UBIQUITOUS COMPUTING: UX WHEN THERE IS NO UI

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Ubiquitous computing is a term used to describe an approach to product and service delivery in which the technology is concealed in the background, requiring little to no interaction with the user to complete the user's and/or the technology's objectives. This creates unique challenges for user experience design because the typical methods and tools are not applicable. Input to the system is limited to the technology's ability to intuit the users' objectives through their natural behavior. Output is executed on the environment as much as to the user. Several cases are presented to illustrate the common user experience challenges when designing partially or completely ubiquitous systems.

INTRODUCTION

Ubiquitous Computing refers to the presence of technology that enables tasks to be achieved without explicit interaction with a user. Zulas et al (2012) characterize ubiquity as low profile, second nature to the user, supportive of conscious and unconscious needs, and not requiring any user behaviors that conflict with their goals and requirements. Boy (2011) describes it as a disappearing computer and a seamless interface.

At present, most systems are only partially ubiquitous. Systems might only be ubiquitous in one direction. For example the 94Fifty basketball is instrumented to ubiquitously record the ball's speed, arc, spin, and other performance metrics, but then presents it to the user on a traditional computer interface. The presentation dashboard still can be designed following traditional design guidelines and testing methods, but the interaction between the user and the ball technology requires a new approach that considers its ubiquitous nature.

Similarly, some systems require the user to do some advanced set up on a control interface, but then ongoing use is ubiquitous. The control interface can be designed and tested using traditional methods, but the ongoing interaction design needs to follow a ubiquitous user experience process. For example to set up a smart thermostat that regulates the temperature automatically, the user may need to establish particular triggers for when the temperature should be adjusted. Triggers can be times, such as 8am, sensed actions, such as a particular individual entering the room, or linked to another technology, such as user's alarm clock. The control interface may follow traditional design processes but the experience will be determined largely by the user's interaction with the ongoing ubiquitous system.

The Internet of Things

The Internet of Things is a term used to describe the strategy of enhancing ubiquitous computing by connecting devices and sensors to the Internet and using analytics to generate a macro-scale understanding of system interaction and usage (Chui, Loffler, and Roberts, 2010). Ferber predicts that there will be 6 billion connected objects by 2015. They are appearing in a variety of domains, including entertainment, health care, manufacturing, sports, and more.

Big data analytics can be added to combine populations of devices and identify even broader insights. Any of the three stages can be enhanced using this approach. Linking multiple sensors allows a wider range of inputs to be used to model the current state of the environment. For example, a smart home thermostat can be connected to a weather forecasting system or a smart alarm clock can be connected to a traffic information system.

Linking computational engines also facilitates the use of a wider set of data to determine the best action. The smart alarm clock can be programmed to ring 15-minutes earlier if there is traffic on the route the user needs to take to get to work. Linking actuators allows the coordination of multiple devices. If the alarm clock sounds 15 minutes earlier, the coffee maker can also be programmed to start 15 minutes earlier and so on. As sensors, computational engines, and actuators are connected, an Internet of Things emerges. Reed, Gannon, and Larus (2012) define the Internet of Things as "the growing and largely invisible web of interconnected smart objects that promises to transform the way we interact with everyday things." The key to this definition is that there is more than an incremental advance in the functionality that is supported by these devices. The difference is a *fundamental* transformation. Deiser and Newton (2013) predict that the Internet of Things will create new business models, technological opportunities, and generate an inflection point in innovation.

Taking ubiquitous computing a further step forward, cloud computing infrastructure can be engaged to implement ubiquitous computing as a service. This allows updates to be formulated and initiated by an external source that may have more expertise than an individual user. Aggregating data from multiple users also expands the capability of ubiquitous computing. A smart home thermostat can model the environment more accurately if it has access to the identity and preferences of a wider population of possible entrants into a room. A traffic management system would have a more powerful actuate stage if it can coordinate multiple cars to balance traffic along multiple routes and minimize delays for everyone individually and thereby for the system as a whole.

UX When There is no UI

The prevalence of ubiquitous systems, both local and Internet-connected, is constantly increasing. The common thread in these conceptions is that the technology resides in the background and supports the achievement of user tasks without explicit interaction. Ubiquitous computing presents a new challenge for user experience design because it is based on the principle of a very limited or even the absence of any explicit user interface during day-to-day interaction between the user and the system. Instead, the system invisibly monitors the environment and the user and takes action based on a pre-established and preconfigured set of conditions.

The user does not have an explicit set of controls to directly interact with the system. There is also not a visible interface through which the user can view the output or status of the system. There may not be a distinct channel for providing feedback to the user when the system takes an action. The traditional methods of human factors need to be adapted to this context.

