

**Alternative realities: from augmented reality to mobile mixed reality**

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**Abstract:**

This thesis provides an overview of (mobile) augmented and mixed reality by clarifying the different concepts of reality, briefly covering the technology behind mobile augmented and mixed reality systems, conducting a concise survey of existing and emerging mobile augmented and mixed reality applications and devices. Based on the previous analysis and the survey, this work will next attempt to assess what mobile augmented and mixed reality could make possible, and what related applications and environments could offer to users, if tapped into their full potential. Additionally, this work briefly discusses what might be the cause for mobile augmented reality not yet being widely adopted to everyday use, even though many such applications already exist for the smartphone platform, and smartglass systems slowly becoming increasingly common. Other related topics and issues that are briefly covered include information security and privacy issues related to mobile augmented and mixed reality systems, the link between mobile mixed reality and ubiquitous computing, previously conducted user studies, as well as user needs and user experience issues.

The overall purpose of this thesis is to demonstrate what is already possible to implement on the mobile platform (including both hand-held devices and head-mounted configurations) by using augmented and mixed reality interfaces, and to consider how mobile mixed reality systems could be improved, based on existing products, studies and lessons learned from the survey conducted in this thesis.

**Keywords:** Virtual Environments, Augmented Reality, Mobile Augmented Reality, Mobile Mixed Reality, Ubiquitous Computing, Mobile Computing.

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## 1. Introduction

Mobile devices, especially smartphones, have seen huge technological advancement during the past decade. Originally a medium for communication, mobile phones have become a hub for entertainment, photography, navigation, the internet and social media, to name a few. Users have access to an immense amount of information via their mobile devices, and these devices also act as the users' eyes and ears, not only for information on the internet, but also for sensing embedded information in the surrounding real-world environment [Olsson et al., 2013]. This information can be accessed and appended *by* the user, and also digitally augmented *for* the user, effectively blending the real and digital (or, perhaps more appropriately, virtual) environments together on a mobile platform. This allows the user to experience both the real and virtual environments in a novel way, possibly providing the user with access to information normally hidden from him (or her) in the surrounding environment, and also granting the user the ability to provide content to the virtual world from his (or her) current location or activities, and most importantly, in real time. Compared with a traditional graphical user interface (GUI), a virtually enhanced view of the real world opens up many new interaction possibilities to users with their mobile devices.

Even if this isn't exactly what early visions of virtual reality were mostly about, the focus on mobile computing, and the resulting technological advances during the past years enabled a shift from a world where technology that was previously mostly bound to laboratories and cumbersome equipment, to a world where applications of this technology (even if not yet in such an immersive and pervasive form) are accessible to most people wherever and whenever they choose to use it [Barba et al., 2010]. The mobile platform, and the means it provides to digitally augment the users' perception of the surrounding environment, provide the user with a completely new user experience, and a clear step towards ubiquitous computing (i.e. the idea of inconspicuous computers in our everyday surroundings, discussed in more detail later on). This is especially true if multiple different mobile devices and wearable computers (e.g. smartphones, smartglasses, smartwatches, possibly even smart textiles) are combined and communicate together, and have access to information embedded in the surrounding world as well as the internet. Considering how fast mobile phones evolved from being just telephones to the multimedia and computer systems they currently are, and how computer graphics and display technologies have advanced in the past years, it is easy to imagine even more sophisticated mobile systems in the near future.

Future advancements may prove the various mobile systems to be a fundamental platform for mixing the real and virtual worlds even more so than they currently do, which might profoundly change the way we interact with digital information and the world around us.

### **1.1. Research questions and motivation**

Motivation for this work was a personal interest in virtual reality technologies and applications, new interaction techniques as well as user interface development as a whole. The idea of focusing on mobile mixed reality applications was presented by professor Raisamo, the other supervisor of this thesis. After reviewing a variety of scientific articles on the subject, specifically on advances in the field of augmented reality as well as learning about existing mobile augmented (or mixed) reality applications and of user experience with such applications, the subject became even more intriguing. Especially considering the widespread use of mobile devices (smartphones being a prime example) and the range of augmented or mixed reality applications the mobile platform could make possible with the technologies it includes.

This work will consist of a survey of scientific research on existing or emerging applications and devices in the field of mobile augmented and mixed reality, including possible user expectations and user experience, as well as discussion based on the results of the survey, attempting to contribute to possible future development issues with insight gained from the results. While some examples gathered for the survey may seem trivial, all examples have been chosen with the attempt to provide an overview of what is currently implemented and available for users, including existing smartphone applications as well as smartglass systems. Other examples have been chosen to represent the development of the technology over the years, as well as studies and research that offer an insight to what is possible, and how future systems could perhaps be developed with this in mind.

To summarize, the main focus of this work is on the mobile platform, including mainly devices such as smartphones, tablet PCs as well as smartglasses (or similar head-mounted displays), as well as applications developed for these platforms, and the aim of this work is to:

1. Clarify and differentiate the concepts of virtual, augmented and mixed realities, and the related terminology to the reader, as well as to provide an overview of mobile technology which makes mobile systems an ideal platform for mixed reality applications;
2. Make an adequate survey of existing mobile augmented and mixed reality applications and research from the recent years, including some historical examples to demonstrate how the systems have evolved greatly in a relatively short time frame;
3. Consider possible implementations or improvements, for mobile mixed reality applications, based on the results of the survey, emerging technologies, and existing studies as well as literature. Additionally, user expectations of such applications as well as, user experience and usability issues are also briefly covered.

## **1.2. Related work**

This work will not go into very specific detail of the technology behind mobile augmented and mixed reality devices, or software development needed to develop applications for these devices. Additionally, only a brief glimpse of existing products, research projects and existing applications have been covered. As mentioned, the aim of this work is rather to provide an overview of the topic, than focus on details, even though the details are naturally very significant. Other work that is related to, and could support, this thesis, would include more detailed topics and research on augmented reality displays (including smartglasses), mobile (smartphone) technologies, computer graphics, tracking algorithms and devices, as well as more detailed studies on user-centered design and user studies concerning mobile augmented and mixed reality systems. While a multitude of such work exists, and one can find much information about existing devices and applications on the internet, the references-section of this work can serve as a place to start if one is interested in the topics briefly covered here in more comprehensive detail.

## **2. Reality and virtuality: definition of concepts, user needs and user expectations**

Virtual reality in many forms has been the subject of much talk and research over the past few decades, ever since the term was popularized in the 1980's. Information technology has evolved in huge leaps during this time, and while the technology required for various virtual reality systems has become more efficient for the purpose (i.e. cheaper, smaller and more powerful in terms of processing power), virtual reality, as in fully immersive, photo-realistic 3D environments, in which the user is not required to wear or equip any specific hardware (for example, mobile devices or any form of wearable computers), is yet to be seen.

Current virtual reality interfaces that provide the user with a high degree of immersion consist mainly of systems utilizing equipment such as head-mounted displays (HMD) and data gloves, or more complex environments, such as the CAVE (Cave Automatic Virtual Environment). In a CAVE system, images are projected to the walls (and in some cases the floor and the ceiling) of a room-sized cube, with the user inside the cube. The user wears stereo-glasses to view the environment and typically uses a hand-held device to interact with it. The system tracks the user based on sensors on the glasses and on the interaction device [Cruz-Neira et al., 1993].

While “true” virtual reality is still more science fiction than real life, and highly immersive virtual 3D environments (such as the CAVE) are mostly built for research, industrial or training purposes and remain far from everyday use for the average consumer, other means of virtually enhancing user experience and interaction in everyday tasks have become very common, especially with the recent advances in the field of various mobile devices such as smartphones, as mentioned earlier.

Considering the above, and the use of the term “virtual reality” to describe a multitude of different systems and applications, especially in media and in colloquial speech, virtual reality can be understood as a somewhat broad term, sometimes even referring to something that is not possible with current technology (or even with that predicted to be available in the coming decades). The following attempts to categorize different forms of virtual reality, or augmented environments, crucial to this work, according to established terminology and scientific research.

### **2.1. Virtual environments**

To differentiate between the ambiguous (and perhaps common) concept of virtual reality as described above, and other perceptions of virtual reality or methods of virtually augmenting user experience, Blair MacIntyre and Steven Feiner [1996] suggest the use of the term *virtual environment* (VE) to describe any computer-based 3D-system which is interactive and attempts to



provide a spatial presence to the user. This can be done by using visual, as well as also auditory, haptic and/or tactile stimuli and feedback. Virtual environments therefore include systems such as the previously described CAVE, virtual worlds viewed by head-mounted displays, or even immersive 3D computer game worlds. *Artificial reality* is a term that can be used to describe an unencumbered virtual environment that does not require the user to equip any specific hardware or wear any computers or other devices [MacIntyre and Feiner, 1996]. Photo-realistic and fully immersive artificial reality (which, of course, is not yet possible to implement today) could be viewed as being nearest to the concept of “true” virtual reality, often used in science-fiction.

In addition to these briefly mentioned virtual environments, other methods of virtually enhancing user experience include, but are not limited to, the following concepts: augmented reality, augmented virtuality and mixed reality [Milgram and Kishino, 1994]. These three categories are the most significant in the scope of this work.

## **2.2. Augmented reality and augmented virtuality**

*Augmented reality* (AR) refers to enhancing and enriching the user's perception of the real world with digital information, for example by superimposing computer generated images on a view of the real world, effectively merging the user's perception of the world and the computer interface into one [MacIntyre and Feiner, 1996]. While augmented reality applications and systems have only recently become available for consumers, augmented reality has nonetheless been under much research for the past few decades, and the basic concept of augmented reality originates from Ivan E. Sutherland's work on the head-mounted three dimensional display [Sutherland, 1968] and his thoughts on the Ultimate Display [Sutherland, 1965]. Feiner [2002] notes, that despite being introduced almost half a century ago, Sutherland's three dimensional display contained the same key components as modern AR systems: displays, trackers, computers and software.

While the head-mounted display from 1968 was not truly mobile, and offered only simple wire-frame overlays on the view of the real world, it provided the foundation on future AR research, defined the basics of enhancing the view of the real world with virtual objects or information, and addressed core issues such as tracking the head (view) of the user to properly align the virtual overlay with the user's view. Even though the basic concepts of augmented reality can be traced back to the 1960's, the term “augmented reality”, however, was not introduced until the early 1990's, when the Boeing Company prototyped AR technology for manufacturing (assembly) and maintenance tasks [Caudell and Mizell, 1992]. These augmented reality prototype systems provided the user with relatively simple wire-frame, designator and text overlays. Caudell and Mizell [1992] also mention that due to the less complex graphics displayed by augmented reality systems, when compared with virtual reality systems (or “true” virtual environments), AR is a suitable field for standard and inexpensive microprocessors. This has proven to be true with the mobile platform becoming a viable environment for augmented reality applications at a relatively early stage.

Since then, research on augmented reality has increased, and the concept of augmented reality has become more exact. Ronald Azuma [1997] defines augmented reality as a system that has the following three main characteristics:

1. Combines real and virtual objects in a real environment;
2. Is interactive in real time;
3. Registers (aligns) real and virtual objects with each other in 3D.

Thomas Olsson [2012] describes augmented reality in the context of information technology as the physical world being enriched with artificial information (or “falsity”) which was not originally counted as reality, and points out that the user might not always even notice the augmentation having taken place.

Augmenting the real world can be done in a variety of ways, depending on what are the goals and the purpose of the augmented environment, and Wendy Mackay [1998] presents three basic strategies to implement augmented reality environments:

1. Augment the user (for example, with a wearable device such as a head-mounted display);
2. Augment the physical object (for example, by embedding computational devices into the objects);
3. Augment the environment surrounding the user and the object (for example, by projecting images on surfaces in the environment).

It is naturally also possible, to combine all of the three methods mentioned above, in one augmented reality environment. The key element, of course, would be the 3D virtual overlay, and interaction between the real and virtual objects. Following from this, augmented reality is often very visual by nature, and visual augmented reality is typically implemented by using one of the following three methods [Azuma, 1997]:

1. *Optical see-through* displays. With optical see-through displays, the user can directly view the real world through the display (which could be, for example, HMD systems or more modern smartglasses), with the augmented overlay superimposed on the display by optical or video technologies.
2. *Video see-through* displays. Video see-through (also known as the magic lens paradigm) is a system where the view of the real world is provided by a camera (or two cameras for stereo view), and the augmented overlay is combined with this view on the display (for example, viewing the real world enhanced with a virtual overlay via a mobile device's camera view).
3. *Monitor-based* configurations. Monitor-based AR systems use cameras (stationary or mobile) to view the environment, and the camera view and the augmented overlay are then combined and displayed on an external screen (the user is not necessarily required to wear any equipment with this approach).

Early augmented reality environments were designed mainly for head-mounted displays, and while such displays are still viable for research purposes, the mobile platform has proven to be more consumer friendly for AR, even though it lacks in immersion what it gains in usability. However, lightweight data glasses (such as Google Glass [Google, 2014] or Microsoft HoloLens [Microsoft, 2015]) can also be used as a modern augmented reality display, and similar systems might prove to be more common in the future. Despite the visual nature of augmented reality, other means of feedback, such as haptic or audio, can be used with (mobile) augmented reality systems to enrich the users' experience [Olsson et al., 2009].

