Augmented Reality 2.0

Dieter Schmalstieg, Tobias Langlotz
Institute for Computer Graphics and Vision
Graz University of Technology
Graz, Austria
schmalstieg@tugraz.at

Mark Billinghurst
The HIT Lab NZ
University of Canterbury
Christchurch, New Zealand
mark.billinghurst@hitlabnz.org

Abstract. Augmented Reality (AR) was first demonstrated in the 1960's, yet is it still not widely used. However a number of technologies have recently emerged that can be used to easily deploy large numbers of Augmented Reality applications to many users. Camera equipped cell phones with significant processing power and graphics abilities provide an inexpensive, versatile platform for AR applications, while the social networking technology of Web 2.0 provides a large-scale infrastructure for collaboratively producing and distributing geo-referenced content. This combination of widely used mobile hardware and Web 2.0 software allows the development of a new type of AR platform that can be used on a global scale. In this paper we describe the Augmented Reality 2.0 concept and present existing work on mobile AR and web technology that could be used to create AR 2.0 applications.

1. Introduction

Augmented Reality (AR) is an area of research that aims to augment the real world by overlaying computer-generated data on it. Azuma [Azu97] identifies three key characteristics of AR systems: (1) mixing virtual images with the real world, (2) three-dimensional registration of digital data and (3) interactivity in real time. The first AR experience with these characteristics was developed over forty years ago [Sut68], but mainstream adoption has been limited by the available technologies.

Early AR applications ran on stationary desktop computers and required the user to wear bulky head mounted displays (HMDs). Despite the ergonomic shortcomings with this, there has been success in certain applications areas, such as industrial assembly [Miz00], surgery training [Sei04] or games [Son09]. However, the truly radical use of AR based on mobile technology that allows "Anywhere Augmentation" away from the desktop has not yet been realized.

In this paper, we describe how recent technological developments allow Augmented Reality applications to be deployed on a global scale and used by hundreds of thousands of people at the same time. We call this approach *Augmented Reality 2.0*, which describes a combination of *Augmented Reality* and *Web 2.0*.

Web 2.0 is itself a recent development. According to Tim O'Reilly[1], the main difference from Web 1.0 to Web 2.0 is that Web 2.0 enables end user participation in the creation of web content, and thereby encourages social networking. In contrast, the original web technology was merely a source for information and was mainly used for one way information retrieval. Only few people created content, while a huge amount of users accessed content without creating or modifying it. Web pages were mostly static and did not allow the users to interact with them or provide additional information.

The advent of Web 2.0 substantially changed the way people use the Internet. Instead of only retrieving content, users are engaged in creating and modifying web material. Web interfaces

[1] http://www.oreillynet.com/pub/a/oreilly/tim/news/2005/09/30/what-is-web-20.html

were simplified to a point that even people with no technical skills could participate in this. This has opened the way for services based on user participation, like Flickr[2], YouTube[3] and Facebook[4], among others.

In a similar way, the goal of AR 2.0 is to provide widely deployable location based AR experiences that enhance creativity, collaboration, communications, and information sharing, and are based on user generated content. With an AR 2.0 platform a user should be able to move through the real world and see virtual overlays of related information appearing at locations of interest. Figure 1.0 shows how this might look.

Figure 1: Contrary to traditional map displays (left), AR 2.0 will navigation information on top of the images captured by mobile phones (right). Users will also be able to create and update 3D registered content, creating a location-based social network.

This information overlay will be dynamically generated from a variety of sources and seamlessly fused together on the users display. In addition the user will be able to generate their own location specific virtual content while in the real world that can then be uploaded to content servers and shared with others. Finally, the platform will provide support for social networking through synchronous and asynchronous context sensitive data sharing. AR 2.0 as a user interface and networked medium has many parallel characteristics to Web 2.0 (See Table 1).

Table 1: Comparison of Web 2.0 and AR 2.0 characteristics

Web 2.0	AR 2.0
Large number of users and web sites (already true for Web 1.0)	Large scale in number of users as well as working volume
No clearly visible separation between accessing local data and remote data	No clearly visible separation between visualizing local data or remote data
Applications running in a browser behave like local application, encouraging the user to interact with them	Applications locally running on the device can transparently download modules or new features from remote servers
A huge amount of non technical people retrieve data and contribute or modify it as well	Users can creating or updating the AR content at specific locations
Information from different sources can be combined and create a new value-added application, in so-called Mash-ups	Mash-ups which access data from sources like traditional web services and combine with AR content to display it in three-dimensional space

[2] http://www.flickr.com/

[3] http://www.youtube.com/

[4] http://www.facebook.com/

If AR applications are going to be deployed on a massive scale, there are several key areas of technology that are needed:

(1) A low cost platform that combines AR display, tracking and processing

(2) Mobility as key requirement for the platform to realize AR in a global space

(3) Backend infrastructure for distributing of AR content and applications

(4) Easy to use authoring tools for creating AR content

(5) Large scale AR tracking solutions which work in real time

In the remainder of this chapter we first discuss the related work that provides the enabling technologies for AR 2.0. We then explain the use of AR for social networking, end-user authoring for AR 2.0, and present several case studies of early AR 2.0 applications.

2. Related Work

AR 2.0 builds on earlier work in several areas, in particular research in mobile AR, social networking, and location based services. In the late 1990s, early experiments were conducted on presenting geo-referenced content in AR applications. The Touring Machine [Fei97] was the first mobile outdoor AR application and was used as a campus tour guide by showing virtual annotations on real university buildings. Although simple, this prototype showed the power of in-situ presentation of geo-referenced information.

