in highly constrained or dynamically changing environment. A good example of such environment can be any nomadic system which is dynamic by definition, and where a number of devices can share storage resources and services. Indeed such environment can provide a better user experience by allowing user to flexibly bring in new devices and to access all information available in the multi device system by using any of the involved devices. But of course that comes at a certain cost.

It is well known that the main issues of distributed systems and distributed storage systems in particular come from the adequate analytical model composition within the real-time scope and in the dimensions of power consumption, responsiveness and predictability. The issues become critical especially when parameters of energy, performance and reliability should be managed concurrently. Therefore, a distributed storage solution can be efficiently designed usually for a particular application area (for a certain type of physical connectivity and distribution of the device participants).

Proposed approach solves issues stated above in the form of a workflow model stochastic approximation which can be applied in case if computing environment is dynamically changing system with multitude of uncertainties concentrated in dimensions of energy/performance/reliability and providing an effective framework for any new constraint accounting which can be incorporated to the system model almost seamlessly in just-in-time fashion.

## III. Approach

### A. Theoretical background

This paper introduces the intelligent workload balancing algorithm which applies stochastic approximation method, in particular conditional density propagation [7], to estimate the importance weights of the tracked "content codewords" inside of local and external workloads and by observing weights to forecast the future accesses to those "content codewords". As add-on the "content codewords" locality can be estimated.

As stated before, the workload models characterize workflow behaviour over time. To simplify workload monitoring these models are considered as auto-regressive processes.

Dispersal content distribution serves the role of "black-box" that should be predicted with help of workload model approximation. In that sense autoregressive models captures input/output behaviour of that "black-box".

In more general case workload model can represent request rate not only for the particular data object, which was dispersed, but for the whole device which plays the role of storage provider.

Since workload model manages content dispersing (codewords), including skewed and the non-uniform cases, content dispersal facilitate construction of the behavioural models by means of the codewords access patterns analysis.

Access pattern is formed as a combination of Read and Write requests that are issued at a certain request rate. Workload model represents forecasted request rate of a system (device) payload as a function *y(t)* that depends on series of actual request rate $x_i(t)$ (Read and Write requests).

The following workload model estimation is assumed, auto-regressive (AR) with moving average (MA):

$$y(t) = \sum_{m=0}^{M} \alpha_m y(t-m) + \sum_{l=0}^{L} \beta_l x_i(t-l) \quad (1)$$

This form can be elaborated from the general form of AR:

$$y(t) = \sum_{m=0}^{M} \alpha_m y(t-m) + x_i(t) \quad (2)$$

And, from the general form of MA:

$$y(t) = \sum_{l=0}^{L} \beta_l x_i(t-l) \quad (3)$$

The values of *L* and *M* above show the MA and AR orders. Coefficients $\alpha_m$, $\beta_l$ can be identified using frequency transform methods, e.g. Fast Fourier Transform (because spectrum domain and model coefficients have the same information).

Workload dynamics are modelled as $2^{nd}$ or $3^{rd}$ order process, represented in discrete time *t* as second and third order auto-regressive process.

According to the estimated workload model can elaborate the necessary impacts on content dispersing and can aggregate and transform conditional probabilities of content codewords location.

### B. *Proposed solution*

In particular the following stages are defined:

1. workload approximation by means of AR models and ARIMA models, initial sampling provides initial probabilities of the "content codewords"
2. as the workload evolves, sampling against it provides weighted probabilities of the "content codewords"
   a. sampling against previous state of workload "content codewords"
   b. the weights of the workload calculation
   c. weights are normalized
3. once the new weights are calculated process "content codewords" selection is undertaken
   a. substitution with new weighted "content codewords" by re-sampling original (bootstrap filtering)
   b. proceed with p.2

Algorithm presented above can be efficiently utilised having distributed workload model as a sustained part of the whole approach, and can be illustrated by Figure 1.

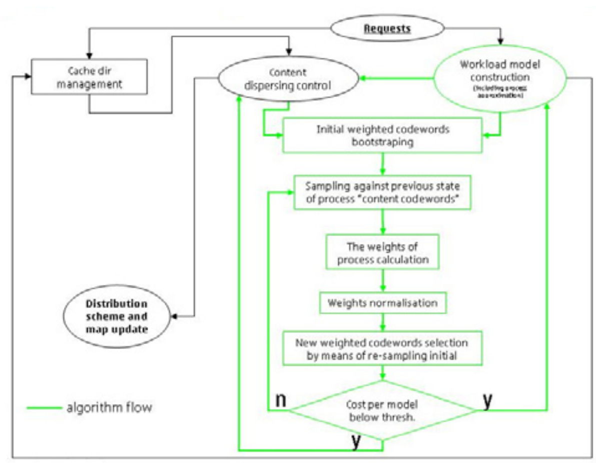


Figure 1. - Workload control, having process approximation as a part of distributed workload model.

Or, in case if workload model, process approximation, is separate solution, the actual distribution or aggregation can be direct outcome then, illustrated by Figure 2.

Solution above, the actual weighted codewords selection, is undertaken during workload model construction which is separated superset process. Every time when workload model is updated or created the determined weighted codewords are destaged or appended to the model hit list for the next workload analysis cycle. Since proposed solution is memory-less and provides reliable estimation even within multimodal case, it is energy efficient and scalable to different platforms.

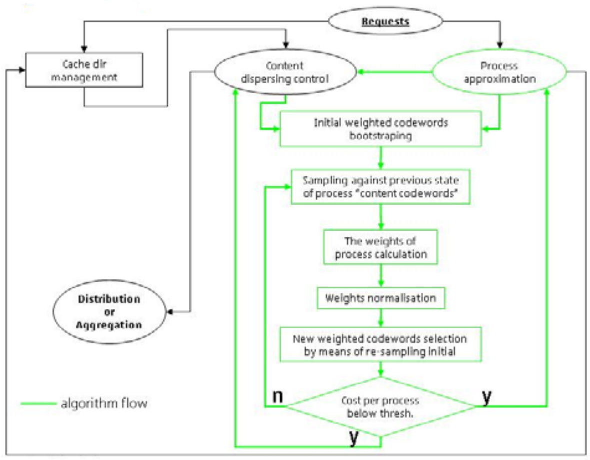


Figure 2. - Workload control, having process approximation as an independent part

## IV. Conclusions and Discussion

The applicability of current approach and results can be underpinned by simulation results. One can note the algorithm scalability, in particular to the "hyper"-modal case when the number of tracked "content codewords" can be enormous. To illustrate the answer we can justify the size of the weighted process areas and provide a weighted clustering when "content codewords" can make groups of "content codewords" with approximately same weights and process model parameters. The process of clustering can be adjusted by means of any known approach, for example by SVM.