Additionally, the virtual environment itself can be enhanced with real-world information, or in effect, be augmented by real objects [Milgram and Colquhoun, 1999]. The term used to describe an environment like this is *augmented virtuality* (AV). For example, a virtual environment could be augmented by the user with the use of an external sensor or tool (e.g. a movement tracker, camera, etc.) which provides context or information to the virtual environment, or by importing digitalized models of physical objects to the virtual view [Milgram et al., 1994]. Milgram and Colquhoun [1999] note that even though the augmented virtuality environment (or more specifically the computer system operating it) has knowledge about where in the virtual world the real-world information or object exists, it does not necessarily know anything about the object itself.

Another example of augmented virtuality could be an accurate virtual 3D model of a part of the real world, where objects (such as digitalized models of real-world objects, vehicles, or even people, etc.) move about in the virtual environment corresponding to the movement of their real-world counterparts.

### **2.3. Mixed reality**

Augmented virtuality and augmented reality are both aspects of a broader concept called *mixed reality* (MR). The idea of mixed reality was first introduced by Paul Milgram and Fumio Kishino [1994] to present the real-world and virtual environments as a continuum (as shown in figure 1), rather than the two environments being only opposites of each other. On the reality-virtuality continuum, an environment consisting solely of real objects is one, and an environment consisting solely of virtual objects is the other extreme. All other forms of augmented environments, real or virtual, fall somewhere along the continuum, with an increasing degree of virtualisation towards the VE extreme, in which the perception of the real world is completely replaced with a simulated (or virtual) environment. A real environment would naturally include any real-world scene viewed directly by a person, but also any non-augmented real-world scene viewed from a display. Virtual environments would include, on a basic level, any completely computer-generated scenes viewed from a display, and on more complex levels also any fully computer-generated virtual systems and environments, as well as the concept of artificial reality discussed in chapter 2.1.

Additionally, to clarify the distinction between the real and virtual, Milgram and Kishino [1994] define real and virtual objects as follows:

- Real objects are any objects that have an actual objective existence.
- Virtual objects are objects that exist in essence or effect, but not formally or actually.

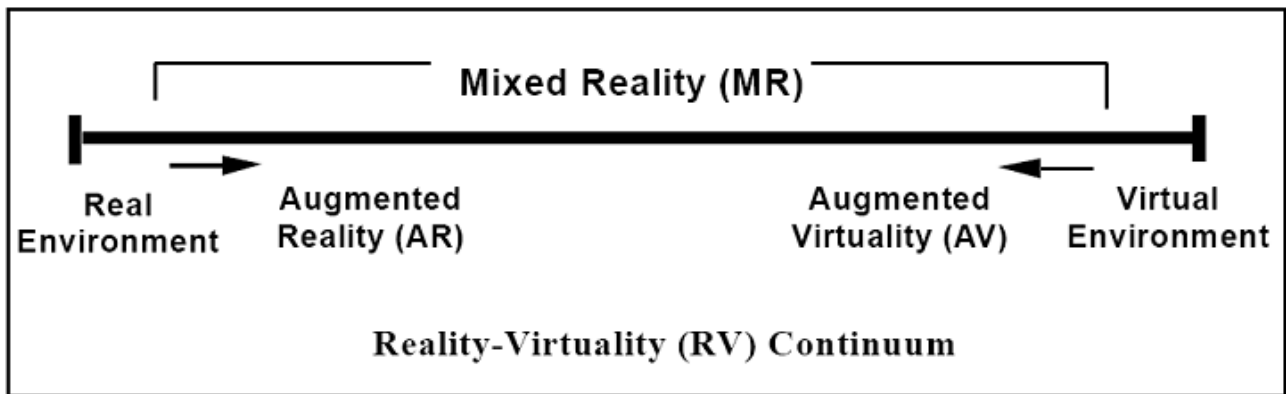


Figure 1: Simplified representation of a reality-virtuality continuum, displaying the relationship between real, virtual and augmented (AR and AV) environments, and how they are part of the concept of mixed reality (MR) [Milgram et al., 1994]

A basic definition of a mixed reality environment would be one in which the real world and virtual world objects are presented and interact together within a single display (or a single environment), i.e. mixed reality can be found anywhere between, but not including, the two extrema of the reality-virtuality continuum [Milgram and Kishino, 1994]. In effect, the reality-virtuality continuum encompasses all mixtures between the real and virtual opposites, and these mixtures can be viewed as mixed reality environments. It should also be noted that, in theory, in a case in which it is not entirely clear if the primary environment is real or simulated (i.e. virtual), it would correspond to the exact centre of the reality-virtuality continuum [Milgram et al., 1994].

In a mixed reality environment, the real and virtual worlds are merged to complement each other, and objects from both real and virtual environments can interact with each other. Therefore an implementation of a mixed reality system should encompass (at least) the functionality of both augmented reality and augmented virtuality, and allow true interaction and seamless transition between the objects in the real and virtual worlds, to differentiate it from being “only” an AR or an AV environment. Mixed reality would allow a user to augment the virtual by providing real-world context to the virtual environment, for example, by the use of a real-world sensor or instrument (perhaps integrated on a mobile device), and the user's perception of the real world would in turn be augmented with data from the virtual environment, for example, by an augmented view through a magic lens display or smartglasses.

There are a few other concepts of reality found on the reality-virtuality continuum, which are not discussed in depth in this work. To mention some examples: *diminished reality* can be seen as an opposite to augmented reality, as it “removes” information from reality (for example, by replacing them in the view by an appropriate background image, obscuring the original object); *mediated reality*, in turn, includes both augmenting and diminishing the user's view of the reality [Olsson, 2012]. Falling between the extrema of the reality-virtuality continuum, both diminished and mediated reality are also part of the broader concept of mixed reality, so they could be included as features of mixed reality applications as well.

#### **2.4. Mobile augmented reality and mobile mixed reality**

As noted previously, mobile devices such as smartphones and handheld (tablet) computers provide an excellent platform for augmented reality applications, thanks to the variety of features and instruments they typically include, such as cameras, sound and image recognition, GPS (Global Positioning System), accelerometers and compasses [Barba et al., 2010; Nokia, 2009]. Mobile devices are also able to augment the virtual environment with information imported from the real world, for example, data such as streamed video, or a user's geolocation (which could be used to, for example, present a virtual avatar of the user, or provide location-aware information from a specific real-world location). A *mobile mixed reality* (MMR) environment would, following the reality-virtuality continuum, basically be a system which uses the functionality, and provides the user with the experience, of (at least) both augmented reality and augmented virtuality, merged together, in a mobile environment. Naturally, other concepts of reality combined with AR and AV, such as those mentioned in the previous chapter, would also be viable aspects of a MMR environment.

Even though mixed reality covers the entire continuum between real and virtual, mobile mixed reality systems are in practice often implemented as augmented reality and augmented virtuality [Olsson et al., 2009], with *mobile augmented reality* (MAR) being the predominant method for providing virtual enhancement on mobile systems.

Hand-held mobile devices also provide an intuitive mixed reality interface to the user, since they offer an egocentric view of the augmented world, based on the pointing paradigm [Nurminen, 2012]. This intuitiveness could be considered to be true for most other wearable computers as well, and head-mounted MAR/MMR display systems can also provide higher contextual awareness (when compared to hand-held devices) to a user in a non-stationary environment [Orlosky et al., 2014]. The mobile platform also allows the users of augmented reality and mixed reality systems to interact, not only with the real and virtual objects within the environment, but also with various ubiquitous computers and smart devices around them.

## 2.5. Ubiquitous computing

Augmented reality and mixed reality are closely related to the concept of *ubiquitous computing* (ubiquitous computing or UC), introduced by Mark Weiser [1991]. In an ubiquitous computing environment technology is embedded into everyday objects in the real world, becoming mostly unobtrusive and undetectable to the user, or effectively disappearing into the background. Weiser notes that ubiquitous computing and virtual reality can be seen as opposing concepts, and to support this, Barba et al. [2012] mention that ubiquitous computing can even be viewed as an antithesis to virtual reality, since instead of placing the user into a completely virtual environment (or “inside” the computer), the concept of ubiquitous computing places the computers into everything around the user, making them mostly unnoticeable. Ubiquitous computing also shifts the user's focus away from the computers themselves to the various tasks at hand, unlike in a traditional computing environment where the computer itself is the main focus of the task [MacIntyre and Feiner, 1996]. Despite of all this, ubiquitous computing and various virtual environments, especially environments such as mobile augmented and mixed reality, can also greatly complement each other.

Augmented reality (and by extension, mixed reality) applications can be designed to use information provided by sensors embedded in objects in the surrounding world [Mackay, 1998], and also to be context and location-aware (with the use of GPS and different orientation sensors built into the device in use), providing the user with information relevant to his or her location and surrounding objects in a mobile environment [Olsson et al., 2012]. This emphasises the relation between augmented/mixed reality and ubiquitous computing, as well as allows augmented and mixed reality systems to be considered a tangible interface to the ubiquitous computing environment, especially on the mobile platform [Olsson, 2012]. Kriesten et al. [2010] present examples and state that mobile mixed reality interfaces offer an intuitive and direct method to control surrounding smart devices, as well as the information flow between them. Ubiquitous computing environments and smart objects can also aid in overcoming issues with information overload, since the computers are embedded into the real environment surrounding users, instead of forcing the users to deal with the information via a computer interface (or, to enter the computer's world) [Weiser, 1991].

By making computers “disappear” into the surrounding world, users can focus more on the environment itself. Therefore in augmented and mixed reality environments which are complemented by ubiquitous smart objects, the user could utilize a virtual (or more precisely, augmented) interface to interact with a smart object (or a computer) in the environment, and the devices operated by the user do not need to know anything about the object, just provide the user with means of communicating and interacting with the object and the data or features contained within it.

## 2.6. Spatial augmented reality

*Spatial augmented reality* (SAR) is another concept worth mentioning in the context of ubiquitous computing, the mobile platform, and virtually augmented environments. Simply defined, a spatial augmented reality environment would be one where projectors are used to overlay real world objects and surfaces with graphical (virtual) information. On a basic level, spatial augmented reality would be only 2D information on flat physical surfaces and three-dimensional objects, but SAR can also provide 3D visual augmentation [Raskar et al., 1998]. For example, a simple spatial augmented reality environment could be similar to the CAVE (as described in the beginning of chapter 2), but instead of completely virtual imagery, an augmented overlay would be projected over the surrounding surfaces, and the user would not necessarily need any equipment to interact with the environment; however, Raskar et al. [1998] mention that the use of shuttered 3D-glasses could be used to enhance the 3D effect of the virtual imagery. User interaction in a spatial augmented reality environment can be implemented by tracking user movement and gestures within the environment, and tracking the user's head can be used to dynamically update the displayed images depending on the user's location [Raskar et al., 1998]. The main difference between monitor-based AR configurations (as described in chapter 2.2) and SAR is that spatial augmented reality is meant to be more extensive than a monitor-based AR system which is mainly focused on providing the AR experience on a single display (monitor). However, spatial AR can be implemented with the use of monitor-based configurations (screen-based video see-through), using one or more displays, depending on the environment [Bimber and Raskar, 2005]. Other spatial display systems mentioned by Bimber and Raskar [2005] include spatial optical see-through displays and projection-based spatial displays.

Spatial optical see-through displays can utilize mirror beam combiners, transparent screens or optical holograms. Drawbacks of these systems include, for example, the lack of mobility and the lack of direct interaction with virtual and real objects (which are located behind the optics). Projection-based spatial displays use projectors to display images on physical surfaces, as already mentioned above. The projectors can be static or mobile, and multiple projectors can be used to increase the potential display area, and stereoscopic projection is also an option [Bimber and Raskar, 2005]. Projection-based spatial augmented reality could also be implemented with the use of immaterial particle displays [Rakkolainen and Palovuori, 2002]. Additionally, projection-based SAR can be implemented with small projectors equipped by the user (hand-held or head-mounted), which further increases the mobile potential of spatial augmented reality.

Spatial augmented reality could be used in conjunction with mobile augmented reality, combining the use of HMDs (or smartglasses) with SAR in a single environment [Raskar et al., 1998]. Mobile mixed reality systems could also, if applicable, benefit from the further enhancement provided by a SAR system used in the same environment. The main benefits of spatial augmented

reality environments are that they scale up to support multiple users (i.e. the SAR environment can be viewed by many people simultaneously, all having access to the same content) and that users do not necessarily need to equip any devices or other hardware to be able to view the augmented environment and interact with it. SAR environments could perhaps be seen as a natural extension to ubiquitous computing environments, in addition to the further augmentation they might provide to MMR in general.

## **2.7. User needs and expectations for MAR and MMR applications**

Augmented and mixed reality environments on the mobile platform are still relatively young and not widely adopted by the public even though the technology itself is already quite mature. Olsson and Salo [2011] conducted a survey which showed that the main reason for using existing MAR applications was curiosity and interest, instead of actual need for such an application. This places additional concerns for the evaluation of user needs and usability regarding MAR and MMR applications, since even the users themselves may not be necessarily aware of what possibilities such applications can offer and what the actual needs might be for such applications. Naturally, existing best practices for usability and user interface design must be kept in mind with MAR and MMR application development as well, since the visual nature and graphical user interfaces (and the included components) of such applications contain features found already in desktop applications.