Over the last several years the increasing computing capability of personal mobile devices has made it possible to move AR systems from the backpack mobile AR systems of the mid-nineties to Tablet PCs [New06], PDAs [Wag03] and then mobile phones [Möh04]. Figure 2.0 shows sample systems in this evolution. Most recently applications such as Wikitude [Mob09] can show location tagged AR content on a mobile phone in much the same way as the Touring Machine. Nokia's MARA[5] project is another commercial ready example of the idea shown in the Touring Machine.

Figure 2: Evolution of Mobile AR Systems

While the mobile AR hardware platform was changing, there was also progress being made on the software. The emergence of the Web as a mass phenomenon prompted Spohrer to suggest the "WorldBoard" [Spo99], a combination of distributed online information systems and geo-referenced indexing. Information could be published in traditional web form, but were indexed by geographic position rather than by a symbolic URL. The short-term goal of the WorldBoard was to allow users to post messages on every cubic meter of space humans might go on the planet, while the long-term goal was to allow users to experience any information in any place, co-registered with reality.

[5] http://research.nokia.com/research/projects/mara/

Unfortunately, the WorldBoard vision was not fully realized, partly because key technologies such as community content creation tools were not mature enough. Later work, such as the Nexus project in Stuttgart [Hoh99], has similar concepts but targets coarse geo-referenced information systems rather than Augmented Reality presentation.

Today, we see a new mass phenomenon, which has been dubbed Web 2.0. This is characterized by open communication, decentralization of authority, and freedom to share and re-use Web content [Bar06]. It is also user collaboration driven and provides a platform offering open APIs and applications that can be combined in sophisticated applications integrating information from multiple sources [Ore08].

One of the key innovations that can be supported through Web 2.0 is social networking and crowd sourced content. Without revolutionary changes, the availability of the web has reached a point that the voluntary joint effort of literally millions of users can produce databases of a size and quality that has previously been considered impossible. For example, Wikipedia[6] has already surpassed many traditional encyclopaedias in coverage and richness, and Flickr is one of the largest collections of digital images worldwide. As a side effect, simple keyword tagging is powerful enough to replace sophisticated semantic web techniques as an organizational principle and can scale to a large numbers of users. The open architecture of the Web 2.0 services allows everybody to enrich these experiences with Mash-ups, while the underlying infrastructure is paid for by advertising. It is important to note that all these results are based on simple existing technologies such as HTTP and AJAX.

As part of the Web 2.0 movement, digital globe and map services have become very popular – Google Earth[7], Google Maps [8]and Microsoft Virtual Earth[9] among others. While the primary source of data of these applications is produced by large enterprises at a high cost and level of effort, it is noteworthy that the results are still made freely available via the Web 2.0 ecosystem.

Using these map services, next generation web technologies may be used to link physical places, objects and people to digital content. For example, Ambient Intelligence (AmI) [Aar01] is a set of projects that explores the convergence of mobile, ubiquitous and intelligent systems (e.g. context-aware systems) and interaction with real objects. Another project is Deusto Sentient Graffiti [Deu09] which consists of an application that allows users to create annotations associated to real places using context location data with Web 2.0 infrastructure. It aims to show the potential of mash-ups, using the capabilities of mobile devices, Web 2.0 mash-ups as a platform, ubicomp Web paradigms and social annotation of objects and places.

Deusto Sentient Graffiti is based on AJAX technology, and real objects offer URL tags to XML virtual post-its. These post-its have multimedia content or a pointer to a web service and contextual attributes. Users of the system can move through an annotated environment, and browse and consume the available annotations according to the user's current context, profile and preferences. Servers store, index, and match user annotations against the user's current context published.

The final key area of related work is social networking. Many mobile devices have versions of desktop social networking applications such as Facebook for the Apple iPhone[10]. However with mobile devices, social networking applications can also be developed based on the device location and other context cues.

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[6] http://www.wikipedia.org/

[7] http://earth.google.de/

[8] http://maps.google.de/

[9] http://www.microsoft.com/virtualearth/

[10] http://iphone.facebook.com/

There are many popular mobile social applications which use context cues. In Dodgeball [Dod09] users receive text messages of friends, and friends of a friend if they are within ten blocks of each other. The location-awareness is implemented by users' entering their location and time, and using cell tower IDs. Plazes [Pla09]] is a location/context aware system that relies on internet infrastructure to serve information about services and nearby friends. Location is based on GPS, and MAC addresses of networks and WiFi access points. Rumble [Rum09] helps mobile users locate nearby friends, or even strangers with the same interests, and offers with access to location related data. Jabberwocky [Jab09] performs repeated Bluetooth scans to create the sense of the "familiar stranger" in an urban community. Familiar strangers are people that are always nearby in an urban region but are acquaintances. Serendipity [Eag05] uses Bluetooth technology to facilitate interactions between physically proximate people through a centralized server. Through the identification of Bluetooth ID's and support of on-line profile matching, Serendipity identifies new people to become acquainted with.

As can been seen there has been related work developed in a number of areas, including social networking, location based services, and mobile AR, however there has been few examples of applications that combine all these areas together. In the next section we discuss how this previous work can be integrated into a platform for developing AR 2.0 applications.

3. Augmented Reality for Social Networking

A low cost hardware platform for AR is key for realizing our vision of AR 2.0. Today's smart phones satisfy all basic requirements as a hardware platform for AR 2.0. They combine a display with 3D graphics generation and enough computing power to track the device using the camera, with the optional assistance of various other sensing technologies like GPS, WiFi triangulation and inertial sensors. Smart phones are inexpensive as they are produced for a mass market, and there are currently hundreds of millions sold per year. This momentum ensures a large scale in terms of number of users and geographic coverage.

