Augmented Reality User Interfaces in Home User Applications

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Abstract: Augmented Reality is an area of Mixed Reality where virtual images are superimposed upon the real environment the user sees. This survey studies, based on previous work, the possibilities for creating Augmented Reality user interfaces for home user applications. Different ways of creating Augmented Reality user interfaces and different types of Augmented Reality applications are introduced and possible home user Augmented reality applications are discussed.

Keywords: Augmented Reality, user interfaces, virtuality

1 INTRODUCTION

The purpose of this survey is to find out how augmented reality (AR) can be used in home user applications. Augmented reality is an area of Mixed Reality where virtual objects are placed in the middle of the real environment (Azuma, 1997). This paper does dot present any new findings, but concentrates on summarizing the existing research results in the viewpoint of home user applications and user interfaces.

Home user is a person who uses an application at home or in an environment similar to what is considered to be an ordinary home. That does not include outdoor spaces or extra rooms for large peaces of equipment. User interface includes all hardware and software that is being used for human- computer-interaction for an application.

Augmented Reality user interfaces offer enormous possibilities for revolutionizing the operation of information systems. If AR applications were to become a part of our everyday life, the world would seem dramatically different from the world as we know it now. By augmenting virtual objects to reality, we can make utility programs more illustrative, games more thrilling and virtual communication more real.

In this research, we will find out what is needed in order to create AR user interfaces to home user applications. First, we will define AR in chapter 2 and study it in relation to other areas of Mixed Reality. In chapter 3 we take a look at the equipment and software needed for creating AR and different possibilities for creating an AR user interface. In chapter 4, we present some existing ARapplications and discuss about the possibilities for using AR user interfaces in applications created for home users.

2 AUGMENTED REALITY AND OTHER MIXED REALITIES

The research on augmented reality (AR) begun on 1960s, when Sutherland (Sutherland, 1968) published his findings about head-mounted three-dimensional displays. However, it took some decades before AR could be referred as a research field. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

Azuma defines AR as a variation of Virtual Environments (VE) or Virtual Reality (VR) (Azuma 1997). Azuma does not separate the concepts of Virtual Reality and Virtual Environment from each other, but considers them to refer to the same entity. Reitmaa, Vanhala, Kauttu and Antila define Virtual Reality as an experience that the user has when he is immersed in an Virtual Environment (Reitmaa, Vanhala, Kauttu, Antila, 1995). Virtual Environment (VE) refers to an interactive, autonomic and realistic environment created with virtual technology. Interactivity means that the environment responds to the actions performed by user. Autonomity means that the environment does not determine in advance all that will happen, so it must not be a pre-determined simulation of the environment only and the actions of the user must have some effect on the environment. (Reitmaa, Vanhala, Kauttu, Antila, 1995)

According to Azuma, the biggest difference between Augmented Reality and Virtual Environments is that AR lacks the illusion of immersion (Azuma 1997). Virtual Environments, on the other hand, often search to bring the feeling of immersion to perfection. In AR, user sees the real world augmented with virtual objects, while in VE the user is completely immersed to the synthetic environment (Azuma, 1997). Azuma also defines three essential criteria for determining whether a system can be called an Augmented Reality system.

It should:

- combine real and virtual objects
- be interactive in real time
- be registered in 3D (Azuma, 1997)

According to a another criteria for defining Augmented Reality, AR system

- combines real and virtual objects
- runs interactively, and in real time
- registers (aligns) real and virtual objects with each other (Azuma, Baillot, Behringer, Feiner, Julier and MacIntyre 2001).

2.1 Mixed Reality and the Virtuality Continuum

Milgram and Kishino define the concept of Mixed Reality (MR), which refers to a subclass of Virtual Reality related technologies in which real and virtual worlds are merged. (Milgram and Kishino 1994) They also present a ”Virtuality Continuum”, which shows the relations between different areas of Mixed reality. In Augmented Reality (AR), virtual objects are added to the real environment. In Augmented Virtuality (AV), real objects are added to the virtual environment. (FIGURE 1)