Additionally, evaluating user expectations for proposed MAR and MMR applications as well as the end users' experience with existing MAR and MMR environments can provide valuable insight on how the mobile augmented and mixed reality platforms should continue to evolve to provide the users with a satisfying and natural way to interact with MAR and MMR environments. Keeping this in mind, proper research on user needs and expectations can further increase the possibilities to develop the mobile platform as an ubiquitous interface to the surrounding world. *User experience* (UX) evaluation and *user-centered design* (UCD) are key elements in achieving this goal.

User experience involves the characteristics and processes attributed to the concept of experience in the scope of interaction with technology, and user-centered design is a methodology where the needs and requirements of end users are in focus at each and every stage of the design process [Olsson, 2012].

Olsson et al. [2009] remark that studying user expectations of novel technologies gives an approximation of user experience before example applications exist and users will have actual user experiences with them. Regarding novel technologies as well as services and applications that don't actually exist yet, it is essential to gather the end users' expectations and to understand how the expectations will influence the user experience, and also vice versa: how the user experience will influence future user expectations. This can help to avoid the risk of unsuccessful and costly development investments [Olsson et al., 2013].



Olsson and Salo [2012] note that there is much potential in experiences of immersion, intuitiveness and awareness, all typical features of augmented reality. With the advances in mobile technologies, smartglasses in particular, the level of immersion in MAR/MMR applications could be expected to increase, allowing much more complex environments, but also with more complex issues with user experience and interaction with the environment.

As mentioned, MAR and MMR applications are not yet widely adopted, and only relatively few (when compared to the total amount of mobile applications) MAR and MMR applications are widely utilized by end users, so applying a user-centered design approach for new MAR and MMR applications can be challenging [Dhir et al., 2012]. One could ask, how to study the user experience of applications that do not yet actually exist? Dhir et al. present three goals for a user-centered design study for MMR services that aim to:

1. Understanding user needs and expectations regarding MMR;
2. Implementing MMR prototypes based on the polished user expectations;
3. Prototyping acceptability testing for reiterating the design process based on user feedback.

This method could be applied to most MAR and MMR user-centered design and development projects, if there is no previous user experience or user expectations from the application field to base the work on.

Additionally, user expectation studies for MAR and MMR services performed by Olsson et al. [2009], Dhir et al. [2012] and Olsson et al. [2013] showed that many user needs and expectations concerning MAR/MMR are practical in nature, for example:

- The need to personalize a service (personalizing service features in addition to the service's user interface);
- The relevance of information (irrelevant information can be found disturbing and interrupting during some tasks);
- The reliability and credibility of information (provided by both official institutions and other users, of which the former was found to be more trustworthy);
- Regarding the previous points, also the ability to filter information;
- Privacy and information security concerns (such as the user's location and personal information);
- Usefulness of the service, i.e. does AR or MR make the service more efficient, and does it help in everyday activities;
- Interaction with the MMR device, such as constantly pointing the camera at an object was found unpleasant;
- Expectations for the MAR or MMR application to be context-aware to some extent, i.e. providing the user with dynamic content that is relevant to their current location and activities.

Other, not so prominent (depending on the application field) needs included social-awareness (the MMR service could be aware of the user's personal contacts who are nearby), and the experience of surprise and inspiration, originating from the environment's information content, such as information added by other users, both friends and unknown people [Olsson et al., 2013].

Regarding virtual annotations added to the environment by other users, Ventä-Olkkonen et al. [2012] found in a survey that least popular annotation types were notes added by friends, whereas most popular were annotation types added by “official” sources that provided relevant information of the surroundings (for example, timetables and opening hours). Related to this, allowing users to liberally add virtual notations to any location of their choosing could provide large-scale information clutter, if the annotations are not filtered in any way. Information could perhaps be filtered so that only data provided by the user's friends or other sources of interest would be displayed by default (with the option to browse all annotations as well, of course). On a similar note, some limitations regarding interaction with the environment is probably required, but since users are unique and unpredictable, adding complex constraints is not necessarily the best approach [Barba et al., 2010]. Less limitations could perhaps offer more creative uses and enhance user experience, but the lack of necessary limitations would probably just make the environment too confusing.

Utilizing a user-centered design approach, it is useful to take into account both satisfying and unsatisfying user experiences, assuming that UX exist in the application domain. Olsson [2012] as well as Olsson and Salo [2012] point out that most satisfying experiences include efficiency in information acquisition, empowerment with novel tools, awareness of digital content in the surrounding area, experiences of surprise and playfulness, as well as experiences of immersion. Unsatisfying experiences mainly include frustration and disappointment with inadequately performing technology and unmet instrumental expectations. As with any computer systems, the technology (both hardware and software) used with MAR and MMR applications needs to function as the user expects it to function, especially if the methods of interacting with the application or environment are limited in the first place (as they often are with present day mobile systems).

Other concerns might include deciding what information to display to a user at specific points. For example, Mountain and Liarokapis [2007] mention that spatial proximity is usually the most intuitive measure of distance, but in some cases users might prefer to learn the travel time instead, or, for example, information on the local transportation network. Feiner [2002] points out that getting the right information at the right time and at the right place is the key in all AR applications. Believability of the mixed environment could also be an important aspect to the users. Barba et al. [2010] note that thorough research into how relationships between physical and virtual objects in mixed reality spaces are conceptualized, depicted and perceived is crucial for the future development of (handheld) augmented reality in general.

Evaluation techniques of augmented reality systems have mostly consisted of objective measurements (e.g. task completion times, accuracy and error rates), as well as subjective measurements (using questionnaires and subjective user ratings to determine the users' opinion of different MAR/MMR systems), with interface usability evaluation techniques being in a minority [Dünser et al, 2008]. This might be explained with the user-centered design approach described above: user ratings and narratives of user expectations have an important influence on the user experience of applications (existing or planned) in a novel technology field. However, as MAR and MMR applications become more widely used, interface usability questions will very likely increase in importance.

To summarize, the novel nature of MAR and MMR applications require a user-centered design approach somewhat different than with traditional interfaces and applications. Careful evaluation of the end users' needs and expectations regarding the application field, as well as possible existing narratives of user experiences help to understand the final user experience of the product. This in turn should lead to better design and better understanding how MAR and MMR environments should be implemented so that they will be accepted and adopted by the everyday user.

### **3. Implementing AR and MR on a mobile platform**

This chapter will provide an overview of features on the mobile platform that enable the implementation of augmented and mixed reality applications for mobile devices, discussion about relevant issues such as privacy and security, interaction, as well as technologies used to implement these applications. As mentioned earlier, today's mobile devices, such as smartphones, are an ideal platform for augmented and mixed reality applications, thanks to their ubiquity and the wide variety of features and sensors they include, as well as the fact that they are a commonly adopted (if not de-facto) platform for lightweight mobile computing. Despite of this, these devices do not really excel in any of the things they are capable of doing (for example, the processing power of a smartphone is nowhere near that of a contemporary laptop computer), so the limitations of the platform need to be addressed as well to help the platform evolve as mobile AR and MR applications become more popular [Barba et al., 2012]. In addition to processing power, complex 3D rendering and scalability, efficient use of battery power can also be an issue with mobile augmented and mixed reality applications [Nurminen et al., 2014].

Early mobile AR systems consisted primarily of portable or laptop computers, head-mounted displays, and other hardware (e.g. orientation and position trackers), usually carried in a backpack by the user, such as the “Touring Machine” example described by Feiner et al. [1997] (see chapter 4.1.1). Modern mobile AR and MR systems include all this in a single, relatively small device; typically a mobile phone or a tablet PC, but smartglasses are also a viable, emerging platform for MAR and MMR applications. To create convincing MAR and MMR environments, the device needs to be able to track the user's orientation and position, generate 3D graphics in real time on a display that presents the augmented reality view to the user, preferably provide a means of non-intrusive interaction to the user and usually also to provide wireless access to remote data (for example, the internet) and to communicate with other users, as well as contain a computational platform that manages to process and control the information handled by the features listed here [Höllerer and Feiner, 2004].

Similarly, Barba et al. [2012] mention that the three central concerns for mixed reality are “vision” (the predominance of displays, cameras and the visual nature of augmented and virtual environments), “space” (the proper alignment of virtual and real objects), and the technology itself. Currently, 3D rendering on the mobile platform, the usability of different devices (i.e. mobile phones not offering a hands-free interface and most head-mounted systems still being at least slightly cumbersome and obtrusive), data transfer and the interaction between different devices, as well as extremely accurate tracking are all issues that pose limitations to what MAR and MMR are capable of, and to what is possible to implement in the first place.

The relevant technologies, however, continue to advance (as shown in the survey in chapter 4, comparing the technology of today to that of the past decade and the turn of the millennium), and thus offer new opportunities to develop more immersive augmented and mixed reality environments, as well as new methods of interacting with them. Other issues, such as social acceptance of the technology and the price of high-end devices, such as smartglasses, can also be seen as a limitation to how popular MAR and MMR can become, especially if the other limitations have not been properly addressed, and using these devices would not grant any significant benefit to the user.

### **3.1. User tracking and correctly aligning virtual objects**

Mobile AR and MR applications need to track the user's position and orientation very accurately, so that they can present the virtual overlay to the user in the correct place as well as align and register it accurately with the physical objects. Accurate user tracking and alignment of the virtual objects is one of the most important criteria for generating believable and immersive AR or MR environments [Mountain and Liarokapis, 2007]. Accurate tracking and alignment have been some of the main concerns with augmented reality from the very beginning [Caudell and Mizell, 1992].

Various methods exist for tracking the user. Today, GPS is perhaps the de facto method to track the user's position in a mobile environment, with most mobile devices containing a built-in GPS receiver. GPS can, at best, provide an accuracy of a few meters for localization, and using differential GPS (which utilizes ground-based reference stations) the accuracy can be increased to less than one metre [Feiner, 2002]. Most mobile AR and MR applications use GPS to track the user's location, and take advantage of the mobile device's built-in sensors, which can include gyroscopes, accelerometers and magnetometers, to calculate orientation. As mentioned earlier, most of these technologies are common in present-day mobile systems. Magnetometers measure the earth's magnetic field using three different axes (three are required so that the user isn't required to place the device in a horizontal position, as with a traditional compass), and use it as a reference to determine the orientation of the device, effectively acting as a compass. Gyroscopes and accelerometers measure rotation and orientation as well as calculate proper acceleration to determine the device's orientation (and can also align the screen either horizontally or vertically depending on how the device is held by the user). In addition to these methods, Papagiannakis et al. [2008] also list various other forms of user tracking:

- magnetic tracking;
- ultrasound tracking (very short range and indoor use only);
- optical (visual) tracking, both marker-based and markerless, as well as tracking with cameras;
- Wi-Fi based tracking (a viable form of tracking since most mobile devices include Wi-Fi interfaces).

Using multiple external cameras for optical tracking can produce very accurate positioning results. The use of fiducial markers as tracking aids can help with aligning virtual images and objects accurately on the correct physical surfaces on which the markers are placed. In this method, special markers are placed on various surfaces, and the MAR/MMR application then recognizes the marker and aligns the proper virtual objects on these surfaces. Markerless optical (visual) tracking uses edge detection and natural feature detection to resolve the camera's position and track the user, as well as align the virtual objects with physical ones. The markerless optical tracking method can minimize visual alignment errors and has the advantage of being able to track relative to moving objects, however, this approach may require large amounts of processing power, and may also rely on previously known textures to register objects properly [You et al., 1999; Wither et al., 2011].

Some existing systems for markerless optical tracking on the mobile platform include Parallel Tracking and Mapping (PTAM) [Klein and Murray, 2007] and Large-scale Direct Monocular Simultaneous Localization and Mapping (LSD-SLAM) [Engel et al., 2014]. As the name implies, Simultaneous Localization and Mapping (SLAM) is a technique which attempts to map an unknown environment and at the same time track the movement of a specific object (such as a camera of a mobile device, an unmanned vehicle, or a domestic robot) in said environment. The PTAM system discussed by Klein and Murray is an alternative to SLAM approaches, and is designed to track a hand-held (mobile) camera in an unmapped (i.e. a markerless area with no virtual model or map of the space) AR workspace. The system is based on the separation of mapping and tracking, mapping keyframes (i.e. snapshots taken by the camera at various intervals), and mapping a large number of different points, to accurately track the camera and map the environment. LSD-SLAM discussed by Engel et al. is an implementation of the SLAM algorithm which uses direct visual odometry (i.e. directly calculates the change of position over time) to track the motion of the camera and is also able to build and maintain a large-scale map of the environment at the same time, the system also runs on a modern smartphone. Both systems are also available for developers.

Wi-Fi based tracking uses networking protocols that provide location estimation (based on signal strength) to calculate the user's position, but it requires multiple wireless reference stations in the environment to calculate the signal strength accurately enough. Both sensor-based tracking and optical tracking (with or without markers) methods can be used to align the virtual objects together with real objects in the AR/MR environment.

Naturally, all tracking methods have limitations (such as the accuracy of GPS), and are prone to errors (such as calibration errors, signal degradation, distortions in compass measurements, etc.), but combining different tracking methods together, can compensate for the shortcomings of a single technology [You et al., 1999]. Combining different tracking methods naturally depends on the available equipment and processing power.