A further feature of smart phones over earlier mobiles phones is their capability to communicate over various channels. They use third generation mobile phone communication technology (3G), which is optimized for data rather than voice traffic. WiFi and Bluetooth complete the set of supported fast communication channels. This makes it possible to access the internet to request additional content or program modules. Furthermore it allows applications to remove the separation of local and remote data.

Spohrer's vision of "information in places" can be realized by using smart phones as the hardware platform and Web 2.0 as the backend infrastructure. Web 2.0 owes its success largely to open standards, which allow interested parties to easily partake in an economy of scale. Likewise, the success of AR 2.0 will require a federated approach and especially open formats for content description and content exchange.

An interesting common standard is the Keyhole Markup Language (KML), an XML dialect utilized by Google Earth, which is open and extensible. It incorporates Placemarks which describe geo-referenced information, and also refers to other web standards for multimedia content. For example, 3D models (essential for AR) are described as COLLADA files, an XML-based 3D exchange format increasingly supported by digital content creation tools. However, while KML is an open format, it still has a lot of properties that are proprietary to Google Earth. Thus it is only partially suitable for describing AR content, which could be referenced in many ways (geo-referenced, referenced by barcodes, etc.). Consequently, we suggest adopting ideas from KML into a new open format called ARML (Augmented Reality Markup Language), which describes the AR content and its spatial reference system.

As shown in figure 3, a location-based AR application uses data and services remotely stored and served by web mash-ups, visualized on the mobile device. Data and services offered to the user must be related to geospatial information corresponding to user location – using GPS, WiFi or Bluetooth tracking, for example – and geo-database web services. Content authoring can be performed using a desktop computer or directly on the mobile device while on location. Taking advantage of open APIs and mash-ups, complex applications can be easily broken down into smaller components and leverage existing online services. Given appropriate sources of geo-referenced data, developers can focus on the user interface experience of AR 2.0 applications.

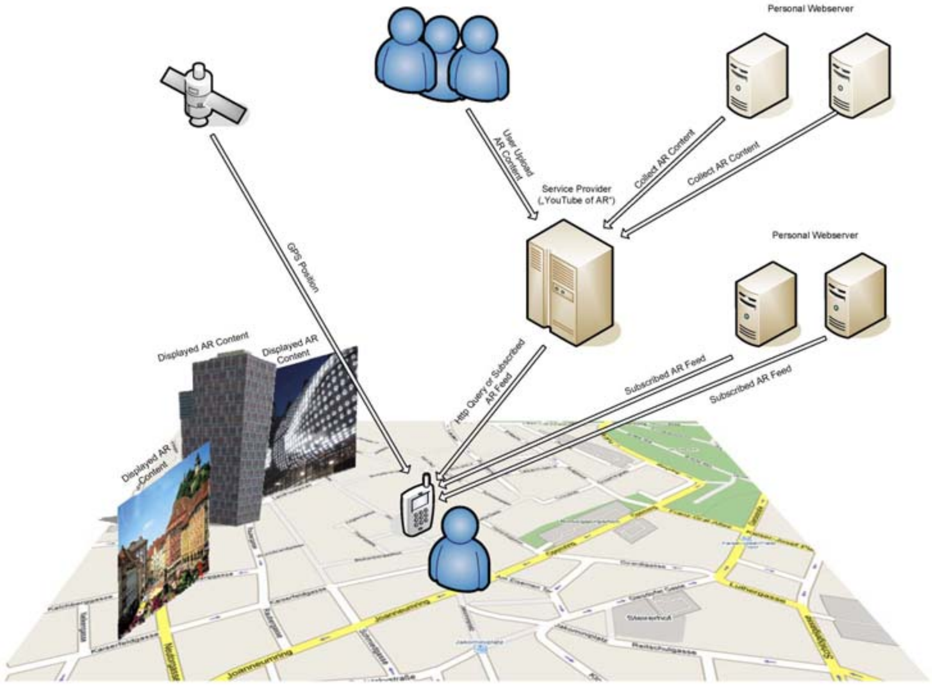

Figure 3: Data flow of end-user provided content in an Augmented Reality 2.0 scenario.

Specific AR data types can easily be integrated into the XML dialects, and hosted using standard web based databases, accessible via HTTP. New types of mash-ups designed specifically to be consumed by AR clients can be derived from a mixture of existing (conventional) content and content specifically created for AR. This content will include the visual objects, other multimedia data, application code and the feature database necessary for local tracking.

The selection of content by the user can be performed using either a push mechanism or a pull mechanism such as a webserver capable of accepting simple HTTP queries encoding the current location or area. This allows everybody with access to a server to provide geo-referenced AR content, either genuine or based on data accessed via mash-up. In addition, larger service providers (the "YouTube of AR") can syndicate content provided by many users and organized through tagging. Such syndicated hosters would allow a wide audience to publish their material, and also provide easy access for the mainstream audience.

For consuming the AR content, we image that an end-user device has subscribed to content feeds from a number of AR service providers, based on personal taste and recommendations from others. At a given location, the device sends a request containing its current position and other context information to all these service providers, and receives an index of available content. The request can ask for all information in a user-defined radius around the current point of interest, or it could describe an area in an alternative form, for example all data along a route to a given destination. The exact details on which information to download and/or to present to the user, and how the user interface lets the user control what he or she sees, is entirely up to the client, and many approaches are possible without modifying the server side infrastructure.