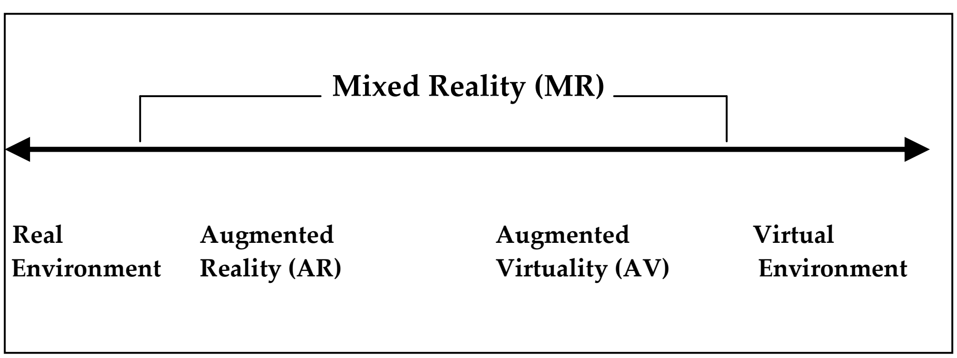

FIGURE 1: Virtuality Continuum (Milgram and Kishino 1994)

They also define six different classes of Mixed Reality which can be located in the different points of the Virtuality Continuum. The classification was carried out by the different equipment used for mixing the realities. Four of the classes could be defined as Augmented Reality classes. The first class is for non-immersive video displays upon which computer-generated images are overlaid. In the second class, the ordinary monitor is replaced by an immersive head-mounted display. The third class adds a see-through capability to the display, so that the user can see the reality with computer-generated images laid on top of it. In the fourth class, a real-time video camera is used instead of the optical see-through classes and the virtual objects are laid over the video. In addition to the Augmented Reality classes, there are two other classes, which include Augmented Virtuality and Virtual Reality. (Milgram and Kishino, 1994)

2.2 Virtuality vs. reality

The concepts of virtuality and reality, while at first seeming quite self-evident, can easily be mixed up when discussing about different levels of Mixed Reality. It is not always easy to tell, whether an object or image should be called virtual or real. For example, is a video image real or virtual? It could seem real compared to computer graphics, but not particularly real compared to the actual environment the user is situated in.

In their work, Milgram and Kishino define real objects as ”any objects that have an actual objective existence” and virtual objects as ”objects that exist in essence or effect, but not normally or actually”. A virtual object must be simulated in order to be viewed. Only real objects can be viewed directly (through air or glass), but both virtual and real objects can be viewed non-directly (from a display after either recording or simulating the picture of the object). In addition to defining real and virtual objects, Milgram and Kishino also define the concepts of real and virtual image. According to them, a real image is ”any image that has some luminosity at the location at which it appears to be located ”. Therefore, a virtual image is an image that lacks the luminosity at the location at which it appears to be located. (Milgram and Kishino 1994)

2.3 Different ways for augmenting the reality

Some researchers limit the concept of Augmented Reality to include only visual applications where head-mounted displays are used. However, Azuma avoids limiting Augmented Reality to visual applications or specific techniques. (Azuma, 1997) Potentially, it can be applied to different senses, like hearing, touch and smell (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre 2001). In this research, we include also other than visual applications and do not require the use of head-mounted display in order for an user interface to be accepted as an Augmented Reality user interface. However, the visual AR applications are the most commonly known of AR user interfaces. Also it is not yet technically possible to efficiently create user interfaces consisting entirely of smell or, in many cases, even of touch. Therefore our main focus in this research lies on the visual and audible AR user interfaces.

3 IMPLEMENTING AN AUGMENTED REALITY USER INTERFACE

In this chapter, we will find out what kind of equipment is needed in order to create an Augmented Reality user interface. All of the equipment introduced here are relatively small and therefore suitable for home usage. Also, we discuss about tracking, registration and calibration in relation to software requirements for AR applications. Finally, we take a look at the problems generally faced when building an AR user interface.

In addition to the other devices presented in this chapter, a computer is needed for modelling the virtual objects that the user sees. In wearable AR systems, the computer is carried by the user. It is also possible to move some of the computation on remote servers to reduce the weight of the equipment.

3.1 Diplays

The displays used for creating visual augmented reality user interfaces can be classified to three main groups: head-worn displays (HWD) , handheld displays and projection displays (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001).