While the user can be tracked very accurately today even in outdoor-environments with the previously mentioned tracking technology commonly included in today's mobile devices, aligning virtual and real objects together in an unprepared environment (for example, using mobile phones or other handheld devices in an outdoor environment without any method for visual tracking) can still be a challenge due to accuracy errors. Wither et al. [2011] present the method of Indirect AR to help overcome alignment errors with handheld mobile AR systems. Their concept of Indirect AR makes the entire scene (i.e. real world view with an augmented overlay) virtual, by capturing a panoramic image of the targeted view with the device's camera, adding the AR overlay to the correct location on the view, and finally aligning the entire (previously captured) view on the display with the background, pixel-accurately. This way, the user is provided with an indirect (virtual) view of the displayed location, with minimized alignment errors in regard to the details of the augmented overlay. This method is likely to work best at medium to long ranges, and would probably increase immersion and believability in scenarios where it is important that the AR overlay is aligned exactly on the correct location.

### **3.2. Displays, 3D graphics and depth cues**

Different types of visual display techniques can be used to implement mobile augmented and mixed reality applications and environments, these include the following [MacIntyre and Feiner, 1996; Azuma, 1997; Mackay, 1998; Olsson, 2012]:

- head-mounted displays which use either video see-through (non-direct view of the real world via cameras) or optical see-through (direct view of the real world) technologies;
- hand-held display devices, such as mobile phones or tablet computers, typically acting as a magic-lens to the augmented world (i.e. video see-through);
- monitor-based configurations, where the user does not necessarily need to wear or use any equipment;
- projection-based displays that project visual augmentation on real-world surfaces, which enable several people to directly view the same environment (such as spatial augmented reality).

Naturally, projection-based display configurations are not always truly mobile in the sense that projection-based environments necessarily do not follow the user, but are more stationary in nature. However, projection-based augmented reality can also be implemented with small wearable projectors (pico projectors), which are equipped by the user, and make the system mobile in this way. For example, a projector could be added to smartglasses or similar HMD equipment, but it could also be a hand-held configuration. The same mobility limitation applies for monitor-based configurations where the display is not carried or equipped by the user. Projection-based augmented reality could nonetheless be used in conjunction with see-through displays (mainly smartglasses or similar systems) in MAR and MMR environments.

In addition to projecting images on tangible objects and surfaces, projection screens can also include interactive and immaterial particle displays, such as the FogScreen, in which images are projected on a thin veil of fog [Rakkolainen and Palovuori, 2002]. Interaction can be implemented, for example, by tracking the users' hand gestures. Immaterial displays would offer the benefit of not physically obstructing the users. Such systems could even provide additional experiences of immersion: for example, using multiple projectors to project the images, interactive 3D scenery is also possible.

As mentioned, current mobile phone and tablet-based systems use the video see-through display system, but modern smartglass systems would preferably use optical see-through displays to allow the user to also maintain normal visual view of the surrounding world at all times, making the experience more immersive and realistic. Optical see-through displays can be implemented with different technologies (with new implementations probably appearing in the near future) such as liquid crystal on silicon (LCoS) displays. LCoS is a type of microdisplay using technology originally designed for larger screens, but which is also suited for near-eye systems and displays with the benefit of low power consumption. Another example is the use of organic light-emitting diodes (OLED) between two layers of glass to form a relatively thin see-through display where the OLEDs produce the augmented overlay.

According to the definition of augmented reality presented by Azuma [1997], AR (and by extension, also MR) applications need to register the virtual objects together with the real-world objects in 3D. Additionally, 3D graphics also provide the user with a more realistic sense of immersion, and as mentioned previously, accurate alignment of the 3D objects is mandatory to properly convey the information from the mobile AR or MR environment to the user.

Modern mobile devices are capable of rendering relatively complex 3D graphics in real time, however there are limits in processing power especially with low-end devices, and it can be beneficial to handle any functionality remotely (server-side) that is not necessary to process on the mobile device itself, to allow more processing power for the actual 3D rendering. This approach, of course, requires a stable and fast enough internet connection. In any case, the rendering of 3D environments that can be very large and detailed, is a challenge to the limited resources of a mobile device, so this is one of the issues that may hinder the development of more immersive mobile MAR/MMR environments. The environment and the virtual 3D objects within must also be believably three dimensional to the user; in addition to the correct alignment of the virtual objects, the sense of depth has to be perceived properly, since depth perception is an important factor in virtual 3D environments. Some existing AR development tools (discussed briefly in chapter 3.5) include graphic libraries and 3D rendering tools to help with creating augmented and mixed reality applications.



Additionally, virtual objects that are not near the user could be partly occluded by real-world objects (i.e. rendered only partly visible), or alternatively rendered as “visible” if completely occluded, for example, by rendering only the outlines of the object, to offer a more “augmented” three dimensional experience to the user. This requires precise knowledge of where the virtual object resides relative to real objects, otherwise the virtual object might be registered and rendered incorrectly (e.g. be visible when it should be occluded), however, managing to properly implement such features will aid in providing the user with the sense of depth.

The user's perception of depth within the environment can be enhanced with various depth cues, depending on the use and nature of the application. James Cutting [1997] discusses our perception of the space around us, and how to apply the knowledge of this perception, vision and various depth cues to the development of virtual reality environments (naturally including also mobile AR and MR systems). In his paper, Cutting lists the following nine cues and sources of visual information that convey the perception of depth to us:

1. *occlusion (interposition)*, an object hides (completely or partly) another object from view;
2. *height in the visual field*, relative measures of objects in a 3D environment;
3. *relative size*, the measure of the angular extent of the retinal projection of two or more similar objects (or textures);
4. *relative density*, the projected number of similar objects (or textures) per solid visual angle;
5. *aerial perspective*, the increasing indistinctness of objects with distance;
6. *binocular disparity*, the difference in relative position of an object as projected to the retinas of the two eyes;
7. *accommodation*, changes in the shape of the lens of the eye when focusing near or far while keeping the retinal image sharp;
8. *convergence*, the angle between foveal axis of the two eyes;
9. *motion perspective*, relative speed and motion of objects (stationary or moving) at varying distances around an observer (moving or stationary). Comparable to *motion parallax*, which is concerned with the relative movement of isolated objects, due to movement of the observer [Drascic and Milgram, 1996].

Occlusion, relative size and relative density work as prominent depth cues at any ranges (i.e. from near the viewer all the way to the horizon), and seem to be the most coherent sources of depth information at medium to long ranges, as does height in the visual field (which, however, does not convey much depth information until beyond the user's personal space). These depth cues make up our perception of *linear perspective*, i.e. the converging of parallel lines at the horizon, naturally a powerful system in revealing depth [Cutting, 1997]. Most other depth cues keep diminishing in terms of information provided as the distances increase. Aerial perspective, of course, functions properly as a depth cue only at longer ranges (however, with the loss of detail).

Pictorial depth cues (occlusion, relative size and density, height and aerial perspective) combined with kinetic depth cues, such as motion parallax and motion perspective, make up our perception of depth in a 3D environment in motion. This is an important point to keep in mind when designing mobile AR and MR applications. Drascic and Milgram [1996] mention that uncontrolled depth cues can end up providing false depth information, which may distort the perception of the user. This, in turn, will obviously degrade user experience. Conflicting depth cues caused by alignment errors may also result in much more uncertain outcomes of the environment as perceived by the user.

Additionally, optical see-through displays might not be able to completely occlude real objects with a virtual overlay (i.e. the real world will always be partly visible behind the virtual objects), unless specifically developed and built to be able to do so, and video see-through (i.e. magic lens) displays typically cause a parallax error, due to the camera(s) being mounted away from the location of the user's eyes [Azuma et al., 2001]. Drascic and Milgram [1996] also note that occlusion is the strongest depth cue within mixed reality systems, so occlusion errors are likely to greatly reduce the user experience of such systems. The method of indirect augmented reality described by Wither et al. [2011], and mentioned in the previous chapter, is also susceptible to errors caused by motion parallax, since the the static (Indirect AR) images might not be aligned properly in a case where the user will not remain stationary. Other perceptual issues mentioned by Drascic and Milgram [1996] that might result from technological limitations (or bad design and implementation) can include:

- size and distance mismatches;
- limited depth resolution;
- contrast mismatches (between real objects in a bright area, and virtual objects on the augmented overlay);
- absence of shadow cues (i.e. virtual objects not able to create realistic shadows on real objects, especially in a complex environment);
- registration mismatches in a dynamic and non-stationary environment (for example alignment errors resulting from fast motion, which could even result in dizziness or nausea, especially with smartglass systems);
- restricted field of view.

Another issue concerning the MAR and MMR systems is the users' safety in a non-stationary environment, i.e. making sure that the virtual objects do not distract the user from real-world events or occlude the users view excessively. With head-mounted systems such as smartglasses, these issues are more relevant than with mobile phones and similar devices. Virtual objects could create blind spots in the users view which may lead to accidents in certain environments, such as traffic [Ishiguro and Rekimoto, 2011]. Depending on the design of the device, the device itself that is used to view the MAR or MMR environment can also restrict the user's view of important parts of the

surrounding world [Drascic and Milgram, 1996]. To prevent accidents in a non-stationary and uncontrolled environment, MAR and MMR applications need to be able to properly present the virtual data to the user in a way in which it will not cause distraction, or occlude important events. This can be achieved, for example, by prioritizing the flow of information and granting the user more independent control on the displayed virtual objects and data. Concerning head-mounted systems such as smartglasses, the design of the physical device itself is also an important matter, so that parts of the device will not restrict the users field of view, for example.

Unlike with traditional graphical user interfaces that deal with large amounts of data, mobile AR and MR applications need to keep the interaction between real and virtual objects clear and observable to the user, so the density of displayed data needs to be managed somehow, preferably keeping the amount of displayed data to a minimum but at the meantime providing the user with the data that he or she needs, and what is relevant to the user's needs at any given time. This can be done using filtering techniques based on the relevance of the virtual objects to control the amount of displayed virtual information [Azuma et al., 2001].

It is also possible that parts of the AR overlay can be obscured by the view of the real world in the background, for example, text on the AR overlay might become unreadable if it is displayed in the same colour as the background, or if a bright source of light in the background (real world) obscures a virtual object or text-overlay [Orlosky et al., 2014]. This could be avoided by managing the colour of displayed text in contrast to the background, or by moving obscured information to another location on the display, but only if the location of the information on the display is not relevant.

### **3.3. Security and privacy**

The emergence of commercial MAR and MMR applications, as well as the mobile platform itself, can produce new challenges concerning information security and the privacy of the users. This is especially true with possible smartglass MAR/MMR applications combined with other mobile devices, since such systems are still quite novel. Roesner et al. [2014] divide the challenges into three categories: challenges with 1) single applications, 2) multiple applications and 3) multiple systems, and list the following characteristics of AR/MR technologies and applications which may produce security and privacy risks:

- A complex set of input and output devices which may be always on (camera, GPS, microphone, display, earpiece, etc.);
- A platform that can run multiple applications simultaneously, with these applications sharing the aforementioned different input and output devices;
- The ability to communicate wirelessly with other systems, including other mobile AR/MR systems, smart devices and remote computers.

Concerning single applications, Roesner et al. [2014] note that malicious applications could provide the user with false information overlaid on the augmented view of the real world (such as incorrect translations of foreign text, incorrect speed limits on navigation applications, etc.), or cause sensory overload to the user (flashing bright lights on the view, playing loud sounds, etc.). While some malicious applications acting this way might only be a minor nuisance, in some cases they could prove to be extremely hazardous (such as in traffic environments). Providing false augmented information could also lead to failure in any project or event the user is performing in the MAR/MMR environment. Other concerns include malicious applications gaining control over the device's data access (i.e. access to sensors, video or audio) and leaking this information to unwanted parties. With multiple applications, security risks can include a malicious application obscuring, hijacking or altering the content presented by an other application, the risks would be very similar as those mentioned above.

Roesner et al. [2014] also point out that allowing only one application to control the output (display) at a time is not a sufficient solution, since it is more or less required that different applications must have access to the display when necessary. Otherwise the user would have very limited choices of what to do and when, which in turn would result in lowering the overall user experience of MAR/MMR systems.

Users would probably also like to have the possibility to share virtual objects between applications, and as with other systems, mobile augmented and mixed reality applications would probably share APIs with each other. Both cases would require appropriate measures to be taken with access control for cross application sharing. Concerning multiple systems (i.e. MAR/MMR systems belonging to different users or other parties), security and privacy risks may arise with applications that communicate with each other and allow sharing of virtual objects or spaces, or other information between users, and how access to personal and sensitive information is controlled.