As it was shown above the main task in this case converges to the content codewords propagation and locality estimation. It is interesting to note that the overall logic can be recognized as optimal cache strategy without destage, since two distinct locality types are valid in this case: temporal and spatial.

The application of stochastic approach presented in this work provides more flexibility in workload adaptation to different environment. This can be characterized by nearly optimal performance in comparison with deterministic approach. As it was shown proposed solution is memory less, which by definition saves more power and demands less computing during the lifetime.

This paper provides a sketch of the intelligent workload balancing mechanism which is scalable to the different cases and, because of the applied approach, has small needs for energy and computational resources.

## Acknowledgments

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# Enhanced and Continuously Connected Environment for Collaborative Design


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### ABSTRACT

This paper describes our current study in the development of a collaborative design environment that considers ICT and architectural space. The authors focus on communication in order to evaluate the collaboration environment, so that the objectives are as listed below.

Objective 1. The evaluation of using the multi-screen and sharing console applications in the face-to-face design meeting at the local site.

Objective 2. Finding problems and its factors of the continuously connected project-rooms in the distributing sites.

In our conclusion, we have verified the relation between the communication and the applications of the environment in the objective 1. with the objective 2, we have realized and extracted four major issues towards improving the distributing project-rooms environment in our future study, which is listed in the table.



### Keywords

Continuously connected, ICT, distributed site, communication, face-to-face group work.


### INTRODUCTION

Using white boards and projection screens in a meeting room is a typical style of a face-to-face meeting. The projector becomes a valuable tool because people use digitized information to work on PC, and project it to share information and discuss issues in a meeting. Although one of the ways to make collaboration success is to install more tools and applications which are developed through ICT, there is another way of focusing on a spatiality.

Projecting on a large screen and white boards of a wall is that the entire space is transformed into "display". It is in fact primitive cases in which the form of information displays is developing three-dimensionally and beginning to make-up environments that envelop people. When one attempt to put those kinds of displays into practice, there is a noticeable difference in the way that information appears between cases in which snippets of data appear on small displays at regular intervals and ones in which data is displayed in three dimensions space and seen at a single glance. To put it strongly, when displays are given spatiality new possibilities in collaboration can be pioneered.

When one operate a specialized display that has developed in three dimensions we stand up, raise our heads and show our abilities. Our eye lines meet and new conversations are initiated. The data structure can be taken in at a glance, understood by repeatedly moving through it, and internalized into the body.

Our study group has been developing a computerized prototype environment for collaboration, which attempts to support synchronous design collaboration in a face-to-face meeting at a local site, and also in continuously connected project-rooms at distributing sites. This paper describes our current study of the development of the collaborative design environment.

#### The specifications of the environment

1) Space frame: It can be attached and removed easily for various instruments such as projectors, speakers, cameras, microphone, etc. The space structured by frames that creates a sense of being surrounded.

2) Four-multi big screens: They are on the white board wall, the glass partition and the roll screen, and the glass top table:

- The White board wall for a wide screen projection. (110inch*2)
- The Glass partition and the roll screen made by a white permeability film for rear-projection. (110inch) One can write in the glass partition by marker pens.

The Glass top table on which surface is filmed for underneath projector has a function for drawing like a white board on the projected surface.

There is a central PC, which is connected network and controls this environment, and it consists of applications for keyboard-mouse sharing, downward camera controlling, etc. Additionally, in order to support distributed collaboration, this prototype also provides the desktop sharing application, the analog document sharing system with scanner, the scheduler for groups and data storage via internet.

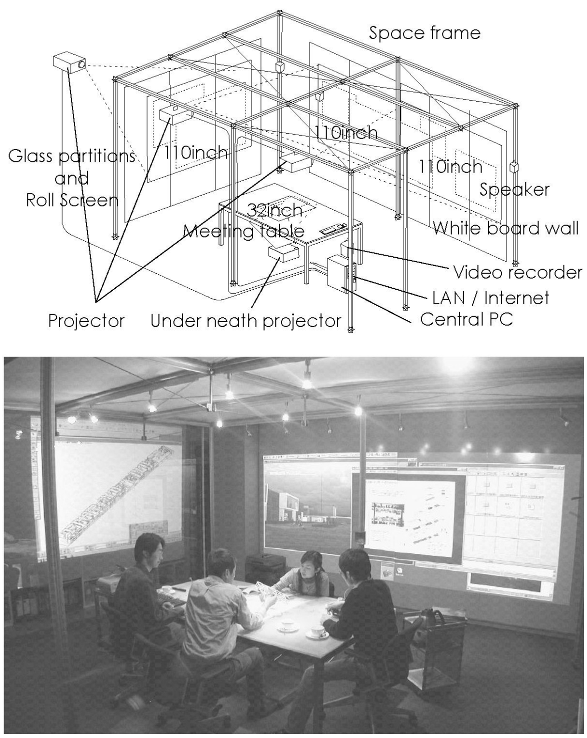


*Fig.1. The configuration of the prototype*

**A Face to Face Local Meeting Environment**

The authors focus on “operation” and “visualization” in a face-to-face meeting at local site. Two experiments as shown below have been carried out to evaluate the environment base on communication analysis.

Exp.1: Sharing the keyboard and mouse for the “operation”. (Exam A, Exam B)

Exp.2: Using the four-multi big size of screens for “visualization”. (Exam C, Exam D)

***The Result of the experiment 1***

All conversations take place in the exams were recorded on voice recorder. When and how the keyboard and mouse operation are recorded during exams. In order to see the relation between communication and the experimental environments, all utterance of each examinee are reproduced on MSWord data sheet. Fig. 2 shows the numbers of Japanese characters that each examinee spoke out in each exam.

The total number of Japanese characters counted 6847 letters in exam A is much higher than one of exam B which is counted 4733 letters (Fig. 2). Additionally, it can be seen that each member of exam A talked a lot more than exam B. In the result of questionnaire survey, we observed positive comments that may indicate possibility to activate interactions of the meeting. For examples, one of the comments says that it is easier to reflect their own opinion to the meeting directly with own keyboard and mouse. Another comment is that sharing the keyboard and mouse environment create a sense of belonging in the meeting.