3.1.1 Head-worn displays (HWD)

Head-worn display (HWD) is a liquid chrystal display (LCD) that the user wears in his head and through which he sees the reality augmented with virtual images. The HWDs can be divided in two categories, optical see-through and video see-through, according to the method by which the see-through property is implemented. The virtual images are usually shown on the display, but it is also possible to form the images directly on the retina with low-power lasers.

Head-worn displays for AR applications are often very lightweight. The lightest of them add less than 6 grams to the weight of ordinary eyeglasses. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

The problems with see-through displays are often related to the quality of the image. They can't offer high resolution or sufficient brightness and contrast for blending virtual images seamlessly with the real images. They also have a limited field of view. Also, most displays have ficed eye accommodation, which means that they focus the eyes on a particular distance. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

3.1.1.1 Optical see-through displays

An optical see-through display is semi-transparent and the user can see the real environment through it. An internal half-silvered mirror in the display combines the image of the real world with the computer-generated images. (Thomas, Piekarski 2002)

3.1.1.2 Video see-through displays

Video see-through displays are opaque and the image of the real world that the user sees is captured by a video camera usually attached on the user. The AR images are overlaid with the video as a background. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

A problem with video see-through displays is that the camera is mounted away from the true eye location. That causes a parallax error, which can make it difficult to adapt to the display. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

3.1.2 Handheld displays

Handheld display is an LCD that the user carries in his hand. When looking through it, the user sees the reality augmented with virtual objects. The display can be used, for example, as a window or a magnifying glass. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

The ovbious drawback of handheld displays is that the user sees the augmented reality only when he makes a special effort of lifting the display in front of his eyes, which can be a distraction.

3.1.3 Projection displays

While the other types of displays display the virtual objects only for the user who carries them, projection displays work on the opposite way. They project the image directly on the physical objects to be augmented. The projectors can be static or mounted on the user's head. If the projector is head-mounted, the only one who can see the virtual images is the user who is wearing the projector, because the images can only be seen along the line of projection. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

The biggest problem with head-mounted projectors is that they can be quite heavy, which makes it tiring to wear them (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001).

3.2 Audio devices

In audio AR systems ordinary, off-the-shelf devices are often enough. For example, Lyons, Gandy and Starner used MP3 digital audio player in their audio augmented reality system. The MP3 player was controlled by a microcontroller so that the digital sounds varied according to the location information received from a RF receiver by the microcontroller. (Lyons, Gandy, Starner, 2000) In their Augmented Reality system of linked audio, Rozier, Karahalios, and Donath used microphone to record sound from the users (Rozier, Karahalios, Donath, 2000).

3.3 Tracking, registration and calibration

Registration in AR systems means aligning the real and virtual images so that the illusion of the two coexisting worlds remains. It is important to accurately track the user's position and viewing orientation in order for the registration to succeed. (Azuma, 1997) The computer receives information of the movements of the user from tracking devices, which can be of different types.

Tracking and registration are especially problematic areas in Augmented Reality systems. Althought proper tracking and registration techniques are also needed in Virtual Environments, problems tend to be emphasized in AR systems. In Virtual Environments, user doesn't necessarily detect small mistakes in registration, because the brain has a tendency to believe that the reality is that which is being seen, even if it does not match with the information coming from the other senses. (Azuma 1997) According to Ribo, Pinz and Fuhrmann, positioning in scene coordinates should be within 1mm and orientation errors shouldn't be more than 0.1 degrees. In order to create proper real-time tracking fo generating 3d graphics, at least 30Hz tracking of all objects in the scene is needed. (Ribo, Pinz, Fuhrmann, 2001)

Tracking systems can be categorized to outside-in and inside-out tracking. Outside-in tracking means that the object to be tracked is observed from the outside, so that the tracking device is not attached to the object itself. Outside-in tracking devices are usually static and mounted on some fixed point in the environment. In inside-out tracking the tracking equipment is attached on a mobile platform, usually the object itself. (Ribo, Pinz, Fuhrmann, 2001)