	<b>Single Application</b>	<b>Multiple Applications</b>	<b>Multiple Systems</b>
<i>Output</i>	Deception attacks Overload attacks Trusted path to reality	Handling conflicts Clickjacking	Conflicting views
<i>Input</i>	Input validation	Resolving focus	Aggregate input
<i>Data Access</i>	Access control for sensor data Bystander privacy	Cross-app sharing	Cross-system sharing

Figure 2: Table outlining possible AR (and MR) security and privacy challenges categorized by system scope and functionality [Roesner et al., 2014]

Security and privacy approaches used on the mobile phone platform alone are not sufficient enough when considering other platforms, independent or linked to mobile phones or other devices, such as smartglasses (of which Google Glass is a good example). Mobile phones have their sensors (including cameras and GPS) turned off occasionally, and even if the device is hijacked by malicious software and the sensors are turned on without the user knowing, a mobile phone is not equipped most of the time (spending most of its time in the users pocket instead). However, on a head-mounted system such as Google Glass, the camera (or any other input device) is typically always on when the device is in use, and if hijacked by malicious software, the camera of the device can be accessed and used by hidden malicious applications without the user knowing anything about it. This can pose a serious security and privacy risk at all times while the user has the device equipped [Roesner et al., 2014].

Mobile AR and MR systems may be seen as intrusive regarding privacy and security even if there is no malicious intentions with their use. For example, a person might feel his or her privacy being violated if viewed by another person via a MAR/MMR display, possibly including video recording or facial recognition software. Similarly sensitive information can be accidentally compromised by a MAR/MMR device's video recording capabilities. Even voluntary sharing of virtual information or virtual objects might compromise users' privacy if applications are allowed to share such data with other applications, users, or even remote systems by default. Roesner et al. [2014] mention that in addition to technical solutions to minimize privacy and security risks, social, policy or legal approaches concerning augmented reality systems may be called for. Enforcing such regulations might prove to be difficult, however, unless the legal and social approaches are similar in all environments (around the world), and also if users act under false identities. Additionally, users might be concerned about sharing private information, such as name, age and location in a MMR environment [Dhir et al., 2012].

Despite the challenges with security and privacy issues regarding MAR/MMR applications, Roesner et al. also note that some augmented reality platforms, such as smartglasses, can also provide increased information security to a user. For example, personal MAR/MMR displays, like Google Glass, efficiently prevent shoulder surfing, since the interaction is visible to the users own view only. If a system or application is proven to be secure enough, personal MMR applications can be used to display information to the user which might otherwise be risky to display in a public mobile environment (for example, presenting passwords or similar information overlaid on the MMR display). Nonetheless, the concerns with privacy and information security are a topic that needs addressing as MAR and MMR systems continue to develop and become a part of the everyday devices people will use, especially since the core functionality and information security of mobile systems is perhaps even more obscured to the everyday user than similar issues with the desktop platform. Many mobile systems synchronize, share and save personal information as a

default, and if a similar approach is used with MAR and MMR applications, the development process needs to address the information security and privacy issues discussed in this chapter.

### **3.4. Wireless networking**

Wireless communication is required for mobile augmented and mixed reality systems, so that the user can connect to the internet and other users, interact with any other smart devices or objects in the environment, as well as access remote data or store data to a remote location. Currently, most mobile phones operate in wireless wide area networks (WWAN), using mainly 2G or 3G mobile telecommunication technologies such as GSM (Global System for Mobile Communications), GPRS (General Packet Radio Service), UMTS (Universal Mobile Telecommunications System) and HSPA (High-Speed Packet Access), however 4G technologies such as LTE (Long Term Evolution) have been emerging as well in the past years, and many modern mobile phones already support the use of 4G technology, even though 4G services are not necessarily provided to all who own devices that could utilize 4G data transfer.

To properly support mobile AR and MR systems, wireless networks need to provide sufficient data transfer rates, low latency, and support for mobility [Papagiannakis et al., 2008]. The slower speeds of most 2G technologies severely limit their use in MAR/MMR applications. Most 3G technologies, however, can in theory offer transfer rates up to 2mbps and 4G technologies have been shown to offer transfer rates ranging from 10 to at least 100mbps. These rates are enough to provide MAR/MMR applications the capability to transfer larger amounts of data without the requirement of real time interactivity suffering too much. Latency is naturally a relevant issue, regardless of the networking technology in use. Wireless local area networks (WLAN) can also be used with most modern mobile devices to provide faster data transfer rates, typically up to 54mbps with the 802.11g (most common) WLAN standard, but faster transfer rates can be also be achieved, such as up to 600mbps with the 802.11n standard.

Different mobile devices can also communicate with each other wirelessly at close ranges by technologies such as Bluetooth, which enables low-power radio frequency communication with other nearby devices utilizing the same standard. This enables a user to wear multiple devices which can operate and communicate with each other as well as remote systems in the same mobile augmented or mixed reality environment. For example, smartglasses combined with a mobile phone and other possible wearable computers (such as currently emerging smart watches), could communicate with each other and access remotely stored information, without every device needing to individually connect to the internet [Höllner and Feiner, 2004]. In an ubiquitous computing environment, a mobile mixed reality interface (utilizing wireless communication provided by the mobile and smart devices) could also be used to control the information flow between various smart objects in the surrounding environment [Kriesten et al., 2010].

### 3.5. Authoring tools and technologies for AR and MR applications

Some mobile AR and MR features, such as 3D graphics and user tracking algorithms can require quite complex programming tasks if developed without the aid of any existing framework or other tools. While many aspects, such as the aforementioned application-specific 3D graphics and the basic functionality of the application, will probably require a lot of original development, various other tools, software libraries, data standards and architectures exist with the aim to ease the development of various AR and MR applications, and also to help in unifying the AR/MR application environment.

For example, augmented reality markup language (ARML) is a standard designed to describe augmented reality scenes. ARML uses XML to describe the augmented reality scenes as well as a scripting language (ECMAScript) to provide access to the properties of the virtual objects in the AR environment. Additionally, Wikitude (see chapter 4.5.5), a commercial MAR browser, provides a SDK to aid the development of AR applications for various mobile devices (ranging from mobile phones to smartglasses). The ARML standard was originally initiated by the creators of the Wikitude browser.

ARToolkit is a software library for augmented reality application development, supporting also mobile AR applications (for different mobile operating systems), also mentioned to be fast enough to run these applications in real time. ARToolkit was one of the first AR software libraries, originally developed by Hirokazu Kato [Kato and Billinghurst, 1999], and it is still available (free of charge for non-commercial use), with ongoing development. ARToolkit features tools, for example, for position and orientation tracking, aligning virtual 3D objects with tracked markers, and camera calibration. The main focus of ARToolkit is to provide tracking libraries to ease the development of various augmented reality applications by providing efficient means to calculate the camera position and orientation relative to the physical markers.

ALVAR (A Library for Virtual and Augmented Reality) is a product suite developed by the VTT Technical Research Centre of Finland, and offers tools for creating both VR (i.e. completely virtual) and AR applications for both desktop and mobile platforms, first released publicly in 2009 [VTT, 2009]. ALVAR offers an application programming interface (API) as well as other tools to handle, for example, marker-based and markerless tracking, 3D rendering, and camera calibration.

KHARMA (KML/HTML Augmented Reality Mobile Architecture) is an architecture developed at the Georgia Institute of Technology with the purpose of letting users create (mobile) AR content using basic web development tools such as HTML [MacIntyre et al., 2011]. KML (Keyhole Markup Language) is an XML notation for expressing geographical information with internet-based 2D maps and 3D map browsers (used by Google Earth, for example). MacIntyre et al. have developed a KML extension called KARML, which lets content authors specify where AR exists in the world.

Argon (see chapter 4.5.1) is an AR browser developed by MacIntyre et al. which is built to support the KHARMA architecture.

Lee et al. [2009] describe a layer-based integration model and architecture to develop mobile mixed reality applications and services. The purpose of this approach is to present a flexible model for constructing mobile mixed reality applications which can use diverse types of media and also provide broader functionality to the user. The model is divided into different layers with different functions to implement various aspects of different applications:

- sensing layer, which receives information from sensors such as GPS, compasses and accelerometers;
- media layer, which handles various media types (any audible or visible multimedia content, online or locally);
- event-control layer, which handles the manipulation and interaction with objects in the environment;
- integrated application layer, which enables different applications to work together sharing the other layers;
- object identification layer, which handles the identification of visible objects and locations using data provided by the device's sensors. Lee et al. mention that this is the most crucial layer of the model.

Regardless of the techniques or approach used, providing developers, or even users, with the means to easily create new AR or MR applications on the mobile platform can greatly increase the emergence of novel MAR/MMR applications. Having tools that make the development process smoother should also in turn allow more focus on usability and user experience issues (such as those discussed in chapter 2.7), and also to look into user interfaces and interaction methods more deeply.

### **3.6. Multimodal interfaces and interaction with MAR and MMR systems**

As mentioned earlier, augmented and mixed reality environments are mostly visual in nature, but multimodal approaches can also be used when designing user interaction with mobile augmented environments. Most mobile devices (and obviously all mobile phones) contain a microphone, so speech is one viable option for interaction. Smartglasses can also feature a built-in microphone which would allow both speech control and a hands-free environment (as opposed to a mobile phone which always occupies at least one of the user's hands). If the wearable device(s) are equipped with relevant tracking sensors and technology, gesture and gaze-based interaction can also be considered (the users gaze and gestures would naturally need to be tracked accurately enough for the system to function reliably). Similarly, in addition to the visual interface, the user can also be given feedback with other means, such as audio and haptic, if the platform allows it.



Olsson et al. [2009] point out that in cases which are related to very important information, users would also find audio and/or haptic cues very beneficial. Audio feedback can, however, be problematic in environments where there is a lot of background noise, and not suitable equipment to provide clear auditory cues to the user (for example, having to rely only on the speaker of a mobile phone). Another point to keep in mind is that the user must be able to hear the sounds in the environment, so earphones are not a viable option in most cases. Concerning haptic feedback, the haptic cues could be blocked completely or partially by clothing worn by the user, if the feedback is not adequately powerful.

Billinghurst et al. [2009] mention that speech, gesture, and gaze-based interaction methods are all viable for augmented reality environments (and would therefore work in mixed reality environments as well) and also provide a case study for a tangible augmented reality user interface, but note that on the mobile platform some multimodal interaction metaphors developed for desktop or head-mounted display based systems (such as tangible and touch interfaces) may not be appropriate for hand-held devices. Some suggestions made by Billinghurst et al. [2009] include using the motion of the hand-held device (e.g. a mobile phone) itself to interact with virtual objects, as well as exploring possible two-handed interaction techniques such as using the hand-held device as a lens in the other hand and a real object, on which AR graphics are overlaid, in the other hand.

Daniel Kurz [2014] proposes an interesting touch interface for mobile augmented reality systems which is enabled by thermal imaging. The proposed system uses an infrared thermographic camera to provide the temperature of the captured environment and a visible light camera to turn any real object into an augmented reality touch interface, both attached to an experimental mobile device. The system does not require any tracking of hand movement, but instead attempts to reliably detect and localize the user's touch on a surface. Current mobile devices do not feature infrared imaging technology as a default, but thermal infrared cameras, such as FLIR ONE [FLIR, 2015] can be added to mobile devices as external accessories.

Possible application fields mentioned by Kurz [2014] could include, for example, augmented reality user manuals, and turning normal paper maps into user interfaces by touching a destination on the map, with the system detecting the location of touch and the text on the specific location on the map. A similar approach could also be used with a multitude of other common objects, transforming them into different kinds of touch interfaces with augmented reality overlays as well. Spray-On GUI's is another example mentioned Kurz, where a predefined GUI (such as a numberpad) is overlaid on any physical surface in the AR view, and tracked so that the device remembers the location of the GUI even if the display moves elsewhere. The system detects the user's touch on the GUI in the thermal image, making this a possible approach to turn physical surfaces in the real world into interactive user interfaces.

Tracking gestures and hand movement is obviously a similar approach, which overcomes some of the limitations of using thermal imaging to track touch, mentioned by Kurz (such as time delay between a touch and detecting it). However, current mobile devices do not normally include systems for either method, even though both would be possible to implement on today's mobile devices. Some modern smartglass platforms such as HoloLens [Microsoft, 2015] do promise gesture-based interaction (i.e. touch and gesture tracking) as a means to interact with virtual objects in a mobile AR or MR environment. Adding a thermal infrared camera to a mobile device (or even future smartglasses) would also make it possible to provide thermal vision as part of the augmentation offered to the user, which might prove to be useful in some application fields.

All in all, the possibilities of different interaction modalities (for example: gaze, touch, speech, and gesture) combined with the ubiquity of mobile devices and the synergy of AR and MR with ubiquitous computing environments and other smart systems may lead to completely novel methods of interacting with, and viewing the world and objects (both real and virtual) surrounding us.

## **4. AR and MR on the mobile platform: a survey of applications and devices**

Next we will take a look of various mobile augmented reality and mobile mixed reality applications that utilize a variety of mobile devices. AR and MR can be used in a wide range of application fields, such as navigation, tourism, maintenance, geographical work, architecture, journalism, urban modeling, medicine, emergency and safety, entertainment and leisure, military, and information management [e.g. Azuma, 1997; Feiner, 2002; Höllerer and Feiner, 2004; Dhir et al., 2012].

The following survey will also include some older and historically significant examples to demonstrate how related technology has advanced during the years, as well as that mobile augmented reality has been under serious research for quite some time, and also to show that many of the basics have actually remained the same, despite the increase in processing power, modern features, and miniaturization of mobile devices. The newer examples in this survey have been chosen from a wider range of applications, with some focused on specific areas of work and special purposes, and some that could offer a larger variety of potential uses. Hopefully the selected examples will help to show the possibilities of augmented and mixed reality interfaces, how AR and MR can be used in a variety of ways on the mobile platform, how the technology has developed in the past years, and what we can learn of the design and implementation of these example applications.