The authors realized in the observation during the exams that conversations tend to be occurred just after someone operates keyboard and mouse, which seems to make the meeting warm up with like the situation someone laughing or the tone of voice change. However, the data we collected this time doesn’t show this phenomenon quantitatively. The phenomenon will be captured clearly in our future study.

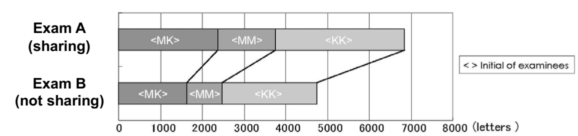


*Fig.2. The number of Japanese letters (experiment1)*

***The Result of the experiment 2***

The numbers of Japanese characters in all conversations are counted in the same way of experiment 1. Fig. 3 shows the sum of the Japanese characters recorded on exam C (1 screen) and exam D (4 screens). The total number of it in the exam C is counted 16888 letters in the meeting period of 77 minutes. The number of letters and the meeting time in the exam D are 9588 letters and 53 minutes. Therefore the number of Japanese character counts per one minute is 219 counts for exam C and 181 counts for exam D, which may explain that four-multi screens makes the meeting more active than one screen.

The authors analyzed the words of conversations that take place in the exams, and then categorize it into three communications types; “discussion”, "arrangement" and "others". The “discussion” is the communication that includes words relating to the subject of the exams. The “arrangement” is the conversation when the examinee talks about arranging the computer operations and environments. The “others” is the communication that is neither the “discussion” nor the “management”.

Fig. 4 shows the percentages of these three types for each exam C and exam D. This indicates that the “discussion” of the exam C is more active than the exam D in the result of Fig. 3 into consideration.

In addition, the status of application windows on the screen such as size of window, position of window, and the number of the active-windows are recorded. When more than two application windows executed in the meeting of exam A, the communication for the “discussion” takes place rather than the communication for the “arrangement”, but on the other hand many execution of the application windows create more “management” than “discussion” in the exam B. It is likely that the multi screen can lead users seamlessly to the discussion level of communication due to projecting many application windows in a same time. But executing many application windows in one screen as the exam B needs to spend a time to manage application windows such as moving, minimizing, maximizing and arranging the windows in the conversation of the meeting.

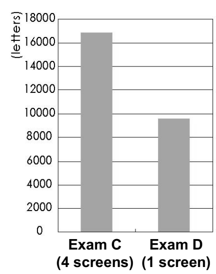


*Fig.3. The number of Japanese letters about “discussion” (Experiment2)*

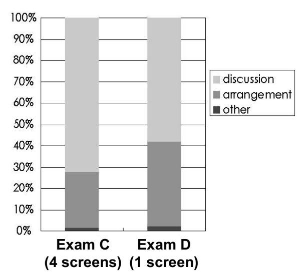


*Fig.4. Communication types (Experiment2)*

**Continuously connected distributed project-rooms**

The prototype environment attempts to support not only a face-to-face local meeting but also distributed project-rooms. Although the TV conference systems via network has developed and been used as a common tool at an office or a home, the function of these systems tend to design connecting people to people for a face-to-face meeting of distributing sites, which means people connect the system when they want to have a meeting with distributing people for a certain time. On the other hands, our approach to develop the prototype is to connect space to space continuously. What we expect is that visualizing other site on a big screen informs a situation and gives an awareness, which may produce communication effectively to collaborate between distributed sites.

In order to understand that the contentiously connected environment affects daily activities, the authors have carried out the experiment in comparing local environment and distributed environment for ten days; first five days is local collaboration and second five days is distributed collaboration. The examinees are six postgraduates engaging in architectural proposal project.

Configurations of collaboration environment are follows.

a) Distributed environment; three personal desks are in each sites. The main screen connects two distributed project-rooms via TV conference system. The live images at another site are rear-projected on the big screen look like the same room.

b) Local environment; six personal desks are in the prototype environment.

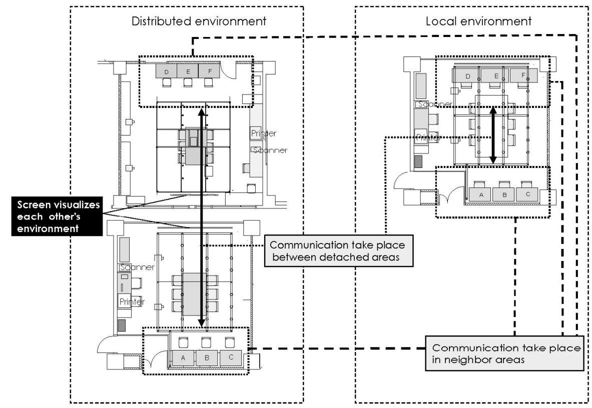


*Fig. 5. Distributed environment and Local environment*

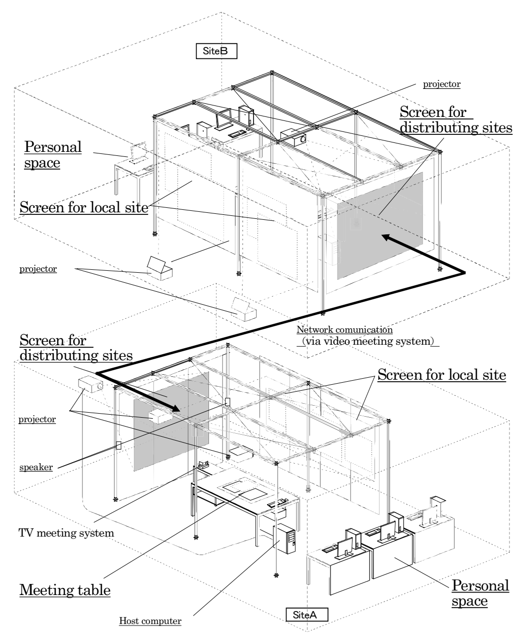


*Fig.6. The Continuously Connected Environment*

**Evaluation and Modification of Continuously Connected Environment**

The authors evaluate the environments of the continuously connected project-rooms at distributing sites in this paper. The communication that is observed from field survey, self-photography survey, and a questionnaire survey are analyzed. Examinee takes a photograph about problems of environment and comment with it in the self-photo survey. This will enable us to understand problems picked out by user about environment. The authors classify all communications into two types according to the place where communications happened. We pick out three aspects about collaboration based on the researches, and consider the factor. Through the self-photography and questionnaire survey, and communication analysis, we extracted four major problems that explain communication barrier between distributed sites, and considered and listed the factors that related to the problems.