Individual tracking techniques, varying from visual and magnetic sensors to GPS, all have their own strenghts and weaknesses. That is why different techniques are often used together in order to better the quality of tracking. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001) For example, in their ARQuake application, Thomas et al. combined different tracking techniques in order to provide continuous indoor and outdoor tracking. They used GPS/compass tracking together with a vision-based system. The GPS positioning was found to be efficient enough when users stayed outside and far away from buildings. When outside and near the buildings, more accurate location information was obtained by adding fiducial markers on places with known coordinates and using them together with the information got from the GPS system. When the user was inside the building, the system used solely fiducial markers that were attached on the walls and the ceiling. (Thomas, Close, Donoghue, Squires, De Bondi, Morris, Piekarski, 2000) The GPS tracking system has its limitations; it is not very accurate and it requires a clear view of the sky. On the other hand, it isn't usually practical with mobile outdoor applications to cover the environment with markers. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

Augmented Reality systems often need a lot of calibration before they can provide accurate registration. Systematic calibration techniques are in use in AR community, but often calibration is still something that is wanted to be avoided. There are at least two ways to avoid the calibration; using calibration-free renderers or an autocalibration algorithm. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

3.4 Interaction and input devices

User interaction with the Augmented Reality system can be implemented in many ways. According to Azuma and al, there can be found two main trends in Augmented Reality user interaction research: using heterogeneous devices in order to use different devices for different interaction tasks and creating tangible, physical interfaces for interaction. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

There is a large amount of possible input devices that can be used for controlling the AR application. There can be props suitable for the particular application and they can include datagloves or other haptic feedback devices (Kangas, 2002) or instead non-force feedback devices like hockey stics (Sutherland, 1968). In their ARQuake gaming system Thomas and Piekarski used a haptic feedback mock-up gun for increasing the seamlesness of the two realities (Thomas, Piekarski, 2002).

3.5 Problems related to AR user interfaces

Real-life experiences in the building of AR systems have shown that some technological limitations still exist, despite the progress made in the last years. Most commonly, problems arise from the displays or tracking. The displays are often designed for indoor use and aren't therefore bright enough for outdoor use. They usually have a fixed focus on the image, which is often too close for outdoor environments. Tracking is difficult, partly because the PCs mostly in use today have only one CPU. The general-purpose operating systems designed for consumers are not built for real-time computing, while specialized operation systems designed for real-time computing don't have the necessary drivers in order to support the graphics and sensors needed. Registration errors often appear because of the delays in data transmission. Depth perception is also a difficult registration problem. In general, AR systems should be more accurate, lighter to carry, cheaper and consume less power. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

The users, when often adapting well to AR systems, sometimes have difficulties when they return to normal reality. Some users have reported to have difficulties in depth-pointing tasks after using an AR system. Bad quality displays can also cause fatigue and eye strain. (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001)

Most of the problems described here (for example the problems with the displays and weight) are emphasized in mobile AR applications and outdoor environments, while static AR applications in indoor environments are much easier to implement.

4 AUGMENTED REALITY APPLICATIONS AND POSSIBILITIES FOR AUGMENTING HOME REALITY

In this chapter we take a brief look at existing Augmented Reality applications and the typical features of AR applications in the different areas of research. We consider the suitability of AR to different kinds of home user applications and discuss the possibilities of implementing AR user interfaces for home use.

4.1 Existing Augmented Reality Applications

Azuma introduces six different areas where Augmented Reality applications have been explored. Those are medical visualization, maintenance and repair, annotation, robot path planning, entertainment and military aircraft navigation and targeting. (Azuma, 1997) While a lot of work has been done in AR since Azuma's work in 1997, those still remain the main areas of research. In a more recent publification Azuma and al. describe the progress that has been made since then. They classify Augmented Reality applications into three different groups: mobile, collaborative and commercial applications. (Azuma, Baillot, Behringer, Feiner, Julier. MacIntyre, 2001)

4.1.1 Medical vizualization applications

Ideally, Augmented Reality could be a useful tool for doctors when performing a surgery. It can offer a 3D-X-ray vision inside a patient and thereby make it easier to perform certain operations. (Azuma, 1997) One of the existing applications makes it possible to look inside a pregnant woman's womb (Bajura, Mike, Fuchs, Ohbuchi, 1992).