### **4.1. Smartglasses and head-mounted displays**

This first category contains examples of mobile augmented and mixed reality systems utilizing mainly head-mounted displays or smartglasses. The devices discussed in this chapter are chosen to show how mobile head-mounted AR/MR displays have evolved from the cumbersome systems with a multitude of required peripheral equipment in early days into the more lightweight displays and smartglasses of today. Head-mounted displays have the feature of being always switched on (if the user so chooses), providing continuous augmentation to the user, this enables more versatile possibilities for application development when compared to hand-held devices, which may end diverting the users attention, or are tucked away in a pocket most of the time.

#### **4.1.1. A Touring Machine**

One of the first mobile augmented reality systems is the Touring Machine, by Feiner et al. [1997]. The system uses cumbersome equipment (as seen in figure 3) by today's standards, but is nonetheless a fine example from the early days of mobile augmented reality, and developing or designing hardware was not the aim of the research in the first place. The system is comprised of a wearable see-through 3D display (with built-in orientation tracker), a handheld computer (running a web browser) with a stylus and a trackpad, and a backpack containing the main computer, GPS

receiver and other peripherals (e.g. a modem for internet connection). Basically, the system has many of the main components found in today's common handheld devices, the main difference being the use of a wearable see-through display which provides better immersion.

The setup for the prototype experiment is urban exploration, specifically on a campus area. The view of the surrounding world displayed by the see-through display is overlaid with information of the surrounding buildings (labels with names of the buildings and departments) and a menu of choices (such as “Departments?”, “Buildings?”, “Where am I?”, and an option to remove the augmented overlay from the view). Menu items are accessed with the use of the trackpad on the handheld computer, and the system also presents a gaze-directed selection system for the labels as well as a compass pointer on the see-through display which is oriented in the selected buildings' direction. The pointer changes colour from green to red if the users' orientation changes more than 90 degrees away from the selected building. The handheld computer displays information about the selected item (department, etc.) with its web browser, by navigating to the selected department's home page, for example [Feiner et al., 1997]. This is an early example of linking to content on the (2D) web from a 3D environment.



Figure 3: The equipment for the “Touring Machine” MAR prototype [Feiner et al., 1997]

The features of this early augmented reality application have a lot in similar with functionality found in many modern mobile applications that provide the user with GPS-based navigation aids, and information found on the internet based on the users location. Indeed, location-awareness is a key feature in most of today's AR/MR applications as well, and many modern AR applications also provide information about objects and/or the users' surroundings by overlaying informational labels on the view of the real world's objects and locations. While the technology itself has developed greatly in the past decades, the basic concepts have changed very little, with the most noticeable changes in interaction with modern interfaces (touch, gestures and voice commands as opposed to trackpoints and keyboard/mouse systems). In modern systems it is also more or less an expected requirement to display 2D interfaces (e.g. web browser navigation and web pages) on the same device that is used as the augmented/mixed reality display.

The next example is somewhat of a present-day counterpart to the Touring Machine.

#### 4.1.2. Google Glass

While not a specific augmented or mixed reality application in itself, Google Glass [Google, 2014] is, by consumers' standards, a state-of-the-art wearable computer and also an augmented reality display (even if somewhat limited in terms of immersion). The device is lightweight and can be attached to a pair of normal eye glasses, the display is a liquid crystal on silicon (LCoS) display with LED-illumination. Interaction with the device is performed by natural language voice commands and a touchpad located on the side of the device. Glass includes a camera for taking photos and capturing video as well as wireless network connection.



Figure 4: Google Glass [Google, 2014]

The main benefit of Glass is that various augmented reality applications (similar to mobile phone apps, but taking advantage of Glass' hands-free display) can be developed for the device by third parties using Google's own API (application programming interface). Another example in this survey (MAR for distributed healthcare, see chapter 4.2.1) utilizes Glass as an augmented reality interface for a medical environment. Glass was commercially available, in a prototype phase, for

consumers for a brief period of time, giving people a chance to get acquainted with the smartglass platform. At the time of writing this, Glass is no longer available to users.

#### 4.1.3. Microsoft HoloLens

Similar to Google Glass, Microsoft HoloLens is a recently announced smartglass system, also offering the user with a current state-of-the-art AR display, and additionally an interface for the Windows Holographic augmented reality platform [Microsoft, 2015]. The HoloLens device is not as lightweight or unobtrusive as Google Glass, instead resembling a more traditional (though not as cumbersome) head-mounted display, but it offers the user with a wider range of interaction modalities such as gaze-, voice-, and gesture-based interaction with virtual objects embedded on the view of the real world, as well as a more immersive augmented environment. HoloLens and Windows Holographic allow the user to pin holograms (virtual objects which can be viewed with HoloLens) in the user's physical environment. The holograms can be, for example, interface menus, notes, video displays and even complex 3D objects. Other features mentioned are spatial sound (which allows the user to more easily locate the hologram that is the source of the sound), remote collaboration with other users in a Holographic AR environment, completely wireless operation and no need for markers or external cameras for tracking and registration.

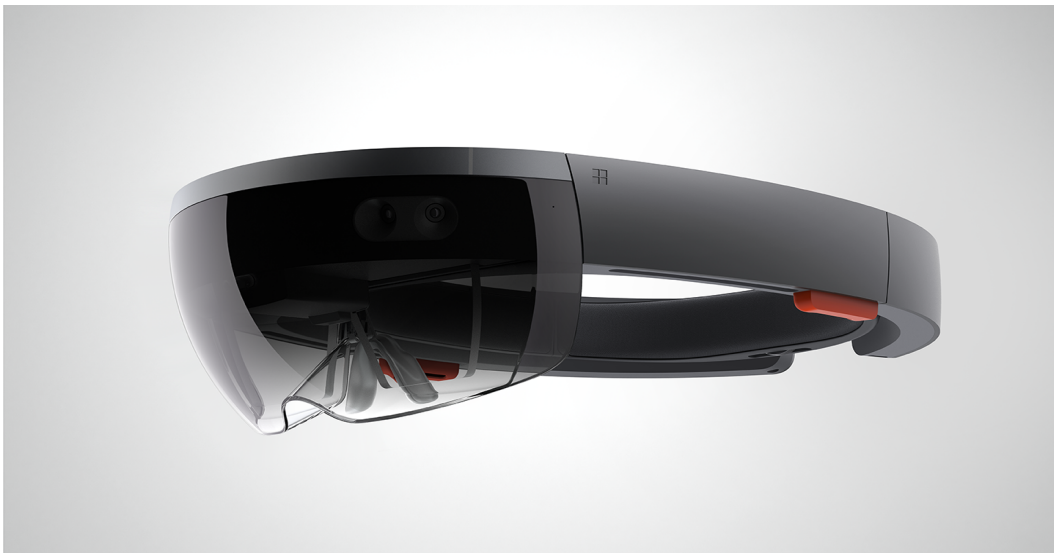


Figure 5: The Microsoft HoloLens device [Microsoft, 2015]

#### 4.1.4. Video see-through headset configurations for smartphones

Recently, headset devices that enable the use of a smartphone as a AR/VR display have become available for consumers. Some examples include Google Cardboard [Google, 2014], Samsung Gear VR [Samsung, 2015] and Homido Virtual Reality Headset [Homido, 2014]. The devices function as a mount for smartphones, i.e. the headset is combined with a compatible smartphone which acts as

the display in the headset. While intended to offer a “virtual reality” experience, the smartphone can also act as an augmented reality video see-through display, if an application combines the smartphone's camera view with an augmented overlay. Speech-based interaction could be provided using the smartphones built-in microphone.

While some of these systems are relatively simple, such as Google Cardboard (which, as the name implies, is basically a do-it-yourself cardboard headset, as shown in figure 6), but some headsets can contain independent tracking hardware (such as Gear VR, which has a built-in head-tracking module for more accurate tracking than the smartphone's own sensors could provide). Gear VR also has a trackpad on the side of the device (connected to the mounted smartphone), to provide the user with additional interaction options. The benefit of these devices is that they can provide an easy-to-use and cheap augmented reality display, with the essential equipment (i.e. the smartphone) being something that is already widely adopted and extremely common amongst users. While emerging smartglass systems, or headsets (such as the previously described HoloLens), may be expensive, and not necessary appealing to a wider user base, cheaper configurations such, as the examples mentioned above ,can provide users with an AR experience. This in turn might make mobile AR and MR more widely known, and promote the use of such systems, which might lead in increased development focused on MAR/MMR systems, providing users with a larger variety of applications and devices.



Figure 6: Google Cardboard, an example of a headset configuration for smartphones. The Cardboard set can be built using readily available items, with Google only providing a list of needed parts and instructions [Google, 2014]

#### 4.1.5. Sony SmartEyeglass

Sony SmartEyeglass [Sony, 2015] is another example of a modern smartglass augmented reality display. The system is capable of superimposing text and images onto the user's field of view. The headset includes a camera as well as sensors for tracking (accelerometer, gyroscope, compass) as well as brightness sensors. The headset can be accompanied with a separate controller which includes a battery, speaker, microphone and a touch sensor for interaction. The device can connect to other systems using Bluetooth and WLAN technologies, and can use applications running on a connected smartphone. The virtual images are projected to the eyes of the wearer using microdisplay technology, which makes the lenses of the device relatively thin and lightweight.



Figure 7: Sony SmartEyeglass glasses and separate controller [Sony, 2015]

SmartEyeglass is an example that could be considered to be somewhere in between the previously mentioned Google Glass and Microsoft HoloLens. The system has a more immersive display than the considerably small one which was found on Glass devices, but seems to have fewer interaction options and less immersion than HoloLens. Combining the small size and weight (77g in the case of SmartEyeglass) of such headsets with the augmented reality experience they are able to offer, could make these systems increasingly appealing to a wider user base.

#### 4.2. Augmented and mixed reality for collaborative remote interaction

This category contains a few examples of mobile systems designed to provide an augmented reality environment for collaborative interaction between remote users. These examples also aim to demonstrate the possibilities of modern AR displays (such as Glass or HoloLens) in the use of distributed interaction environments.



#### **4.2.1. Mobile augmented reality for distributed healthcare**

Aquino Shluzas et al. [2014] from Stanford University present a mobile augmented reality study for the healthcare field, specifically: an augmented reality point-of-view sharing system during surgery. Their proposed system uses Google Glass as a head-mounted display, with software applications developed and designed specifically for the surgical scenario, utilizing Google Glass' camera, infrared sensor, microphone and inertial measurement unit. The aim of the study is to provide a system which enables the attending surgeon and remote participants to connect and communicate with each other, and allow the remote participants to see the operation from the surgeon's point of view. Other features include acquiring a patient's sensory data to the display via wireless connection to sensors in the healthcare environment, and transmitting information (e.g. images of the wound captured with Glass' camera, with attached notes) wirelessly to and from an electronic medical record. The system is mainly controlled by speech and gestural-based commands to provide the surgeon with a sterile hands-free environment, for example, the view on Glass could be changed with voice commands to display electronic medical record data or wound images. Additionally, the images on the Glass' display could be projected on an external screen or wall, so that local assisting medical staff (or medical students) can see the operation from the surgeon's point of view. This would be useful since there usually is not too much room available around the patient (or more precisely, the incision site) to view the operation.

Example use cases would include:

- Consulting and collaboration with remote colleagues during surgery, for example, consulting expert advisors or a remote lab.
- Aiding trainees to learn operating procedures more accurately (by seeing it from the surgeon's perspective as opposed to a reversed perspective) and possibly in real time.
- Taking photographs and video of the operation and transfer it, along with notes, into the patient's electronic medical record [Aquino Shluzas et al., 2014].

This application presents the possibilities that augmented reality offers combined with remote collaboration between experts/colleagues at remote locations and personnel operating at the actual location of the task (or surgical operation, in this example case).

#### **4.2.2. Mediated reality for crime scene investigation**

Poelman et al. [2012] present an augmented reality system for crime scene investigation, which supports the participation of remote colleagues and observers as well as provides a gesture-based, hands-free interface for the user. The user is equipped with a lightweight head-mounted display and a colour based hand tracker (using coloured finger caps). The user is able to augment the scene with placed virtual objects, observe bullet trajectories and load 3D models.

The system also constructs a 3D model of the environment, based on the position and orientation of the user, and tracking natural features of the environment (an important requirement for a crime scene, since the scene must be kept untouched, so physical tags cannot be placed around the scene as tracking aids) via two cameras attached to the head-mounted display that provide stereo images. The 3D model is saved remotely and remote participants can explore this 3D model with their computers. The user can select actions from a menu displayed on the augmented reality view using hand gestures to point and select a menu item, and the menu itself is presented on the users palm, viewed through the display, following a specific hand gesture which is first presented to display the menu.

Just as the previous example of using augmented reality as part of a distributed healthcare environment, this example also highlights the possibilities of AR in remote collaboration, especially in areas of work where a novice might need guidance from an expert. It also demonstrates how tracking natural features can be used to create 3D models, possibly a good method to augment a virtual environment (AV) in mixed reality applications that use hardware capable of handling the modelling.