*Table 1. The results of contentious connected distributed project-rooms*

| Communication problems between distributing sites | The factors to occur the problems |
|---|---|
| It is difficult to communicate casually. | The casual communication is set low priority of conversation. Members feel possibility to interrupt and disturb the progress at the other site due to less understanding of the context. |
| More than two conversation groups cannot communicate in the same screen. | The screen which shows other site is the only cannel to communicate to distributing members. |
| Communication take place depend on particular place. | Member need to move the position where microphone and camera can capture their voice and Fig.. |
| Project members tend to communicate in local site. | It is easier to communicate locally. The sound of local conversation is too low to listen, and the sound breaks due to network problem so that member at other site can not follow the conversation. |

The environment is modified in aspects of digital tool and architectural space with being clear to distributed environment's defects and theirs factors. We have improved the situation of taking place communication and awareness in distributed environment. In case of using VNC, sharing the desktop computer continuously as trigger activate communication because it works the awareness of "intention of doing" and" understanding the object".

Changing personal desks layout is mainly effective in "notice the existence of distributed members". It is meaningful to make architectural modification, such as changing personal desks layout without adding any information equipments and applications.

Turning our attention to screen that is the hub of the communication between distributed sites, the authors verify the effect of screen layout on communication. Screen layout are classified as two types which are "Screen visualizes distributed site" and "Screen shared operation between each site". We sustain the space construction for smooth communication in meeting, and its effect and importance of attention on space. Concretely speaking, members in local environment intuitively understand the direction of pointing and looking in distributed site. And so consideration to screen layout have smooth communication enabled.

## DISCUSSION

In order to evaluate the face-to-face local meeting environment, the console applications of keyboard and mouse and the four-multi big size of screens are focused and studied based on communication analysis. From the evaluation of sharing console applications, the authors verified that communication activate if the input device of the keyboard and mouse can be owned individually to control central PC. Additionally, we observed the phenomenon that the meeting during the exams gets warm up gradually just after the console applications are operated. In the result of the four-multi big size of screens evaluation, executing several applications and viewing information at a glance on multi-screen cut a time to arrange applications and create much time to discuss issues in the meeting. All of these amounts to saying that four-multi big size of screens and sharing console applications make collaboration proceed seamlessly.

The environments of the continuously connected project-rooms at distributing sites are also evaluated. Through the self-photo and questionnaire survey, and communication analysis, we extracted four major problems that explain communication barrier between distributed site, and considered and listed the factors that related to the problems.

## Future works

Future studies might consider examining awareness support between distributing sites of continuously connected project-rooms based on the result of this paper. Furthermore, the tabletop interface can be developed considering not only local meeting environment but also continuously connected project-room.

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# Secure and Dynamic Coordination of Heterogeneous Smart Spaces


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## INTRODUCTION

Recent advances of ubiquitous technology enable development of smart rooms and spaces in several research organizations. Generally, smart rooms and spaces are equipped with sensors, appliances, and computer controlled actuators. Also there might be a middleware or software for controlling these smart rooms.

Nagoya University has developed a middleware named "cogma"[1] and constructed a smart room named "cogma room". "cogma" can be used as a tool to support everyday life in the ubiquitous computing. Ritsumeikan University and Uchida Yoko Co Ltd. have developed a smart space and a control software named "UnitedSpaces"[2]. Like the initial stage of the internet, this kind of smart rooms should be interconnected each other(Figure.1). However, our middleware are based on completely different concepts. So it is not possible to directory connect and cooperate each other. In 2006, we started a joint research project to overcome several difficulties related to federation of the smart rooms and users.

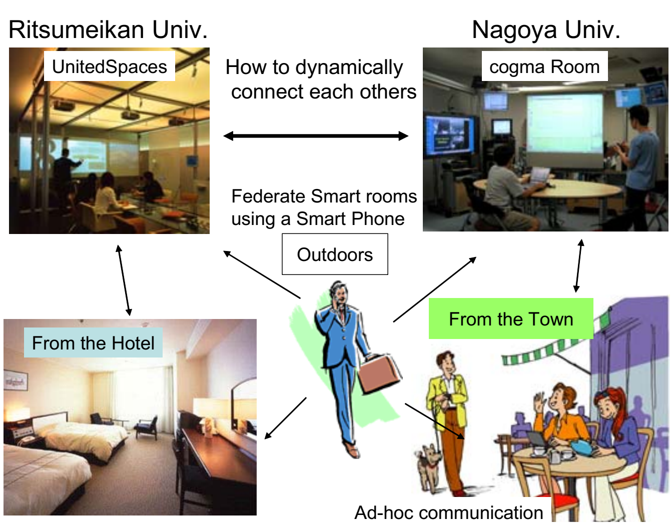


**Figure 1. Secure and Dynamic Coordination of Heterogeneous Smart Spaces.**

## CURRENT STATUS OF SMART ROOM COORDINATION

We have developed solutions for each of problems in the heterogeneous coordination of smart spaces.

### Heterogeneity

Different smart rooms may have their own design concept. So it is not easy to standardize a protocol for coordination between heterogeneous smart rooms. In the current status, we employ simple "RESTful" Web service interface described by WADL[3] for smart room services.

### Secure Communication

By employing REST interface, we just use "https" as a secure transport protocol. In the smart room environment, it is not easy to specify the authorization on each user. We employ a "ticket" based authorization. In this scheme, the manager issues a ticket for the guest user. Current ticket is defined as a XML format with digest signature.

### NAT problems

We have developed a smart virtual network technology named "PeerPool". By using PeerPool, user can add a direct connection between private networks using dual-NAT.

### Simple Configuration

It is not easy to configure the several technologies. We introduce a "Instant messenger" based smart interface for smart room coordination named "NUE".