When considering the recent observations made about the problems still existing in tracking and registration (Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001), it does not seem very likely that AR applications would become commonly used in surgeries or other medical tasks in the near future.

4.1.2 Maintenance and repair applications

By an AR application, maintenance and repair instructions for complex machinery could be made easier to understand. (Azuma, 1997) For example, Feiner's research group has built an application that helps the user in the maintenance of a laser printer by augmenting the printer with illustrative pictures about the different tasks. (Feiner, Steven, Macintyre, Seligmann, 1993)

4.1.3 Annotation applications

With AR applications, it is possible to create notes or windows that seem attached on real objects. For example, Feiner et al. attached standard user interface windows in the specific locations in the environment and as notes to the objects. (Feiner, Steven, MacIntyre, Haupt, Solomon, 1993) The windows or notes can appear for example when the user points the desired object. (Azuma, 1997)

4.1.4 Robot path planning applications

Sometimes, when teleoperating a robot, it can be easier to control a virtual version of the robot than the actual robot itself (Azuma, 1997). It has been shown that with stereoscopic Augmented Reality it is easier and more accurate do do robot path planning than with traditional interfaces (Milgram, Paul, Zhai, Drascic, Grodski, 1993).

4.1.5 Entertainment Applications

When Azuma first published his Survey of Augmented Reality in 1997, many entertainment AR applications didn't exist. Since then, this area of AR has become particularly popular among researchers.

Two examples of different entertainment AR applications are the Magic Book project (Billinghurst, Kato, Poupyrev, 2001) and the ARQuake project (Thomas, Piekarski 2002). In the Macic Book application the user can choose to switch into an immersive Virtual Environment from the page of the book, while other users see an AR avatar of him appearing to the page of the book (Billinghurst, Kato, Poupyrev, 2001). ARQuake is an outdoor/indoor combat game where game objects like monsters appear in the ordinary environment (Thomas, Piekarski 2002).

4.1.6 Military Applications

Military applications is one of the first fields where Augmented Reality applications have been in use. In military aircraft, head-up displays and helmet-mounted sights have been used to superimpose vector graphics upon the pilot's view of reality. (Azuma 1997)

4.1.7 Mobile AR

Lately, the research of mobile AR applications has increased due to the development achieved in tracking techniques and the increase of computing power. Mobile Augmenter Reality applications can be divided in outdoor and indoor systems. Indoor environments are often equipped with fiducials, which makes it easier to position the virtual objects when not knowing accurately the location of the user. (Azuma, Baillot, Behringer, Feiner, Julier. MacIntyre, 2001) For example, in NaviCam application, video stream coming from a handheld camera is augmented in order to create a magnifying glass effect. (Rekimoto, 1997)

The first outdoor AR system was the Touring Machine. The system provides the user with information about the buildings and departments when walking around the Columbia campus. (S.Feiner et al, 1997) Later, many other outdoor AR systems have been developed, among them the ARQuake gaming system in which the players move both outside and inside. (Thomas, Piekarski, 2002)

4.1.8 Collaborative AR

According to Billinghurst and Kato, collaborative Augmented Reality provides seamless interaction with existing tools and practices and enchanges practice by supporting remote and collocated activities that would otherwise be imposible (Billinghurst, Kato, 1999). Collaborative AR can be created by using projectors for augmenting the surfaces or by tracking, see-through displays (Azuma, Baillot, Behringer, Feiner, Julier. MacIntyre, 2001).

4.2 Augmented Reality in Home User Applications

In chapter 3, we described some of the commonly faced problems realated to AR user interfaces. We also found out that AR user interfaces are much easier to implement for indoor environments than for outdoor use. Inside a building it is feasible to use fiducials for tracking and the environment is much more predictable than outdoors (it doesn't start to rain, for example). The displays work better indoors and the isn't usually the need to carry around heavy equipment. Electricity is also easy to get. All those remarks sound very promising for implementing AR user interfaces for home user applications.