### **4.3. Enhancing user perception of the world with MAR**

The following applications have been designed with the intention to provide the user with a view of the real-world that would not normally be viewable by the human eye, or otherwise display information which is hidden or unknown to the user. These examples show the possibilities of mobile AR and MR for providing enhanced access (mainly visual, but perhaps also with other modalities in future systems) to various objects, locations, data sources and environments. The examples listed here utilize both head-mounted systems as well as hand-held devices, the best approach would probably depend on the application itself. Naturally, if an application scales from hand-held devices to head-mounted/smartglass systems it would be available and offer benefits for a wider user base.

#### **4.3.1. Battlefield Augmented Reality System**

The Battlefield Augmented Reality System (BARS) [Yohan et al., 2000] is an older example of a mobile augmented reality study for military applications. The BARS concept builds on the work of the Touring Machine (see chapter 4.1) with aspiration to increase the functionality and amount of relevant information displayed in the augmented reality view, all aimed to assist a soldier in an urban warfare environment (in which a 3D view with augmented information about critical and important features would undoubtedly be useful). Various head-up displays, which embed information on a view of the world, exist in military machines, such as combat aircraft, but personal infantry systems such as BARS are not yet in widespread use.

BARS uses a similar head-mounted display design as the Touring Machine, and the purpose of the system is to provide an augmented view of the battlefield, with highlighted objects and structures as well as virtual objects overlaid on the view. The system also features displaying occluded structures as wire-frame models in the AR view, however not in such detail as in the example in chapter 4.8. The study also pays a lot of attention to analysing how to select what information is relevant enough to display at what point, and how to decide the importance of objects. We can learn from this that information filtering can be an important design issue in MAR/MMR applications which are focused on complex or important fields of use; information clutter is naturally a bad thing, but deciding the priority of important objects or events to be highlighted in an AR view can require a lot of research and testing.

In addition to this, Yohan et al. [2000] state that the most important areas of research involving such a system, and similar AR environments in general, include:

- tracking the user accurately
- user interface design, and
- user interaction.

Obviously, all are important design criteria for almost any MAR or MMR application, regardless of the field it is used in, or what it is designed for, but perhaps even more so for a military application. It is however good to note that such important issues have been recognized in quite an early phase of emerging mobile augmented reality systems.

#### **4.3.2. Smart Glasses**

Smart Glasses is an augmented reality face recognition application for the mobile platform presented by Kurze and Roselius [2011], which can be used on both mobile phones or wearable (e.g. goggle-based) augmented reality displays. Kurze and Roselius have also developed an open architecture and runtime environment for augmented reality applications, such as Smart Glasses which utilizes this architecture. The application uses the mobile phones' or wearable displays' camera for face detection and tracking, and does the actual face recognition on a remote cloud service, where the face is matched with data on the user's personal contact list. Matched information is then displayed to the user on the mobile devices' screen along with the image of the face, the information contains the name and affiliation of the person as well as recent social network activities.

The authors present a generic use case: the user is in a meeting with a number of people, who are already on the user contact list (a social network, for example), but whose backgrounds' the user might not fully remember. Smart Glasses takes an image of the users' field of view, separates the faces and presents them to the user who can select which to recognize. Recognition takes place on a cloud-based service which compares the selected faces with the users contact list, and returns the

information (described above) to the users' display. The whole process can be done with just one press of a button [Kurze and Roselius, 2011].

The use of a handheld mobile device to scan other people might be seen as intrusive, and while the goggle-based approach is not suited for everyday use, lightweight hands-free devices such as the previously mentioned Glass might be a proper platform for facial recognition software (or similar applications) that also has augmented reality functionality included. Social acceptance of such systems will very likely still remain an issue.

### **4.3.3. Virtual X-Ray vision**

Bane and Höllerer [2004] have developed a set of interactive tools to provide a virtual X-Ray vision effect for users of mobile augmented reality applications, with X-Ray vision being defined for their study as a means to visualize a target through at least one layer of occluding structure. The study uses the virtual X-Ray tools applied to buildings on a campus area as an example application.

The system uses a head-mounted display as an augmented reality display, a trackpoint for user input, and hardware for orientation tracking and video capturing mounted on the display.

The presented tool set is comprised of four different tools:

1. Tunnel tool, which enables the user to slide forward and backward (using a trackpoint) between different predefined planes, which are rendered according to how “deep” they are situated in the view. The user can, for example, view a 3D image of a room occluded by a wall, when it is located in the tunnel tools' focus region (see figure 8).
2. Room selector tool, which allows the user to select a specific room revealed by the tunnel tool. The reason behind this is to allow the user to focus on a single room (and the artefacts within) instead of many partially visualized rooms with numerous artefacts all rendered by the tunnel tool. As with the tunnel tool, the user can zoom in on the view of the room.
3. Room in miniature tool, which allows the user to view the selected room from a third-person perspective. This way the user can explore the content of the room more easily (i.e. without having to move to another location) than with the room selection tool, which might include occluding objects on the same layer.
4. Room slicer tool, which is used in conjunction with the room in miniature tool, and allows the user to view volumetric data from a third-person perspective [Bane and Höllerer, 2004].

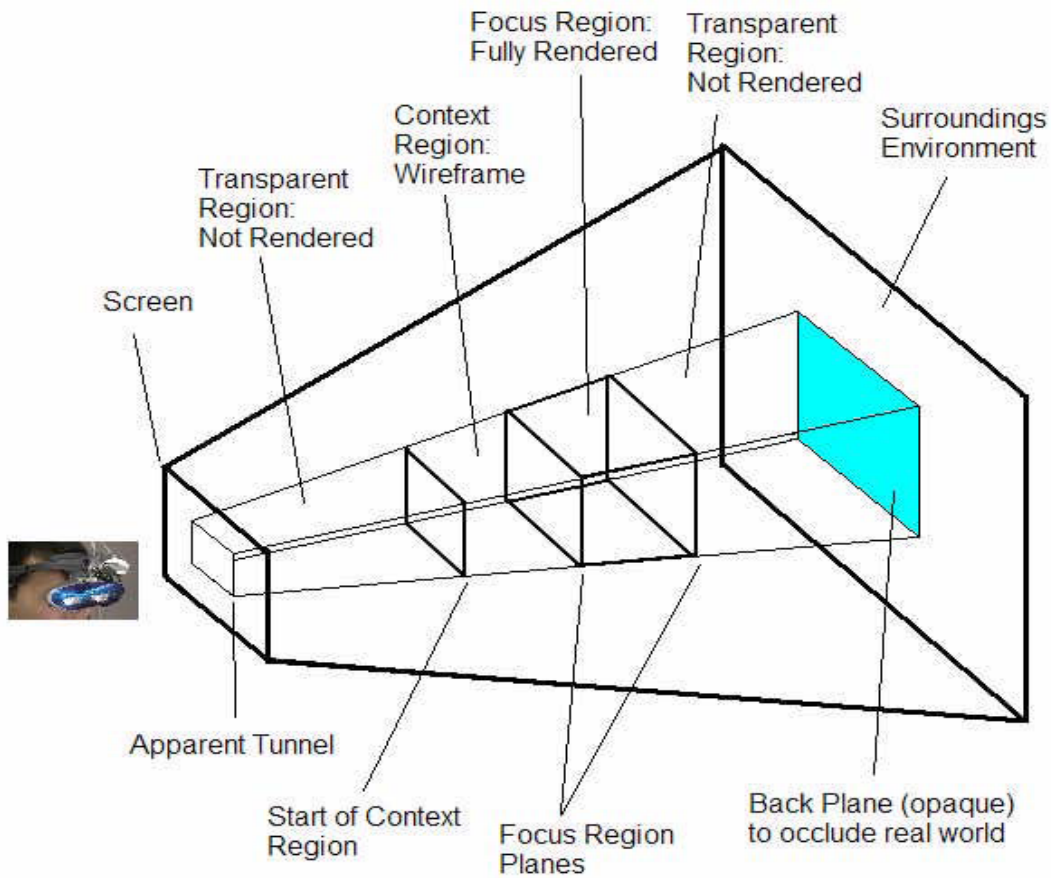


Figure 8: A conceptual diagram of the tunnel tool of the virtual X-Ray vision system, showing the different regions of the view and what is rendered in them [Bane and Höllerer, 2004].

Core concepts of the tool set are the use of different layers to present information, and slicing to access volumetric data that would otherwise be hidden to the user. Also, since the user can interactively select the information to be displayed, the problems of showing too much information, and not being able to display occluded information, are mostly averted. Considering the dominant depth cues (i.e. occlusion and relative size, see chapter 3.2) for an application focused mainly on the medium and long ranges, the functionality of the tunnel tool combined with the interactivity of the tool set also conveys sense of depth to the user in a non-confusing manner [Bane and Höllerer, 2004]. Apart from viewing the rooms, objects and volumetric data, the application is shown also to be able to display simulated heat distribution in the rooms. With enough sensors in a smart environment combined with modern mobile devices and processing power, similar applications could theoretically be used to visualize a wide range of interesting information augmented on a view of the real world.

Bane and Höllerer [2004] mention that challenges in implementing such a system include the amount of data and mapping needed to construct the 3D models of each room and object. Such a system would require a large amount of sensors for the data feed, as well as a mechanism for

tracking (possibly multiple) objects. The application is, however, a good example of using augmented reality to achieve an unusual view of the surrounding world. On a wider scale, a similar system would require a huge amount of data on different objects, locations and other relevant subjects, which in turn could perhaps make an ubiquitous computing environment a suitable platform to implement similar MAR or MMR applications in the future.

#### **4.4. Augmented and mixed reality for guides, navigation and manuals.**

This category consists of applications chosen to represent the use of mobile augmented and mixed reality to aid with various tasks, ranging from navigation to maintenance and manufacturing. The purpose is to, once more, demonstrate the versatility of mobile AR/MR applications, and how they can be user for different tasks in different environment.

##### **4.4.1. Task localization in maintenance of an APC turret**

Henderson and Feiner [2009] present a prototype augmented reality application for the maintenance of an armored personal carrier (APC) turret. The aim of their research is to assist in reducing the time required to navigate complex maintenance sequences and make the tasks easier for the mechanics. Henderson and Feiner also provide a comprehensive quantitative user study of the system. The prototype system uses a tracked head-mounted display for visualizing the augmented environment, as well as a wrist-worn mobile device (an Android mobile phone, to be exact) with a touch screen used to interact with the augmented reality interface.

The augmented reality view provides the user with a number of visual cues to assist with the maintenance procedures. First, a screen-fixed arrow indicates the shortest rotation distance to reach the target (an important design factor considering the restricted space in an APC turret). After the user begins to orient on the target, a larger, semi-transparent arrow will point to the target of the maintenance procedure, gradually fading as the user gets closer to the target. After this, a brief highlight will mark the precise target location. Additional information displayed to the user include virtual text/instruction labels overlaid on the view, context-setting 2D and 3D graphics (for example, 3D images of required tools and components) and a close-up view, as well as short animation sequences. The wrist-worn controller is used, for example, to navigate from a maintenance task to another, and to replay animation sequences/instructions.

The user study conducted by Henderson and Feiner [2009] showed that using the AR display resulted in less overall head movement in the confined space, and the AR display also allowed the users to locate the tasks more quickly, when compared to displaying the instructions on an external LCD display. Additionally the authors note that the users found the AR system to be intuitive and satisfying to use.

#### 4.4.2. Real time tracked public transportation

Nurminen et al. [2014] have developed a mixed reality interface study for tracking public transportation in real time, with a mobile device (such as a tablet PC, which is used to demonstrate the system). The system combines both augmented reality (AR) where the tracked vehicles are depicted virtually and directly overlaid on a view of the real world, and augmented virtuality (AV) where the virtual vehicles are visualized on a mobile 3D map depicting a real city. In addition, the application allows smooth visual transition between both views and represents the tracked vehicles in real time, effectively making it a true mixed reality environment, as discussed in chapter 2.3. The system also displays vehicles that are occluded (e.g. by a building) in the 3D view, rendering them fully in red colour, which visualizes them “behind” the occluding structure.

Nurminen et al. also discuss the challenges with augmented reality and augmented virtuality. Some issues raised include accuracy with registration and tracking in AR environments (i.e. how accurately the virtual augmentation is placed on the real world) as well as sensor inaccuracy; and concerning AV, the rendering of potentially large 3D environments with limited resources.



Figure 9: 3D visualization (AV) of real time tracked public transportation, displaying the bus numbers on top of the virtual vehicles. A red occluded vehicle is also shown on the left of the device's screen [Nurminen et al., 2014]

Nurminen et al. analyse the challenges of conventional 2D spatial interfaces (e.g. maps), such as culturally bound map marking conventions which may require some effort from the user to understand properly, as well as difficulties with orientating with the surrounding world, since traditional maps don't necessarily share any recognizable visual cues with the ground level of the user. Using a 3D mixed reality interface aims to overcome these challenges. Nurminen et al. [2014] remark that in short range visual cues and visible content might be better expressed with mixed reality interfaces instead of traditional visualization methods, which in turn are better for long distances. The implementation is based on their previous research for mobile 3D city maps, and utilizes open data on public transportation. Example use cases for the implemented mixed reality application include locating a bus stop and spotting an arriving bus.