For example, if an online service for image recognition from a large database of geo-referenced images is available, this service would act as a filter: The client device takes a picture and sends it to the recognition service, possibly assisted with GPS coordinates to reduce the search space. If the image is recognized successfully, the recognition service returns an exact position match, which can then be used by the client to query for content.

Another approach is the use of 2D barcode markers, such as DataMatrix[11] or QR-Code[12] (see figure 4), which contain enough information to point to a specific web address of an AR content service. This can substitute the need for GPS or image recognition, and directly point to specific content rather than having to know a specific server feed or channel beforehand. It is also a suitable method for non geo-referenced content, for example, for downloading an AR game board game printed and advertised in a newspaper. If barcode markers are used, they can also initialize tracking, and thereby establish a common frame of reference (for a shared space of multiple users), while ongoing tracking can be based on natural features in the surroundings.

Figure 4: DataMatrix and QR-code

4. Application Development and Authoring

Although mobile devices provide a good hardware platform for AR experiences, there is still a need for creating the content that is going to be viewed, and authoring the AR 2.0 applications. Most web based social services provide tools for easy content creation, however there are no such tools yet for AR 2.0 experiences.

In developing AR 2.0 applications there are several aspects that must be considered; the application data, programming the mobile AR client interface and creating a representation of the real world. In this section we consider each of these aspects in turn.

Authoring in an Augmented Reality 2.0 ecosystem is transformed from a monolithic problem into one that can be simultaneously addressed with a multitude of tools. Authoring activities range from genuine creation of new applications from ground up to simple Mash-ups with only minimal original contribution. They key factor is that standard file formats can be used at least for passive content. Work on actual content creation will likely be done primarily on the desktop, while layout may either be performed on the desktop (e.g., using a map of the area), or in-situ. For many instances of application logic, wizards can be created (for example, for AR Magic Books or a timeline-based self-running presentation), which make the task accessible for end users without

[11] http://datamatrix.kaywa.com

[12] http://www.denso-wave.com/qrcode/index-e.html

programming. Complete integrated development environments for code-centric applications are also conceivable.

4.1 Application Data

As described in the previous section, AR 2.0 applications involve the aggregation of multiple data sources depending on the users needs. Combining multiple data sources through open APIs into a complex "mash-up" application makes it easier to create mobile social software:

(1) Complex social network algorithms and huge databases can be processed on servers, offering light-weighted data and services to clients;

(2) Mash-ups can use the benefit of existing social networking applications and other related applications to concentrate in designing features truly related to mobility, pervasiveness, location and context awareness;

(3) APIs (like GoogleMaps[13]) and geo-databases can be used to create geospatial mash-ups, simplifying the development of location aware social software;

(4) Users' preferences and other data that might be used to infer context can be gathered from web sources end combined with mobile client acquired data.

A possible extension is the use of AJAX for live client-server collaboration. If the content is represented at the client side as a document object model (DOM), for example as an X3D compatible scene graph, a client-server connection, e. g., based on XML and Javascript, can be used to shift the execution of part of the application logic to the server. This avoids lengthy downloads, allows exploitation of the greater computational power of the server, and facilitates multi-user applications. In many cases it should be possible to mask the incurrent latency of network transmission using the asynchronous, multi-threaded execution model of AJAX. Applications that are not just passive browsers of AR information, and that cannot be encoded with a simple approach such as Javascript, will have to be provided in binary form, forsaking platform independence. However, even platform-specific downloads are a large step forward towards the interoperability of AR application compared to current approaches.

4.2 Client Application Development

There has been little previous research on client authoring tools for end-user AR 2.0 applications, although there are several existing authoring tools for building AR applications, and for mobile phone applications that provide a useful starting point. These can be broadly organized into two types: 1) AR authoring tools for programmers, 2) AR authoring tools for non programmers. These categories can be further organized into low level tools which require coding/scripting skills, and higher level application builder tools which use higher level libraries or visual authoring techniques (see Table 1).

Table 1. Types of desktop AR authoring tools

	Programmers	**Non-programmers**
Low level	ARToolkit[Kat99] arTag[Fia05]	DART[Mac04] ComposAR[Don08]
High level	Studierstube[Sza98] osgART [Gra05]	AMIRE[Gri02] BuildAR[Bui09]

Low level AR computer vision tracking libraries such as ARToolKit [Kat99] can be used to calculate camera position relative to physical markers. However in order to develop a complete application more code needs to be added for 3D model loading, interaction techniques, and other

[13] http://code.google.com/apis/maps/

utility functions. High level programming libraries such as Studierstube [Sza98] and osgART [Gra05] provide a complete system for developing AR applications. Studierstube includes all of the functions needed for building an AR application such as scene graph rendering, networking, window management and support for input devices, etc.

There is another set of authoring tools that have been developed for non-programmers. At the most basic level, tools such as BuildAR [Bui09] allow users to associate virtual models with visually tracked AR markers, but there is no support for object interaction or more complicated behaviours. A more complete system is DART [Mac04], the Designer's AR Toolkit, which is a plug-in for the popular Macromedia Director software and which allows non-programmers to create AR experiences using the low-level AR services provided by the Director Xtras, and to integrate with existing Director behaviours and concepts.

Although there are several tools for building desktop AR applications, there is less support for mobile AR. These tools can be summarised in table 2. At the low level, the ARToolKit tracking library has been ported over to the Symbian operating system [Hen05] while the Studierstube tracker library [11] is available for multiple mobile platforms such as Symbian, iPhone and Windows Mobile.