There are also difficulties in current AR user interfaces that are especially disturbing in home user applications. One of them is the price of the equipment;

in other than audio AR applications the devices needed are still relatively expensive (Azuma, Baillot, Behringer, Feiner, Julier. MacIntyre, 2001). However, especially glasses-like HMDs are usually designed especially for the home users. (Azuma, Baillot, Behringer, Feiner, Julier. MacIntyre, 2001) Another problem is the calibration. Does a home user have the skill and the patience to go through the extensive calibration usually needed for the AR equipment? In chapter 3 we presented possible solutions for the calibration problem.

4.2.1 The suitability of existing AR applications for home use

Here we estimate the suitability of the AR application types described before to home use. Many of the different categories have some potency for being home user application cadidates.

While medical applications (Azuma, 1997) att first don't seem to have anything to do with home users, they could still potentially be used at home. Medical students could use them as tools for practising surgeries or, for example, studying the anatomy. Schoolkids could do their biology homework by stydying the human organs through a 3D AR user interface.

Maintenance and repair applications (Azuma, 1997) could at their best be extremely useful to home users. For example, there could be an AR application that comes along with bought furniture, to advice how the piece of furniture should be put together.

People could use annotation applications (Azuma, 1997) for writing tabs for other members of the family or just for themselves, but the real potential of the annotation applications most likely lies elsewhere than in home environment, which the user is already familiar with. Also robot path planning (Azuma, 1997) is an area which, at the moment, doesn't have much applications in home environment, because robots are not generally used at home.

Entertainment applications(Azuma, 1997), especially games, would potentially be suitable for AR, because they often include 3D graphics, which would become much more realistic by using an AR user interface. The military applications could possible be of service to them, for example in building AR home flight simulators.

4.2.2 Bringing AR to existing home user applications

Haikala and Märijärvi list different areas of software applications. The areas that consider home users are system software and software tools, which mean utility programs like word processing software, communication software and operating systems. (Haikala, Märijärvi, 1998) The one area of applications that they don't discuss is games, which make also a considerable part of software used at home. Here, we classify home user applications in three categories:

(1.) utility, non-communication programs (includes for example word processing, spreadsheets and drawing programs)

(2.) games (and other entertainment applications)

(3.) communication (includes e-mail programs, web browsers and other programs used for communication via network)

The question related to bringing AR to different types of home user applications is: Is it feasible and useful to create AR user interfaces to that specific area of applications and in which ways could it be done?

In utility programs that don't provide communication, AR could potentially be used for 3D vizualization, which might be helpful for some cases. For example, spreadsheets could be shown as 3D images. However, there are no existing applications where conventional monitor would have been replaced by an AR system for utility programs and the area has not been researched much.

Games often include 3D graphics and different kinds of 3D objects (for example game characters or game pieces) to be moved, examined or manipulated. There are existing game controllers that differ from ordinary keyboard and mouse, some of them even include tracking properties. Also, computer and console games often aim at being as realistic as possible. Therefore, games could be potential applications when creating AR user interfaces for home users. In fact, there are many existing AR games and other entertainment applications, some of which could be used at home. For example, the Magic Book project created a collaborative application where users could virtually go inside a book while others were watching (Billinghurst, Kato, Poupyrev, 2001).

Many communication tools, like video conferencing applications, aim at giving the user an impression that the person he is communicating with, althought far away, is actually present. Other tools, like web browsers, often display graphical information. By AR technique, the communication could potentially be made more realistic and visually exiting.

5 Conclusions

In this research we introduced Augmented Reality as an area of Mixed Reality among other types of Mixed Reality. Different methods and equipment for implementing AR were presented with other relevant issues like tracking and registration. We presented different types of existing AR applications and discussed the possibilities for using Augmented Reality in home user applications.

The biggest problems today in Augmented Reality were found to be related with displays and tracking. The problems are faced most commonly in visual, mobile and outdoor AR applications. Other problems include the relatively high cost of the AR equipment and the extensive calibration needed for AR systems in most cases.

While outdoor and mobile applications are often difficult to implement because of the problems described, indoor applications seem to be easier to build and have less problems because the existing displays used for AR are more suitable to indoor use. Also, tracking is often easier indoors, where it is feasible to use fiducial markers to help the tracking.