MODEL OF UBIQUITOUS COMPUTING

The rest of this paper presents a model of ubiquitous computing that can be used to examine the user experience of these systems. Examples from several domains, and the common user experience challenges that emerge, are used as illustrations.

Ubiquitous computing involves a three step process: sense, compute, and actuate (Zaslavsky, Perera, and Georgakopoulus, 2012). The sense and actuate steps are loose parallels with the traditional input and output stages of human-computer interaction but with different interaction modalities because of the absence of an explicit interface.

Sense. In the sensing stage, the technology monitors the environment, the user, and/or other linked technology to determine the current state. The monitoring can be initiated based on a periodic schedule or be triggered by something in the world, such as a door opening to a room. Sensing is often done using smart meters, which have advanced computing capabilities and may be connected to the Internet to leverage a wider information base on which to interpret what is being sensed. For example in health care, diabetic patients can have an implanted blood glucose detector that can communicate its readings directly to the patient's computer or tablet. Zaslavsky, Perera, and Georgakopoulus (2012) cite a prediction that there will be 200 million smart meters in operation by 2014.

One user experience challenge in the sensing stage, noted by Zulas et al (2012), is the difficulty of measuring internal phenomena such as user cognitions or emotions. Users' time-dependent cognitive capabilities, current focus of attention, contents of working memory, and other factors are virtually invisible to the current sensor technologies available for integration into ubiquitous systems.

Some secondary measures, such as facial expression modelers and eye-tracking, constitute the current state of the art. Camera-based image processing can be used for eye tracking to predict the users' focus of attention (Stephane, 2011). The analysis of facial features can provide cues about emotional valence (Essa and Pentland, 1997).

Several solutions have been proposed to measure user intentions through physical gestures. Maes et al (2013) investigated the potential of using the orchestra conductor as a conceptual model, with these exaggerated hand movements serving as commands to the sensing system. But this reduces the ubiquity of the system. If natural motions can be interpreted through image capture, the system would deliver a more effective experience.

Blackshaw et al (2011) report on some of the challenges they encountered when developing a model for gestural inputs to a CAD system. While their design is only partially ubiquitous, the model is illustrative for ubiquitous sensing in general. They investigated video capture of the users' hand and finger movements to determine their intention for manipulating a shape in a CAD system. They created a "grammar of gestures" to measure four user intentions: selection, translation, rotation, and scaling. Unfortunately, testing of the system showed that even with a depth camera suspended directly over the hands the system was unable to reach the required level of precision to identify the relevant event thresholds for taking action. More development of this kind of user modeling is necessary to achieve sufficient levels of user experience.

Another challenge at this stage occurs when the system misunderstands the user's intentions or when the user has an inaccurate mental model of the system's ability to interpret her intentions. A process for error detection and error recovery is needed that does not require explicit interaction is needed.

Compute. In the computing stage, the technology applies a set of pre-programmed instructions to determine if any action is needed. The compute stage needs to include the capacity to identify events that reach a threshold of change that is relevant to the user in the current context.

The instruction set may be a fixed part of the environment that is not configured by the user but is set by an outside party such as an employer or law enforcement. This would include a security system that monitors a retail store's doors and windows for intrusion. The system would need to differentiate between an acceptable entrant, a security breach that requires action, or an ambiguous situation for which additional monitoring or explicit user interaction is needed.

The instruction set also may be customizable by the user, such as a programmable thermostat that is part of a smart home system. The user configures the system with the relevant instruction sets and criteria up front so that later when this or another user enters the environment the technology can act without any additional explicit user interaction.

The user experiences challenge most often faced at this stage is to create a set of rules that are transparent to the user without requiring any explicit interaction, feedback or error recovery. One approach is to use the best fit. Based on its interpretation of the environment at the sensing stage, the system would match the normatively optimal response. Another approach is to default to the lowest risk option as a rule. If any action could cause high levels of user dissatisfaction, physical harm, or other consequence, the system would only take this option if it is clear that it is the user's intention. A third approach leverages the Internet connection to use a crowd-based solution. Whatever the most popular action is among the user's social network or other specified group would be selected. This is an effective approach for expertise-based domains such as health care.

Actuate. In the actuate stage, the technology implements the action based on the results of the previous two stages. For example, a user entering a room that was previously empty may result in the air conditioning temperature being lowered from 80 degrees to 78 degrees. Again, the ubiquitous nature of the system implies that the user does not need to adjust the thermostat; his or her presence in the room, the sensing of that presence by the system, and the set of preconfigured rules trigger the rise. But because the response is automatic, a user experience challenge that arises is the lack of feedback. The user may want to know when changes are actuated and what the change is.