## ACKNOWLEDGMENTS


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# Toward Easy Operation of Interactive Smart Meeting Space with Networked Display

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## INTRODUCTION

Extended computing and networking infrastructures are now enabling diverse set of new services by linking a wide range of networked devices embedded in the ubiquitous computing environments. As an example, to support advanced collaboration among knowledge workers distributed geographically, there have been extensive researches under the scope of ubiquitous computing environments. Especially, to cope with several known problems in traditional room-based collaboration environments such as limited display resolution, uncomfortable sharing of visuals and documents, difficult operation of collaboration tools, several prototypes have been developed [1, 2]. To solve the above restrictions, we have been developing a prototype collaboration environment, named as SMeet (Smart Meeting Space) [3, 4], for practical and interactive collaboration with ultra-high-resolution interactive networked displays.

As showcased in [4] and improved afterwards, connected SMeet nodes are depicted in Fig. 2. Each SMeet node consists of several networked devices, which can be flexibly combined to construct customized meeting spaces based on user intention. To organize collaborative environments between various types of meeting nodes (e.g., light-weight mobile node and fully equipped conference room), the designed meeting space enables users to select and use the most suitable networked devices and collaboration services to match the capability of meeting nodes. Thus, SMeet is designed to provide users to experience smart meeting rooms with following collaboration services: high-quality audio/video communication among participants, large-scale tiled display representing a variety of video formats simultaneously, and user-friendly display interaction using pointing and hand motion tracking devices.

Recently our development effort on SMeet has been shifted toward easy node operation in order to enable the customization of network-based interactive sharing of HD-quality media and data, human-display interaction using multi-tracking pointer-style devices, and intuitive GUI-based configuration support.

## SMART MEETING SPACE (SMEET) AND EASY OPERATION

As mentioned above, SMeet is featuring interactive networked display for multiple participants. However, the initial prototype in [4] requires the involvement of several operators per each node. Thus, in order to help participants to operate the complex SMeet nodes with diverse networked devices, the basic framework of SMeet has been revised as shown in Fig. 1.

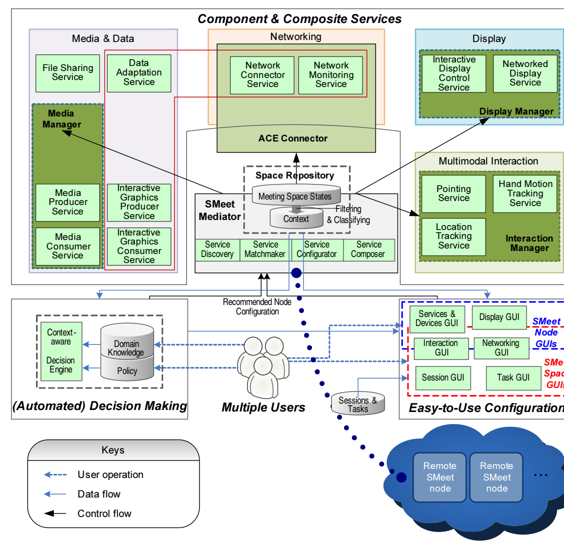


**Figure 1. SMeet framework with agent-based mediation and GUI-based configuration.**

In the revised SMeet framework, following issues are specially addressed.

- **Multi-agent-based Mediation** The SMeet mediator (shown in Fig. 1 is a control point for a meeting node, which discovers distributed devices and services, configures them (e.g., starting and stopping services, or customizing the tuning of service parameters), combines (or composes) distributed services for supporting user-intended collaboration tasks such as contents sharing by using interactive tiled display. To cooperate with other meeting nodes, the SMeet mediator represents the meeting node in order to exchange information (e.g., sharing meeting context) or to negotiate with them (e.g., consulting cooperation strategies for given task). The meeting context (i.e., situation information such as service capability, service status, and users' preferences) is united with services, which is stored in the space repository. Also, service agents are attached for SMeet collaboration services in order to act as the intermediary between collaboration tools and the SMeet

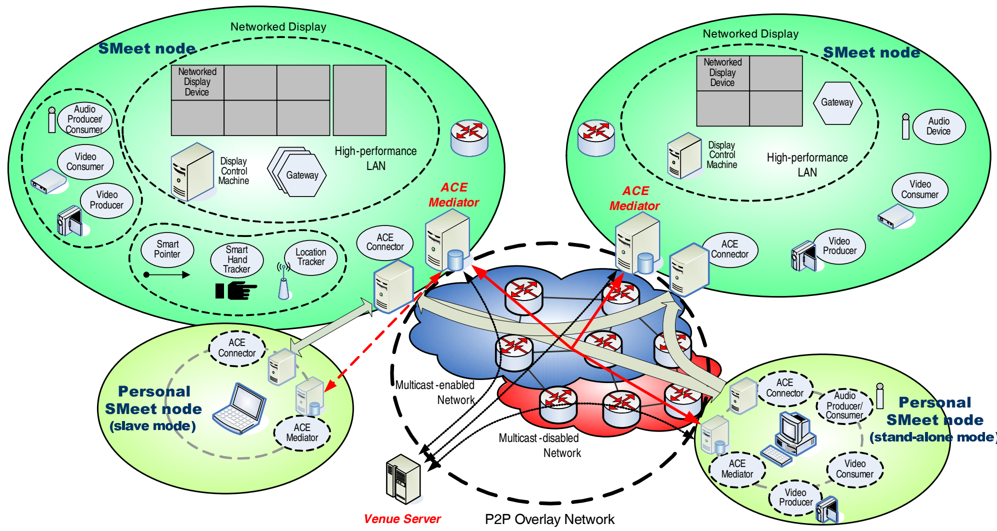


**Figure 2. SMeet nodes with diverse networked devices.**

mediator. It parses the service description and executes the corresponding collaboration tool. Since service agents can communicate with the SMeet mediator in each SMeet node, the desired service can be controlled by following pre-defined actions such as start, stop, and configuration. Note that we utilize a multi-agent system based on JADE (Java Agent DEvelopment Framework) to realize the required mediation. As of now, by using JADE, we are developing a toolkit, where participating users access (via SMeet mediator) various service agents to be operated by device agents.