As a conclusion, we could say that there are many different possibilities for using Augmented Reality user interfaces in home user applications, thought some types of applications are potentially more suitable for AR than others. A possible barrier for implementing AR user interfaces for home users is the price of the equipment needed. A comparison of the prices of the equipment would be needed in order to find out, how easy it would be for an ordinary home user to get it. There is also a challenge in making it easy enough to calibrate the equipment properly. While there has been advances in mobile and outdoor AR applications, further research would be needed in applications designed for home users in order to really make it possible for ordinary people to have a change to use AR outside the laboratory.

6 References

1. Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre, 2001, Recent Advances in Augmented Reality. IEEE Computer Graphics and Applications, November/December 2001, p.34-47
2. Azuma, Ronald T. 1997 A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments 6, 4 (August 1997), 355-385
3. Bajura, Mike, Fuchs, Ohbuchi, 1992, Merging Virtual reality with the Real World: Seeing Ultrasound Imagery Within the Patient. Proceedings of SIGGRAPH 1992, Computer Graphics 26, July 1992, 203-210
4. Billinghurst, Kato, 1999 Collaborative Mixed Reality. Proceedings of International Symposium of Mixed Reality (ISMAR '99) Springer-Verlag, Secaucus 1999, pp. 261-284
5. Billinghurst, Kato, Poupyrev, 2001, Moving Seamlessly between Reality and Virtuality. IEEE Computer Graphics and Applications 21, 3 May/June 2001, 2-4
6. Feiner, Steven, MacIntyre, Haupt, Solomon, 1993, Windows on the World: 2D Windows for 3D Augmented Reality. Proceedings of UIST 1993, 145-155
7. Feiner, Steven, Macintyre, Seligmann, 1993, Knowledge-based Augmented Reality. Communications of the ACM 36, July 1993, 52-62
8. Haikala, Märijärvi, 1998, Ohjelmistotuotanto. Suomen ATK-kustannus Oy, Gummerrus Kirjapaino Oy, Jyväskylä

9. Joseph Rozier, Karrie Karahalios, Judith Donath, 2000, Hear&There: An Augmented Reality System of Linked Audio
Online Proceedings of the International Conference on Auditory Display, April, 2000

10. Kangas, Katri 2002, Haptiset laitteet tietojenkäsittelyssä. Pieniä atk-alan tutkimuksia, autumn 2002, editor Pertti Järvinen, Department of Information Systems, University of Tampere

11. Kent Lyons, Maribeth Gandy, Thad Starner, 2000, Guided by Voices: An Audio Augmented Reality System. Online Proceedings of the International Conference on Auditory Display, April, 2000

12. Milgram, P., Kishino, F., 1994 A Taxonomy of Mixed Reality Visual Displays. IEICE Transactions on Information Systems special issue on Networked Reality, Dec 94.

13. Milgram, Paul, Zhai, Drascic, Grodski, 1993, Applications of Augmented Reality for Human-Robot Communication. Proceedings of International Conference on Intelligent Robotics and Systems, 1993, 1467-1472

14. Reitmaa, Vanhala, Kauttu, Antila 1995, Virtuaaliympäristöt –kuvan sisälle vievät tekniikat. 1. Painos

15. Rekimoto, Teleoperators and Virtual Environments, 1997, NaviCam: A Magnifying Glass Approach to Augmented Reality. J. vol. 6, no. 4, August 1997, pp. 399- 412

16. Ribo, Pinz, Fuhrmann, 2001, A New Optical Tracking System for Virtual and Augmented Reality Applications. IEEE Instrumentation and Measurement Technology Conference

17. S.Feiner et al , 1997 A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment.,

Proceedings of International Symposium of Wearable Computers (ISWC '97) 1997 pp. 74-81

18. Sutherland, I.E, 1968 A Head-Mounted Three-Dimensional Display. AFIPS Conference Proceedings, vol. 33, part I , pp. 757-764.

19. Thomas, Close, Donoghue, Squires, De Bondi, Morris, Piekarski, 2000, ARQuake: An outdoor/Indoor Augmented Reality First Person Application. Proceedings of the Fourth International Symposium on Wearable Computers (ISWC'00) IEEE

20. Thomas, Piekarski, 2002, ARQuake: The Outdoor Augmented Reality Gaming System. Communications of the ACM, January 2002/vol 45, No.1, p.36-38