In some cases, only partial ubiquity is achieved. The user retains control of the actuate stage, either by preference or because the system is not capable of taking the needed action. In these cases, the system presents some combination of the data used by the sensors and the computed system state and a specific request to the user for interaction. This is an area where user experience is critical. Zulas et al (2012) note that raw sensor data can overwhelm the typical user because of excessive volume. Rather than presenting the data, smart visualizations are needed to transform the data into useful and actionable information. This requires an accurate model of both the user and the context.

The usability of this interaction is further challenged because the normal course of ubiquitous interaction reduces the user's experience and expertise with the user interface that they must operate during such exception handling. The user interface and user experience designs must follow the approach used for novice and infrequent use, even for systems that are ubiquitously used on a regular basis. This is similar to the deskilling often seen with the use of automation (for example, Saffarian, de Winter, and Happee, 2012).

DOMAIN EXAMPLES

Smart Homes

The home is a common environment for the application of ubiquitous design. One ubiquitous technology that makes a home smarter is the Nest smart thermostat (Simonite, 2013). The thermostat uses each of the trigger types described earlier. The sensors monitor user activity and automatically adjust the temperature setting 30 minutes after it detects the last user has left the residence in the morning. The 30-minute trigger was developed based on modeling of population-wide morning behavior. It also uses a push strategy to update these models as it learns more rules for the computing stage. When the user wants to customize the settings, they can adjust the models using a smart phone and mobile app (making the design only partially ubiquitous at this stage.

Because there is no ongoing user interaction, the system cannot use log-in information to customize the settings for each user. Identity recognition through image processing has become an effective replacement. Locally, this would work for residents of the house and perhaps a unique setting for all non-residents. Using the Internet of Things model, a more universal image database can be used to search for the identity of the non-resident. But this could increase the false alarm rate, hurting the user experience for residents. The rules established at the compute stage should balance accuracy with the greater importance of residents' priorities. For example there is a conflict if a resident is an environmentalist but a non-resident's profile indicates a preference for higher heat settings. Even with a balanced set of rules, without any feedback interface the resident might misinterpret a higher temperature and the non-resident might misinterpret the lower temperature – both leading to a reduced user experience.

Ubiquitous computing is making multiple inroads into the kitchen to improve the health or safety of the consumer. A soup spoon in Japan monitors the salt content of food and warns the user if a preset level is exceeded. A new ice cube developed at MIT monitors not only the alcohol content of drinks but also the aggregate amount of alcohol that is consumed by a particular user. It alerts the user by text message if he/she is drinking too fast or too much, using preconfigured thresholds. The text message channel for notification increases the scope and quantity of information that can be communicated, although it makes the system only partially ubiquitous. These capabilities are more important in light of the 2008 GAO study which found that the nutrition labels on packaged food are not particularly accurate (Freuman, 2012). But it still remains a challenge to connect individual drinks with individual users. Image processing would only be feasible if the ice cube can be connected wirelessly to a room-based video capture system and some form of spatial location.

Social Gaming

Yao et al (2011) describe a series of social games that are played across distances using partially ubiquitous technology. They stress the importance of haptic realism in order for games to reproduce the social aspects of co-located games and deliver a satisfying user experience. This requires the sensing, computing, and actuating to be sufficiently effective. Sensation combines video monitoring of the players and a force transducer to measure their physical exertion on the rope that serves as the game controller (see Figure 2). The rope in the other location serves as the actuator by applying the identical force. Because the rope is a natural part of the game, it can serve as an input/output device without degrading the ubiquity of the experience.

But there are still user experience challenges. The game needs to sense player actions accurately and precisely, compute the meaning of those actions within the scope of the game rules, and implement actions in the other location(s) so that competing players can respond. The quality of the user experience was highly dependent on the lag time of the network and the synchronization of the players' activities in each location. A high bandwidth was necessary to create the illusion that the virtual world was real. This was a must-have quality (Aoko, 1990).