- **GUI-based Configuration** For each SMeet node, we consider that, for automatic operation, the SMeet mediator may consult declarative rule-based inference engines. However, it is believed that manual (easy-to-use) configuration with minimal intervention of participating users are the initial key for easy SMeet operation. Collaboration participants can manually configure the meeting node by using specific interaction interfaces such as SMeet Space GUIs and SMeet Node GUIs. Note that SMeet Space GUIs are covering space-wide aspects and includes Session, Task, Networking, and Interaction GUIs. On the contrary, SMeet Node GUIs are designed to cover node-specific aspects and mainly covers Device and Services GUI and Display GUI. Note that Networking and Interaction GUIs belong to both Space and Node-level GUIs. The SMeet node is built with services providing elementary and unique service function(s) for advanced collaboration. Users can select the services to organize customized meeting nodes, considering node capabilities and meeting purpose. The service manager combines relevant services based on given composition rules and assists to execute complex collaboration tasks, for example, interactive display control task by using a combination of interaction services and display services. Finally, as of now, we have rather mature GUI for Display and preliminary version of GUIs for Session/Task, Devices/Services, and Interaction.

## CONCLUSION

In this paper, we have introduced our vision to improve the usability of SMeet collaboration environments. By focusing on networked display and user-friendly display interaction, we have been prototyping SMeet nodes. With the proposed multi-agent-based mediation and GUI-based configuration, it is partially verified that we can ease the operation of SMeet nodes.

### *Acknowledgments*

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# Contents and Conditions of Face-to-Face Communication in the Workplace


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**ABSTRACT**

The aim of this study is to find out suitable spatial requirements for creative work. This paper focuses on "contents" of communications so that valuable communication for creative workers should be evaluated on the basis of quality rather than quantity. Then we organized the relation between communication contents and environmental condition when people talk in the office.



**Keywords**

Face to face communication, workplace design, observation


## INTRODUCTION

Key requirement for the physical office is "workplace for groups" in order to maximize the knowledge productivity of a company. Effective face-to-face conversations between workers in physical environments are becoming more important in this information age [1]. It is necessary to make communication active and smooth in a limited amount of time while people are in the same space [2].

This study discusses what constitutes an ideal space to support the worker's good communication in the office through a case study. In order to find out the suitable environments for the communication we have grasped the situations of conversation that occurred in office.

The authors define the communication that produce an effect or value as good communication. Communication has been evaluated by questionnaires and observation about communication quantity that is the number of the times conversation occurred.

## STUDY FLOW

It is shown the flow of this study in Fig.1. At first, the authors classified face-to-face communication into five indexes by main topics in Table.1. Then we analyzed the relation between the five indexes and eight factors that express the situation of the communication. Moreover we organized the situation when workers communicate.

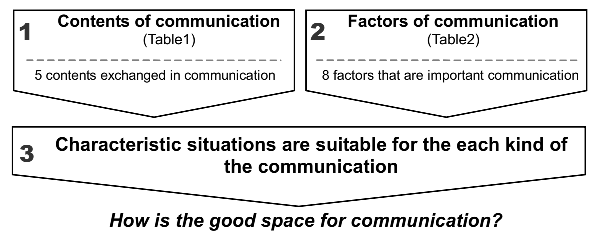



*Fig. 1. Flow of this study*

Table 1 indicates five communication topics that occurred in the office and traded the new effect or value. The authors classified the main topics of communication into five categories (knowledge / information, experience / know-how, idea, motivation, answer/ new direction / agreement).

*Table 1. 5 topics that result from communication exchanges*

| Index | Topic |
|---|---|
| 1.Knowledge / Information | Insights, intuitions and thoughts that based on substantive understandings |
| 2.Experience / Know-how | Skills, techniques that it is difficult to express. |
| 3.Idea | Conception, thought, imagination |
| 4.Motivation | Feelings that people want to achieve something. Incentive for action. |
| 5.Answer/ New direction / Agreement | To make decisions, to draw a conclusion. |

## OBSERVATION OF ACTUAL OFFICE SITUATION

### Outline of case study

People in two of all five sections were selected as subjects in this company. Group A had 29 workers and Group B had 21 workers and their job was to make people comfortable to work in order to increase the efficiency on the company. These fifty workers worked in the same room.

The case study was carried out for 8 hours a day during two days. It was continued for eight hours a day. A field observation, video and interval shooting, and questionnaire were carried out.

### Office environment that took as object of this study

It is shown in Fig.2 that we carry out this research. The area of this office space is 881[m2]. We divided object room for this case study into four zones; 1) A personal-work zone, 2) An avenue zone, 3) A meeting zone, 4) An amenity zone.

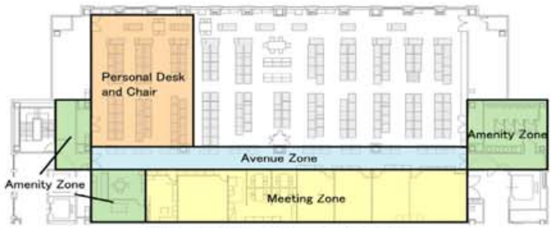



*Fig. 2. The case study office*

### Survey method

The authors have recorded all conversations and taken pictures of the scene that took place in this office during the experiment. When a communication was finished, all participants handed in the questionnaires. The people wrote the answers about four indexes that the observer can't expect on the questionnaires. The four indexes are as follows.

1) Trigger that people started the conversation,
2) Main topics,
3) Type of the shared information,
4) Information that was obtained and given.

### Way to count communications

The authors created the data sheets and defined "communication IDs" and "communication scenes" as units to count the number of times communication occurred in the office [3, 4]. It is described in the image of "communication IDs" and "communication scenes" in Fig.3.

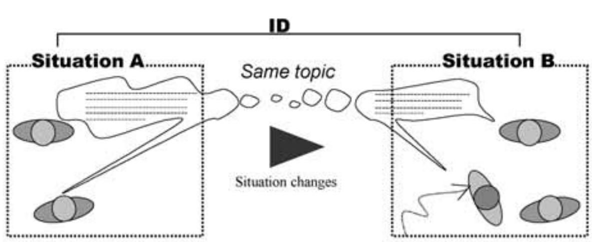



*Fig.3. Define of a com- situation and a com-ID*

In this analysis, "Communication situations" is minimum unit of communication. When a tool, place or a person was changed, we counted up to "Communication situations".

In this analysis, "Communication situations" is minimum unit of communication. When a tool, place or a person was changed, we counted up to "Communication situations". "Communication ID" is counted as sequence of "Communication situations" in the same topics of the conversation.