Table 2. Authoring tools for mobile phones

	Programmers	**Non-programmers**
Low level	Studierstube Tracker [Sch08] ARToolkit for Symbian [Hen05]	Python[14]
High level	Studierstube ES [Sch08] M3GE[15]	FlashLite[16]

One of the only higher level programming libraries for mobile AR applications is the Studierstube ES [Sch08] (StbES) library. This is a low-level C++ based application framework for developing AR applications for mobile devices. StbES provides support for 2D and 3D graphics, video capture, tracking, multimedia output, persistent storage, and application authoring. For non-AR applications there are mobile 3D game engines such as the Java M3GE library that can be used for image loading, input, output, and general functions like AI, collision detection and other 3D rendering facilities.

For non-programmers, there is no mobile AR authoring tool but Python is available for rapid development of non-AR mobile applications. The Symbian version of Python has support for 2D and 3D graphics, camera input, file handling and networking, and many other functions for rapidly prototyping mobile applications. Users can develop python scripts on their desktop and then run them on their phone using a native interpreter. Other high level visual design tools are available to author mobile graphics applications. The most popular is Flash Lite, a version of the Adobe Flash Player that has been specifically designed for use on mobile phones. With this a developer can use a combination of visual authoring and ActionScript scripting to build interactive phone applications.

Developing an AR 2.0 authoring tool for non-programmers is an active area of research, but as can be seen there are a number of options for developing AR 2.0 applications using existing low level and high level tools.

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[14] http://www.forum.nokia.com/Resources_and_Information/Tools/Runtimes/Python_for_S60/

[15] https://m3ge.dev.java.net/

[16] http://www.adobe.com/products/flashlite/

4.3 In-Situ Reconstruction and Authoring

One of the most important aspects of AR 2.0 is how the representation of the real world is captured. This is necessary so that AR 2.0 content can be attached to real world locations and objects. Of course, simple configurations can be created from markers, and environments that are planar (such as a wall) or near-planar (such as a façade) can simply be photographed and then turned into tracking targets with an automated tool. We also assume that wide-area geo-referenced information sources, such as a database of streets and even textured 3D models of buildings, are available through large geo-data providers. Moreover, large collections of geo-referenced photos are already available through image services. However, this does not solve the immediate problem of creating 3D models of specific environments, or register user-generated content in such an environment.

Early work in in-situ authoring focused on placing virtual objects in the real scene and supported users through triangulation from different views [Bai01] or working plane constraints [Pie04]. Another approach, which allows the user to create AR applications in place, was presented in [Lee04]. The designer can thereby interact with the virtual world by using a marker based tangible interface. Another example is sketchand+ [Sei03] an AR collaboration tool geared towards urban planner and architects. The approach was to annotate design proposals with 3D sketches, text snippets and audio clips in order to communicate processes, design decisions and other spatial artefacts to peers.

More recently, systems have been demonstrated that simplify the task of arranging virtual objects in 3D through constrained modelling. Wither et al. [Wit08] presented a system that uses a single point laser range finder to measure the object surface. Afterwards an annotation can be stuck to that object and automatically aligned to the surface of the object. A pure camera-based approach to specifying the location and orientation was demonstrated by the University of Cambridge [Rei06] [Rei07] by integrating an online model estimation framework to extract the 3D geometry of the real world and place annotations automatically with respect to it.

As can been seen, there are currently no ideal tools for authoring AR 2.0 applications. This is an active area of research. However, there are methods that can be used for content aggregation, rapid prototyping and in-Situ authoring. Over time these will progress from being low level developer libraries to tools that can be easily used by non-programmers.

5. Case Studies

Although large scale deployment of AR 2.0 applications has not occurred yet, there have been several mobile AR experiences that display features that are needed in such applications. In this section we report on several mobile AR case studies that have important lessons for developing complete AR 2.0 applications.

5.1 Mobile AR Advertising

For AR 2.0 applications one of the challenges is how to deliver AR experiences to mobile devices on a massive scale. Traditionally AR applications have been preinstalled on devices or just distributed to a small number of users. However, recently researchers have begun to explore mobile AR advertising experiences. These rely on being able to widely distribute AR applications, and begins to address the AR 2.0 deployment challenge.

In 2007 the HIT Lab NZ delivered the world's first mobile AR advertising campaign. Working in collaboration with Saatchi and Saatchi[17] and the Hyperfactory[18], they developed a marketing campaign for the Wellington Zoo in Wellington, New Zealand. For three days in a local city

[17] http://www.saatchi.com/worldwide/index.asp

[18] http://www.thehyperfactory.co.nz/

paper an advertisement was printed with a number that a code could be texted to (see figure 5). When the reader sent a text message to the number they were sent back a small 200K application that they could run on their mobile phone. When the application was running they could point their mobile phone at the printed advertisement and see a virtual zoo animal, such as a cheetah, popping out of the newspaper page. This appeared overlaid on a live video view from the phone camera. To achieve this, a mobile AR application was written using the Symbian port of ARToolKit [Hen05], which combined a simple 3D model loader with marker based tracking.

Printed AR Advertisement Virtual Zoo Animal Appearing

Figure 5: Wellington Zoo Mobile AR campaign

Although technically the AR application being delivered was very simple, just a single static model, there were challenges in being able to freely distribute a mobile AR advertisement outside of the lab environment. In this case the application was built for Nokia N-series mobile phones running the Symbian operating system, such as the N95, and N72 phones, etc. This meant that code on the application server needed to detect the type of phone that the text message came from. If the phone was not an N-series phone then the AR application was not sent since it could not be run. Instead a picture was sent back showing what the AR application would have looked like if the phone could have run it. There were also different versions of the application that needed to be developed depending on the N-series phone model that was being used. If the text message was sent from a Nokia phone then there was a specific executable sent to the mobile phone depending on the model of phone it was.