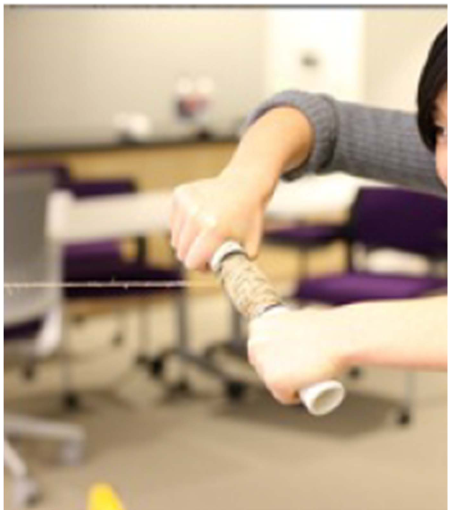

Figure 2. Rope Plus social gaming device

Consumer Products

There are some simple consumer products that leverage ubiquitous technology to provide capabilities without disturbing the user experience. For example a technology-enabled pen was recently released in Germany that vibrates when the user makes a spelling or grammatical error (www.bruynzeel-mygrip.com). Of course the error-detection algorithms need to deal with the same kinds of challenges as word processing spellcheckers. But the ubiquitous computing dimension adds a new wrinkle to user experience design. The pen needs to convey the presence and nature of an error without being overly intrusive or disturbing the user experience.

The Quantified Self

The quantified self is the practice of tracking one's life in terms of attributes such as activities, inputs, and states (http://en.wikipedia.org/ wiki/Quantified_Self). It is significantly enhanced through ubiquitous computing because 24/7 tracking can be onerous if it requires active sensing, computing, and actuating.

The Jawbone Up (see Figure 3) is an example of how ubiquitous computing has been applied to the quantified self movement. The Up collects a wide variety of data on the user's sleep patterns and physical activity and integrates it with data from other apps to track user health and make recommendations. But as Fortune (2011) warned, the Up's success depends on its attention to user experience. The wristband is designed to require the least possible input from the user so that it maximizes the ubiquity of the interaction. The setup interface needs to be comprehensive enough so that the day-to-day experience can be interface-free. And to add value, the Up needs an effective compute stage to determine what actions to take as a result of the data it collects. It can maximize the ubiquity by doing less or it can include a more extensive an interface and do more. This balance may shift as technology changes and it becomes more feasible to support additional functionality ubiquitously.

Figure 3. Jawbone Up bracelet

Industrial

GE has made a significant investment in what it calls the "industrial internet" (Leber, 2012) to leverage ubiquitous computing in its manufacturing facilities and service centers. In service, GE jet engines (20,000 in the field) send data on various performance attributes to the service center. The computing algorithm determines if maintenance is needed and if so a message is sent to the user informing them of the need. The power of this system is that the computing algorithm can predict maintenance needs 30 days in advance. Using Internet connectivity, as GE improves the algorithm they can distribute new computation rules automatically to the engine sensors. And by aggregating the data from 20,000 engines all used in unique contexts, they can develop better models for understanding usage and predicting maintenance needs. The system still requires a user to performance the maintenance activities and it notifies this individual using a standard channel. As technology advances, more of the process will shift to ubiquitous connections.

In manufacturing, GE has placed 10,000 sensors in a battery factory that monitor physical attributes such as temperature, air pressure, and energy consumption. The system applies data mining at the compute stage to explore relationships among these inputs and important performance metrics to identify important events and relevant actions to take as a result. For example, by combining weather predictions (from the Internet) and ambient humidity readings (from the sensors), the factory can adjust the HVAC system to improve the quality of the manufactured batteries without requiring operator intervention. They have outfitted floor managers with tablet computers to allow them to explore additional opportunities to leverage the sensor data. Although this interaction is not ubiquitous, they determined that the added capabilities was worth the tradeoff. This is a common user experience challenge when implementing ubiquitous computing in a business environment.

USER EXPERIENCE SUMMARY

Although these examples vary widely, several challenges arise frequently enough to be worth a holistic approach for user experience research and design. In the sensing stage, the system needs to recognize individual users and their current state. Cognitive processes are invisible and are likely to stay challenging to model reliably for the foreseeable future. A focused effort to identify observable behaviors that reveal cognitive processes relevant to the computing algorithms would be extremely valuable. The sensing must also be executed within the privacy concerns of the user, especially for cloud-enabled systems that might reveal data to external parties.

At the computing stage, the primary user experience challenges are in setting up and modifying the rules for taking action. In part, this is because a well-functioning system would not need to be modified often so the interface would rarely be used. Also, users often are not aware of or unable to articulate their needs with sufficient precision. And as more of the compute stage leverages the Internet of Things model, it may become increasingly less transparent and accessible to the user.

When executing an action, it is important that any effects that the user needs to be aware of are transparent. The actions must also be reversible if they incorrectly interpret the user's intentions or desires. There must be enough information for users to know what is happening without interfering with the ubiquity of the interaction.

Conclusion

The purpose of this paper is to provide a model of ubiquitous computing, the user experience challenges, and a range of examples to demonstrate the wide applicability of the approach. It can serve as a call to action for user experience professionals to get involved in this fertile state of the art domain and help it evolve into a more effective approach to developing rich and satisfying products and services.

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