### Analysis method

In order to grasp the situations we analyzed the data we have gotten by the field observation and questioners. There are 2 kinds of data that are contained in the eight factors 1-8 in Table.3. The five factors 1-5 in Table.3 that observers witnessed in field observation were contained in the first data. The three factors 6-8 in Table.3 that examinees wrote down in questionnaires were contained in another data.

*Table 2. Eight factors that are important for communication*

| factors | contents |
|---|---|
| 1. Time | Time that people keep talking. |
| 2. Member | Same section/ Other section/ Other floor/ Same section and Other floor |
| 3. Total of members | How many people participate |
| 4. Place | Where people talk in the office |
| 5. Position | The attitude adopted when talking<br>Beside/ Standing and sitting/ Surround/ Turn/ Confront/ Cross |
| 6. Trigger | The reason that the communication start |
| 7.Category of info. | What kind of information for the worker |
| 8.Direction of Info. | Which he/she exchange the information in the conversation |

## ANALYSIS AND RESULTS

### Information that are exchanged between workers

Fig.4 indicates the ratios of five topics that workers exchanged. As the diagram indicates, it is clear that "Knowledge / Information" were exchanged through the communication in the office with highest frequency and "Answer, New direction or Agreement" came next. Unfortunately we realize that the other three factors, "Experience / Know-how", "Idea" and "Motivation", that were expected as important factors were fewer than 10%.


*Fig.4. Frequency of information exchange*

### Definition and the way to calculate "ratios of frequency"

In order to find out the features of the situation when people communicate, the authors compared frequency using the formula in Fig.5. To be concrete, if this "ratios of frequency" were around 1, it means the index has little features. The larger the values mean the higher the frequency.

$$P= \frac{X_1 \cap A_1}{X_1} \Big/ \frac{\overline{X_1} \cap A_1}{\overline{X_1}}$$

P=Ratios of frequency"
$X_{1\text{-}5}$= Five contents that people exchange in communication (Table1)
$A_{1\text{-}8}$ = Eight factors that important for communication (Table2)

*Fig.5. Formula for "ratios of frequency"*

*Table 3. Ratios of frequency classified by topics and factors of communication*

| | Continuation | | | | | | | Number | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Shorter than 1min | 1-5min | 5-10min | 10-15min | 15-30min | 30-60min | 60-120min | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Knowlede/Informati | 1.4 | 0.9 | 1.1 | 0.8 | 1.2 | 0.5 | 1.1 | 1.0 | 1.0 | 1.1 | 4.2 | 0.0 | 0.3 | 0.0 | - | - |
| Experience/Know-how | 0.3 | 1.2 | 1.5 | 4.0 | 0.0 | 1.6 | 0.0 | 1.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - | 0.0 |
| Idea | 0.5 | 0.9 | 1.4 | 5.3 | 0.0 | 3.2 | 4.5 | 1.1 | 0.6 | 4.5 | 0.0 | 0.0 | 0.0 | 0.0 | - | 0.0 |
| Motivation | 2.4 | 0.5 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 19.1 | 0.0 | 0.0 | 0.0 | - | 0.0 |
| Answer/New direction/Agreemen | 0.5 | 1.1 | 1.2 | 0.5 | 3.2 | 3.4 | 10.1 | 1.0 | 0.9 | 0.2 | 0.5 | - | 8.1 | - | - | 0.0 |

| | Position | | | | | | Trigger | | | | | Category | | | | Direction | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cross | Confront | Beside | Standing and Sitting | Turn | Surround | Scheduled | Be Spoken to | Speak to | Ad hoc | Other | Useful information for one's work directly | Useful information for one's work indirectly | Useful information for one's work in the future | Irrelevanat information for one's work | Acquire | Give | Both |
| Knowlede/Informati | 0.7 | 1.1 | 1.5 | 0.8 | 0.5 | 0.5 | 1.0 | 1.1 | 1.0 | 0.8 | 0.8 | 1.0 | 1.5 | 13.1 | 0.3 | 0.9 | 1.1 | 1.1 |
| Experience/Know-how | 0.0 | 1.7 | 1.9 | 0.4 | 1.3 | 0.7 | 0.8 | 0.8 | 1.0 | 1.7 | 0.0 | 0.8 | 1.6 | 3.7 | 0.7 | 1.0 | 0.9 | 1.4 |
| Idea | 0.0 | 1.3 | 1.5 | 0.7 | 1.2 | 1.4 | 2.2 | 0.9 | 0.5 | 1.7 | 4.4 | 0.9 | 1.2 | 0.0 | 1.4 | 0.7 | 0.8 | 2.7 |
| Motivation | 0.0 | 1.4 | 1.7 | 0.2 | 8.6 | 0.0 | 0.0 | 0.3 | 0.5 | 4.5 | 0.0 | 0.4 | 1.3 | 5.8 | 5.0 | 0.7 | 1.0 | 2.2 |
| Answer/New direction/Agreemen | 2.7 | 1.0 | 0.6 | 1.2 | 0.5 | 2.3 | 2.4 | 1.0 | 1.2 | 0.4 | 0.3 | 1.3 | 0.5 | 0.3 | 0.1 | 1.1 | 0.9 | 0.9 |

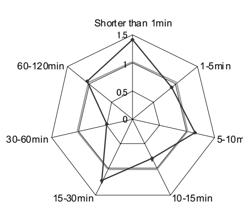
| | Place | | | | | | | | | | | | | | Member | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Personal-work Zone | | | | Meeting Zone | | Avenue Zone | | | Amenity Zone | | | | | | | | |
| | personal desk | Around personal work zone | Around printer | Meeting table | Meeting coner | Meeting room | Aisle | Around cabinet | Utility | Smoking room | Rest space | Vending machine/ boiler room | Bath room | Other floor | In same section | In other section | On the other floor | In other section and on other floor |
| Knowlede/Informati | 1.1 | 1.2 | 1.1 | 0.2 | 1.3 | 0.8 | 2.1 | 0.4 | - | 0.5 | 0.0 | 1.1 | 0.0 | 0.4 | 1.0 | 1.2 | 0.7 | 0.4 |
| Experience/Know-how | 1.0 | 1.3 | 0.0 | 0.0 | 0.0 | 1.8 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.9 | 0.7 | 0.0 |
| Idea | 1.0 | 0.0 | 0.0 | 1.4 | 2.2 | 1.7 | 1.6 | 1.1 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.7 | 0.0 | 22.4 |
| Motivation | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5.0 | 3.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 1.2 | 0.0 | 0.0 |
| Answer/New direction/Agreemen | 1.0 | 1.2 | 1.0 | 1.4 | 1.7 | 12.3 | 0.3 | 1.3 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.8 | 0.9 | 1.0 | 1.7 | 2.0 |

### Features of communication that frequency appear

Table3 shows the ratios of frequency classified by topics in face-to-face communication and eight factors that influence communication. The following graphs in Fig.6-13 show characteristic situations for every kind of content. Only part of the outstanding situations were picked up and mentioned as follows.