In addition there were challenges in creating the AR content. The initial virtual models delivered were very large with many tens of thousands of polygons. Significant work needed to be done to reduce them down to the size that they could be rendered in real time on the mobile phone. The texture map images for the models also needed to be reduced in size and converted to the file format that could be rendered on the phone.

Despite the work involved, the advertising campaign was a success. Attendance at the zoo increased, there was a large amount of press generated, and Saatchi and Saatchi won several advertising awards for the innovative use of leading edge technology. Since that time several more campaigns have been run exploring different aspects of AR marketing. In all cases the most challenging aspects have been the content creation and application distribution, not the application programming.

Although not a complete AR 2.0 application, this simple application shows both the impact that mobile AR applications can have, but also the challenges that must be addressed in terms of content creation and application distribution.

5.2 Content Delivery

On of the key challenges of AR 2.0 applications is how to provide location based delivery of software and services. For example, when a person is visiting a new city location they may want to be able to automatically download AR tags of building names and virtual comments that other visitors have left at that location.

Mobile service provides typically provide a 3G or GPRS service that can be used to deliver content directly to the handset. However this is often expensive to use (especially with service providers that charge for data transfer) and the 3G service isn't location specific.

Researchers at the Australasian CRC for Interaction Design (ACID)[19] have been exploring an alternative delivery method that could be useful for AR 2.0 applications. The first version of this is an embedded device supporting transfer of digital content to and from nearby mobile phones. Called the InfoPoint, this is a small Linux computer connected to wired networking and Bluetooth hardware than can detect when mobile phones are within range and then use Bluetooth to automatically push content on the phone. In this way location specific applications or data (such as txt, image, audio and video files) can be delivered to phones at no cost to the end user, exploiting the use of the mobiles as 'third screens' [Gog06]. The design intention behind InfoPoint is to manage and deliver situated content for mobile phone users without the need for custom software.

The InfoPoint access hardware was tested in a heritage trail tourist application in the Fishing Boat Harbour in Fremantle, Perth in 2008. This was adaptation of a guidebook prototype that supported the upload and download of situated content by mobile phone users running custom software. The prototype used LightBlue to support Bluetooth features (OBEX) that avoid the need for users to install client software [Che05, Sch06]. The unit was solar-powered, sealed for protection against the coastal climate and mounted on a traffic pole (see figure 6). It also included a web interface for Fremantle Council to remotely manage content and review logs.

When users with Bluetooth enabled mobile phones walked within 30 meters they were asked if they would like to receive historic information about the site. If they accepted, they received an mp3 file with an audio dramatization of a letter written by a Captain D.B. Shaw in 1892 describing Fremantle as 'the worst damn hole I ever saw.'

The system was tested over several months during which the InfoPoint detected an average of 600 distinct phones each day. The installation highlighted issues related to long-term real-world deployments. Only around 5% of users accepted the offer to receive the digital content, showing a reluctance on the part of users to download unsolicited content. There were also major variations found in Bluetooth interfaces between mobile phone models, and wide variations in familiarity with Bluetooth-based interaction, with a strong generational bias.

Figure 6: InfoPoint Hardware

As can be seen, the InfoPoint prototype delivers rich media content to visitors' mobile phones, providing a platform for research into mobile experiences and interactions, user-generated content and system architectures. In the future the platform can be used to understand mobile phone users' experiences of situated content, and to explore interfaces for managing this content, with a longer term aim of exploring options for user-generated situated content.

5.3 Signpost

Signpost is an indoor navigation system, which takes advantage of associating locations with markers, thereby providing an inexpensive, building-wide guide executing solely on the end

[19] http://www.interactiondesign.com.au/

user's camera-enabled mobile phone. While previous work on barcode-based location tracking, such as applications relying 2D barcode such as the QR Code, rely on non real-time "snapshot" processing, our approach continuously scans an environment in search for navigation hints. The navigation therefore scales from sparse, strategically placed fiducial markers to continuous navigation in 3D with AR overlays.

Pose tracking based on fiducial markers is a well established mechanism in AR. Unlike natural feature tracking, it is highly robust and works well under varying lighting conditions. Furthermore, efficient algorithms for detecting and estimating the pose of these markers exist, making the approach highly suitable for devices with minimal processing capabilities such as mobile phones. Although marker tracking systems can do 6 degree-of-freedom (DOF) pose estimation, in Signpost we typically use only 3DOF to reduce the effort in creating a building model (map), thus making the system more practical. Full 6DOF tracking can still be used for advanced interaction mechanisms. Deploying our system to a new location consists of three steps: Creating a map and database of marker locations, deploying markers on-site and finally making the software available to potential users.

The mobile phone software activates the phone's built-in camera and continuously scans for markers at video frame rate. Since the phone is not a dedicated appliance, it was important to achieve a performance allowing the phone to remain highly responsive without disrupting regular cellular services.

Based on the technology presented in the previous section, we created a location based conference guide, Signpost, which was deployed at several large trade conferences with thousands of attendees. The application is designed to work with typically sparse tracking, so as to limit deployed markers to a manageable number. The left image in Fig. 7 shows the location of 37 markers that were installed at the conference site in the Venetian Hotel Las Vegas, an area of roughly 100x200m.