#### *Knowledge/ Information*

Regarding the communication that people exchange "Knowledge / Information", it showed tendencies to occur in personal-work zone, to talk in a group with 2-4 people who work on the same floor, to do during comparatively short time (Fig.6). We can realize in Fig.7 the information that seemed to relate in the future got higher point remarkably than other three categories.



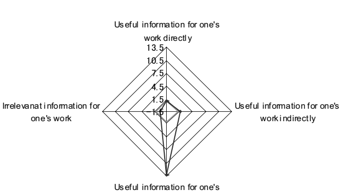
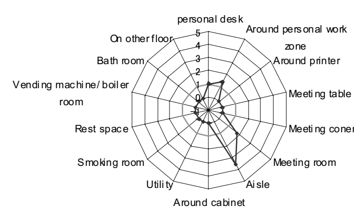




*Fig.6. Conversation length* *Fig.7. Information categories*

#### *Experience/ Know-how*

This kind of communication seemed that the tendency to talk during comparatively long time and to do on aisles or around personal desks and chairs (Fig.8). Moreover, it is clear that few workers (Fig.9) who are sitting in the next seats or confront with tend to start communication ad hock. In terms of the category of job, "Experience / Know-how" were often evaluated as the information that seemed to affect the future of one's job.



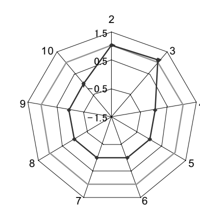



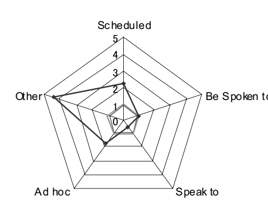

*Fig.8. Places* *Fig.9. Number of participants*

#### *Idea*

In case of "Ideas", we can find the tendency that meeting spaces, meeting rooms and meeting tables caused a communication that was scheduled beforehand such as an arrangement or staff meeting. And these communications were often formed by participants from different sections.

However, ideas were often expected to be caused ad hock (Fig.10) because we can notice that Fig.11 shows that almost idea was exchanged by workers to each other.

Moreover, it was only ideas that had high ratio to communicate in the smoking room. An interesting point to emphasize is that some communications began when workers who were around him/her moved.



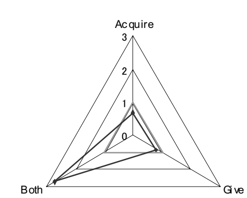




*Fig. 10. Triggers* *Fig.11. Information direction*

#### ***Motivations***

Motivations occurred on main aisle ad hock by people who work in same room during short conversations (Fig.12, 13). Furthermore these communications showed that people exchanged motivation interactively. On the occasion that it occurred around personal desk, we could frequently find that two people who are sitting closely started to talk ad hoc. In this case the contents often had nothing to do with his/her work directly.

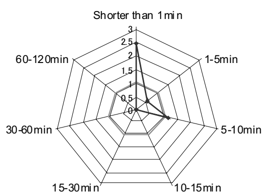



*Fig.12. Conversation length*

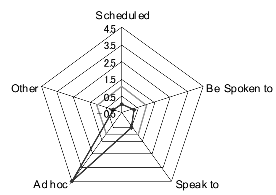



*Fig.13.Ttriggers*

#### ***Answer/ New direction/ Agreement***

As for communication that people traded during question and answer discussions, they had tended to be occurred in meeting rooms between workers belong to different sections. In addition to this tendency, we can often find out comparatively long time and scheduled conversation (Fig. 14 and 15). Moreover, effective information for one's job directly occupied about 90%, it is higher ratio than all five contents that in communication. Therefore, it is clear that answer, new direction or agreement was regard as the effective information for one's job directly.

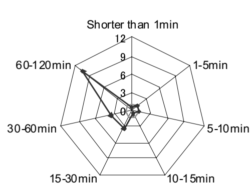



*Fig.14. Conversation length*

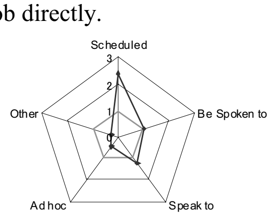



*Fig.15.Ttriggers*

## CONCLUSION

The authors focused on the topics of conversation take place in the office and propose a way to evaluate qualities of communication that regarding the communication that produce new knowledge or idea as valuable communication. Consequently the communication style in office environments between workers became clear. Below is a table (Table 4) showing special situation.

Generally speaking as for the tendency of place the communication occurred on "Main aisle" in the office recurrent. Moreover, concerning trigger the communication that people start "ad hock" is high frequency. These seemed to become important viewpoints in order to design space to support good communications.

All the consequences and consideration of this study are based on a case study carried out in a section. Therefore, from now on we will perform observations at different offices and workers to confirm the results of this study. We also need to determine a way to analyze and observe more carefully.

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*Table4. Characteristic situation classified by 5 topics and 8 factors*

| | Knowledge / Information | Experience / Know-how | Idea | Motivation | Answer/ New direction / Agreement |
|---|---|---|---|---|---|
| Time | - | 10-15min | Rather long | Shorter than 1min | Long time |
| Member | - | - | Other section / other floor | Same floor | Other floor |
| Number of people | 5 people | 2-3 people | 4 people | 2 people | 7 people |
| Place | Avenue Zone | Avenue Zone | Meeting Zone / Avenue Zone | Avenue Zone | Meeting Zone |
| Position | Beside | Confront | Beside | Beside / Turn | Cross / Enclose |
| Trigger | - | Ad hoc | Scheduled / Ad hoc | Ad hoc | Scheduled |
| Category | Useful in the future | Useful in the future | - | Useful in the future / Unrelated | Useful directly |

## Author Index