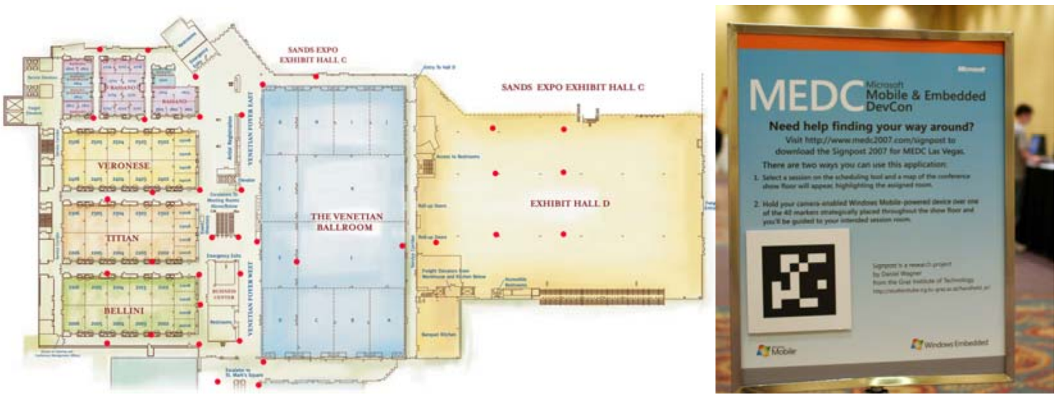

Fig 7. Left: Marker placement for Signpost2007 at the MEDC 2007 conference in an area of roughly 100x200 meters. Red dots mark locations of posters with instructions and markers. Right: Poster with instructions and marker for tracking.

While the 6DOF tracking can deliver centimetre level accuracy when markers are tracked, presenting only 2D location on a map reduces accuracy requirements considerably. This was found important as conference organizers have to consider the logistics of deploying and inspecting marker placement. The most efficient way that was developed after consulting conference organizers was to stick markers onto poster stands which can be quickly deployed on-site at pre-planned locations. The right image in Fig shows such a poster stand. The poster stand also attracts attention and provides details on how to download the application from the local Wi-Fi network.

The core function of Signpost is its combination of a conference calendar and a navigation system. The conference calendar can be browsed using various filters such as per day, per session or full text indexing. Live RSS updates from the Wi-Fi network make sure the latest changes are reflected in the schedule. All calendar entries are linked to locations, so that the navigation module can compute the fastest route from the current location (sampled from the last seen marker) to the desired lecture hall. The results are displayed on a map that can be freely navigated by panning, rotating and zooming relative to a marker or using phone hotkeys.

For large events in venues with multiple levels or buildings, a single map is no longer sufficient. Signpost therefore supports multiple maps linked to a 3D overview, or alternatively an interactive 3D representation of the building showing the global geographic relationship of the current location and the target location (Fig).

Fig 8. Left: Switching between maps; Middle: 3D view of the building with the current user's location; Right: built-in Augmented Reality mini-game.

A built-in Augmented Reality mini-game challenges users with a treasure hunt. In this game, each marker in the environment holds a specific 3D game object such as a company logo (see right image in Fig). The game objects only appear in the AR video view. A user managing to collect all game objects may register for a prize drawing or win a free-bee such as a conference hat.

6. Next Steps

In this chapter we have described the concept of the AR 2.0 platform, and have also discussed some early case studies that show technology that could be used to develop that platform. However before AR 2.0 applications become commonplace there are an important number of next steps that must take place. In particular important work needs to be conducted in the following areas, among others; Localization and Registration, Applications, and User Evaluation.

6.1 Localization and Registration

In order to provide compelling AR 2.0 applications there is a need for research on better methods for outdoor localization and registration. Early AR systems developed for outdoor use relied on GPS for position measurements and magnetic compasses and inertial sensors for orientation [Fei97, Hoe99, Bai01, Tho98, Pie01]. Recent examples, such as Nokia's MARA project [Gre06] and Wikitude [Mob09] work on mobile phones and exploit the embedded sensors, including GPS, accelerometers, and a compass. However, GPS is only typically accurate to about 10 meters, creating large registration errors for virtual objects and its reliability significantly deteriorates in urban environments due to shadowing from buildings. Indoor, the GPS signal is usually unavailable. Similarly, inertial sensors are prone to drift and magnetic sensors are disturbed by local magnetic fields encountered in urban environments.

Computer vision techniques can be used to overcome these limitations. These directly rely on the image to be augmented, so the placements of virtual images can be accurate up to the pixel. The camera pose is estimated by matching image features and minimizing the re-projection error of these features in the image. This is an active area of reserach. The University of Cambridge has demonstrated a fast edge-based 3D tracking algorithm [Dru99] and successfully applied it to Augmented Reality in [Kle03] and [Kle04]. EPFL developed a feature point-based system that matches points with reference images and also tracks feature points over time to prevent drift and jitter [Vac03].

The recent developments of feature point descriptors such as SIFT [Low04] or SURF [Bay06a] allow for fast matching of the captured image against a set of reference images. EPFL also developed an approach called Ferns that is computationally more efficient but requires more memory [Ozu07]. These techniques can be used for accurate, autonomous, and robust initialization. These techniques have been tried in localization methods by matching captured images against databases of geo-referenced images [Siv03, Nis06,Mob09b]. Some authors demonstrated that techniques from this category perform relatively well with large datasets of city landmarks [Phi07, Phi08]. However, these approaches require large amounts of memory, and are not feasible on mobile devices.

Since both sources of information, image matching and geo-location sensors, one promising area of research is to develop systems combining both sources. Reitmayr developed one of the first handheld augmented reality devices that rely on a combination of edge-based tracking, inertial sensors and GPS to perform robust and accurate 3D tracking in outdoor conditions [Rei06, Rei07]. More recently, [Tak08] uses the SURF local descriptor and fast computation of near-neighbor using kd-trees to match images. Real-time performance is achieved by running feature extraction and matching on the client-side against a local database of features determined by the current GPS estimate.

One of the main problems is that handheld devices such as mobile phones have limited processing power, while computer vision algorithms typically perform heavy computations. So more work needs to be conducted on developing computer vision tracking algorithms for mobile devices. In 2003 the ARToolKit library was ported to Windows CE [Wag03] and creating the first self-contained AR application on an off-the-shelf embedded device. This evolved into the ARToolKitPlus [Wag07] and Studierstube Tracker [Wag08a] libraries. Most recently the first natural feature tracking solution running at frame rate on mobile phones was developed. Wagner et al. [Wag08b] modified the SIFT [Low04] and Ferns [Ozu07] approaches and created the first real-time 6 Degrees-of-Freedom natural feature tracking system running on mobile phones.

6.2 AR 2.0 Application Areas

Once AR 2.0 hardware and software platform technology has been developed there is future work that can be conducted in exploring possible application areas. Some of the possible application areas include the following:

Personal city exploration: Users can create and browse recommendations, comments and hints about tourist places, restaurants, bars and shops, and leave personal, user generated content created by tourists and citizens for others in the community. This would form an ideal test-bed for the usefulness of the interfaces for selecting and creating content, and system scalability.

Urban sub-culture: Providing tools for young people to express themselves creatively, such as virtual graffiti, where the mobile phone can be used as spray can, city tagging with exciting media, or video and image diaries that are related to a certain location. In this way a virtual dimension is added to street art. It can also be used to mark cool locations and organise events.

Culture information: Professional content can be experienced for cultural highlights and sight-seeing spots in the city. Cultural objects can be enriched by virtual media that explains its origin and significance for the city. The accurate overlay of digital 3D reconstructions or adequately historical images can simulate a view into the past. Users can contribute with their annotations, post comments or recommendations.

Urban planning: Planned, virtual architecture can be viewed within the real environment of the city. This provides a completely novel way in which architects and urban planners can visualise and examine their visions. The same data can be kept open for the public to give interested citizens the chance to comment on planned constructions.

Urban maintenance: People responsible for maintenance of the city infrastructure can retrieve important status information on site, coordinate with other staff members and create and anchor their own situation assessment and status reports. Here AR makes it possible to accurately mark critical spots or objects and provide valuable annotations for an efficient and flawless handling of maintenance or emergency cases.

6.3 User Evaluation

An important part of AR 2.0 development will be to evaluate prototype interfaces and provide guidance to on-going application development. Evaluation methods for handheld augmented reality applications are only beginning to emerge. Early examples are the evaluation of AR Tennis [Hen06] and the Virtual AR Guide [Wag06b] applications. However, those tests were performed with only small user groups in very formal test setups. In the future there will be a need to move beyond the state of the art by developing novel methods for evaluating AR user interfaces designed for large scale use, and social networking applications with many simultaneous users.

Most of the published AR research has been on enabling technologies (tracking or displays, etc), or on experimental prototype applications, but there has been little user evaluation of AR interfaces [Dun07]. For example, in 2005 Swann et al. [Swa05] produced a literature survey reviewing all of the AR research papers from leading journals and conferences and they found that less than 8% had any formal user evaluation as part of them. Thus there is a need for examples of user evaluations of AR applications and development of new methods for AR user evaluation. The HIT Lab NZ has since then developed a report reviewing all of the known AR user studies, again identifying key gaps in the research literature [Dun08]. One of the areas with smallest amount of research is on evaluation of collaborative systems with only 10 out of total of 161 AR papers with user evaluations focusing on collaborative applications, or just 6% of all known AR user studies. Our research will contribute strongly to this area by providing several examples of user studies of collaborative AR applications that can be used as a guide for further user studies by the research community.

There is research that needs to be conducted in the evaluation of the social network and collaborative communities facilitated by the AR 2.0 platform. There has been many papers published on evaluation of social networks on such topics as the effectiveness of social networking visualization tools [Hen07, Tur05], social network user interfaces [Riv96], impact on collaboration [McD03, Don99], and user behaviour in social networks [Acq06, Vie04] among other topics. However there has been little previous work on user studies of location-based social networking, such as [Bur04], and no work on the evaluation of augmented reality for location based collaboration. Many of the evaluations of social networks have been focused on qualitative methods such as user surveys and interviews, and not quantitative measures. There is a need to conduct research in evaluation of augmented reality for location based collaboration and also develop new evaluation methodologies that can be used by the broader research community for these types of user studies.

7. Conclusions

In this chapter we have described the concept of AR 2.0. Augmented Reality technology has developed to the point that it can be widely deployed on handheld devices and consumer level hardware. Web 2.0 infrastructure and tools allow user generated content to be created and shared with social networking communities. Combined together this allows us to create location based AR experiences that can be enjoyed on a global scale.

Early case studies presented show the potential for using mobile phones for experiencing AR content, for widespread deployment of AR applications and for supporting real world navigation tasks. However these case studies have also identified important issues that need to be addressed in terms of the user experience, installing applications and tracking user location.

In the future, before AR 2.0 applications become commonplace, there are important research issues that must be solved in terms of device localization and registration, building demonstration applications and user evaluation.

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