This application is a good example in displaying the capabilities of MR on the mobile platform, such as the ability to render somewhat complex 3D environments in real time. The discussed challenges give some good insight into issues that need close attention in the development of a MMR application.

Mountain and Liarokapis [2007] point out that 3D scenes in general have many advantages when compared to paper maps, most prominently the ability to recognize features and buildings, which removes the need to map-read. Considering this, applications such as the one discussed in this chapter can provide users with an intuitive way to navigate an unfamiliar city and more easily track public transportation (when compared to paper maps and timetables).

#### **4.4.3. Smart Vidente**

Schall et al. [2013] present Smart Vidente, a mobile augmented reality application for civil engineering, designed to provide interactive 3D real-time visualization of the urban underground overlaid on a view of the real world on the ground level. The purpose of Smart Vidente is to provide a system that provides field access to geographic information systems (GIS), mainly aimed for the utility industry operating with underground infrastructure, with focus on applications such as asset localization, contractor instructions, planning and surveying. Important design issues for such an operating environment are, for example, accuracy and correct registration [Schall et al., 2013]. A similar approach could also be used with other fields of work where people can benefit with the view of normally hidden objects and information.

Possible use cases and scenarios presented by the authors of the study include but are not limited to:

- supporting in visualizing, planning and preparation of digging activities on-site,
- fast localization of underground assets, which reduces the risk of accidental damage to underground infrastructure, and
- taking augmented screenshots for documentation purposes.



Overall, the system aims to reduce time and effort in surveying and planning digging sites for the utility and civil engineering industries. Smart Vidente also provides an interactive AR interface as opposed to a traditional 2D map or blueprint.



Figure 10: Smart Vidente augmented reality visualization showing underground features overlaid on a view of the real world on ground level [Schall et al., 2013]

The system has some similarities with the virtual X-Ray vision AR interface presented by Bane and Höllerer [2004] (described in chapter 4.3.3), as it provides visual access to otherwise occluded objects and structures. Both systems give much insight in possible future applications that would provide similar functionality in visualizing occluded objects in the surrounding world. Naturally, the data sources providing information about the occluded objects needs to be exact and up to date, and special detail must be paid to the accuracy of tracking, as noted by Schall et al.

#### 4.4.4. GuideMe

GuideMe is a mobile augmented reality application presented by Müller et al. [2013], which assists the user with operating everyday appliances, such as stoves and microwave ovens. It is somewhat similar as the previous example (APC turret maintenance) as it also displays operating instructions overlaid on a view of the real world. The difference being that GuideMe is used on a hand held mobile device (functioning as a magic lens) as opposed to a head-mounted display. In effect, GuideMe is an augmented reality user manual, or more precisely, has the potential to be many manuals in one device.

The system consists of markers placed on the appliances, and the mobile device (a tablet PC) which acts as an augmented reality user manual. After the mobile device detects the marker, it adapts the coordinate place according to the size and position of the marker. The user manual

elements (symbols and instructions) are placed on the augmented view relative to the marker's position. The AR view only includes a toolbar at the top of the screen, which displays current progress and supports navigation, and leaves the remaining area for the augmented camera image; the design is meant to provide flexible ways to display a manual in an intuitive way [Müller et al., 2013].

The authors also conducted a test to measure efficiency (time used) in tasks between GuideMe and a traditional printed manual as well as a video tutorial. The authors state that while using a printed manual provided significantly faster completion times and lowest error rates, the users nonetheless enjoyed using the tablet-based approach.

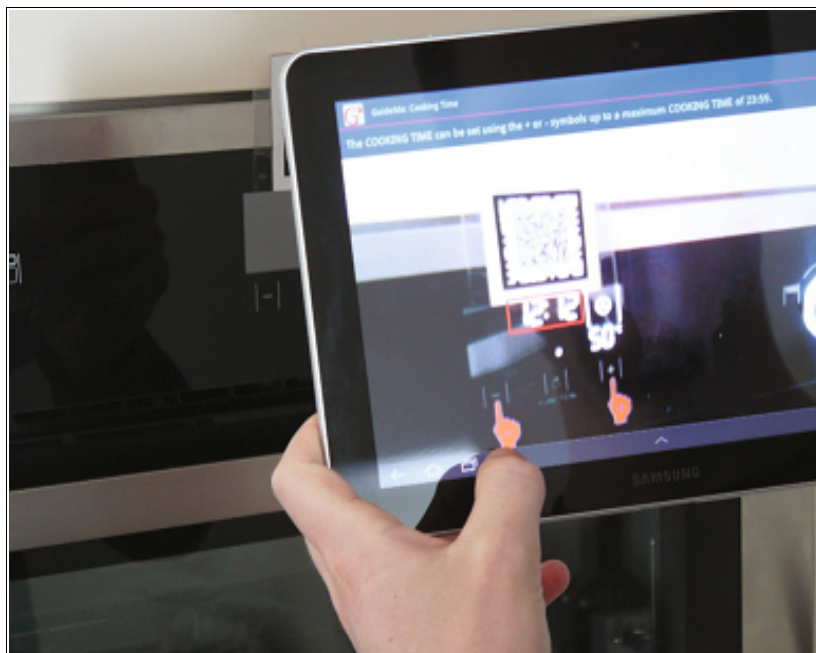


Figure 11: The AR user manual displayed by the GuideME system [Müller et al., 2013]

Müller et al. also discuss the design of user manuals in context of augmented reality environments. Their study showed that users felt more secure using a video or AR based manual, and they had a positive attitude towards the new concept of AR as a manual. The study mentions that the design of the appliance should be noted in the design of the manual, and that the concept of augmented reality manual design as a whole would require more research. Possible feedback from the appliances to the manual would lower error rates, however such a feedback system isn't quite yet foreseeable [Müller et al., 2013]. With advances in ubiquitous computing and smart devices however, some system of feedback could possibly be developed to certain smart objects that could interface with a MAR/MMR device running an operating manual application.

#### 4.5. MAR and MMR applications for smartphones.

The final category contains example applications aimed mainly for the smartphone platform. It is worth noting that publicly available mobile AR and MR applications do not always fulfil all the requirements associated with augmented reality, for example, applications might not align virtual information properly and accurately with real world objects, and some are not truly 3D applications, but rather represent the augmentation in 2D. Olsson and Salo [2011] point out that despite of this, such applications have already gained visibility as augmented reality applications, and that for end users these kinds of details can often be irrelevant, since the interaction paradigm remains largely the same. The applications listed here contain early MAR/MMR examples for mobile phones, as well as some newer and more widely known examples which are available for most modern smartphones. The main point here is to present what is already available to a wide user base, and what features are (and should be) common in MAR/MMR applications.

##### 4.5.1. Argon: AR web browser and AR application environment

MacIntyre et al. [2011] present the Argon augmented reality web browser and application environment. The purpose of Argon is to demonstrate that web technologies are a viable tool for developing mobile augmented reality applications with existing standards, and to research the concept of displaying any augmented reality content in one unified augmented reality application environment. Argon can browse, and the user interact with, multiple independently authored augmented reality applications (called *channels* by MacIntyre et al.) simultaneously. Applications can also hide the Argon UI to present a single application experience to the user. Client-server-based interactivity and data filtering is also supported [MacIntyre et al., 2011].

Some examples of application development for the Argon AR platform mentioned in the study include:

- Web-service-based searches, capable of dynamically creating place-marks overlaid on an AR view using the Argon API,
- Location-based AR content presentation for predefined landmarks using region monitoring (for example, a location near a building that is under construction could render an image of the completed building on the AR view),
- Applications (such as games) based primarily on 2D can incorporate clear AR aspects on the Argon environment (i.e. two-dimensional interactive game characters blending into an augmented real-world environment seen via the devices' camera view).

The concept of allowing users to view multiple AR channels (i.e. applications) simultaneously, is meant to make augmented reality environments more immersive on the mobile platform [MacIntyre et al., 2011].

#### **4.5.2. Mobile augmented reality for books on a shelf**

Chen et al. [2011] have developed a mobile augmented reality system for book recognition. The application enables a user to recognize book spines of books placed on a shelf. The system does not require any other interaction from the user most of the time, except for moving the mobile device as a magic lens over book spines on the shelf, i.e. viewing the books through the mobile device's camera view. The system deduces the user's interest in a particular book by tracking the movement speed of the device, when the movement slows down, the application will display overlaid information (e.g. title, author, prices, optionally an image of the cover) about the book whose spine is in the middle of the view to the user. Additionally, the system can present an audio review of the book by the use of text-to-speech. The application also displays the location of the book in the shelf in a thumbnail view of the entire bookshelf at one corner of the view. To enable this, the user must have taken a photo of the bookshelf prior to use. The system also recognizes individual books, based on the taken photo, with image recognition algorithms, described in detail by Chen et al. [2011].

The authors of the system state that the MAR application provides a fast way of retrieving information about books in, for example, a library or book store, without having to take the books out of the bookshelf. The application could also guide an individual towards a particular book in a store or a library.

While quite a few augmented reality applications already provide information in real-time, and with little interaction required, about objects and locations for the user, also typically using a similar magic lens system, this example presents the possibilities of obtaining precise information from a cluttered area (such as a bookshelf) using an AR display. Worth noting is also the way how the application deduces the user's interest by measuring the movement speed of the device.

#### **4.5.3. Snap2Play**

You et al. [2008] developed and evaluated a mobile mixed reality treasure hunting and image matching game titled Snap2Play. Snap2Play is a location aware game for a mobile phone, which utilizes GPS and orientation data provided by the mobile devices' sensors, and uses the devices camera view to augment the users perception of the surrounding environment.

The goal of the game is to collect and match virtual and real “cards”. Virtual cards are obtained from virtual items (for example, a computer generated image of a treasure chest) which are visible on the mobile devices' camera view when the player is in the correct location, and capturing the item with the devices' camera provides the player with a photograph of the real world (the virtual card). The player must then find the physical card: travel to the location where the photograph is taken from, and take a picture of the same scene. The picture is the physical card, ready to be matched with the virtual one.

Features of the game include augmenting the view of the real world with the virtual objects, as well as importing data from the real world (in this case, photographs) into the game world, so it combines both AR and AV in its game mechanics, at a basic level, making it a mixed reality application.

While mobile games have developed quite a bit since 2008, Snap2Play is nonetheless a good, early example of including facets of both augmented reality and augmented virtuality into entertainment and games, as well as utilizing sensors (such as GPS and an accelerometer) which are now almost a standard in mobile devices, but weren't such de facto features in 2008.

There have been similar games that present an augmented reality interface to the player even back in 2008, such as Jamba's "Attack of the Killer Virus" [Nokia, 2009], and considering the features of today's mobile devices (as mentioned above), developing immersive MAR and MMR games should not be a huge challenge for modern mobile devices. Similarly, MacIntyre et al. [2011] mention more recent examples of mobile AR games for the Argon AR platform (chapter 4.5.1). Additionally, since smartphones can be used as head-mounted video see-through displays with the configurations presented in chapter 4.1.4, which would provide better immersion and perhaps prove to be more popular or fun.

#### **4.5.4. Nokia Point & Find**

Nokia Point & Find [Nokia, 2009] is a mixed reality application for (currently outdated) Nokia mobile phones. The application uses the phone's camera view as a magic lens, and allows the user to point the camera at objects, images and points of interest, and get access to additional information about the target as well as possible actions relevant to the result (e.g. viewing a movie poster would direct the user to reviews of the movie). The application also allows the user to place tags on points of interest, which can be viewed by other users arriving at the same location. This combination of augmented virtuality (placing information from the real world to the corresponding locale in the virtual environment) and augmented reality makes the application one of the first, even if basically simple, commercial mobile mixed reality applications for the mobile phone platform

#### **4.5.5. HERE City Lens and Wikitude**

Wikitude [Wikitude, 2014] is another mixed reality application for the mobile platform, which uses location-based data from the device's sensors to track the user. As in Point & Find, the user can add location-based content to the virtual representation of the world, and the user can view information about the surrounding environment via the mobile device's AR interface (i.e. the camera view as a magic lens). HERE City Lens offers a similar AR interface to the real world as Wikitude does, providing the user with dynamic location-based content about the user's surroundings, such as information tags about nearby points of interest [HERE, 2015].



Figure 12: A street viewed with HERE City Lens [Here, 2015]

Unlike Nokia Point & Find, Both HERE City Lens and Wikitude are available for the high-end mobile devices of today, and HERE City Lens actually requires sensors that are not even found on all modern mobile phones to work properly. Wikitude also offers a SDK to aid with the development of AR applications. However, as a contrast to the definition of augmented reality, many of the embedded virtual objects in these applications are represented in 2D (such as the annotation tags displayed in figure 12) rather than 3D. Here City Lens and Wikitude are perhaps more widely known to consumers, since their availability on different mobile platforms make them an easy step into augmented reality for a user curious or interested in the practical possibilities of MAR and MMR.

#### 4.5.6. Word Lens

Word Lens [Quest Visual, 2014] is a mobile augmented reality application for translating foreign languages. The application uses the camera of the mobile device to scan and identify foreign text, and then display the translation in another language on the device's display, displayed in real time on top of the original text (with an option to pause a single frame as well). The application is also available for Google Glass.

While a relatively simple example, Word Lens demonstrates the possibilities of annotating and aligning augmented information on specific points of interest in the real world, on a smaller scale than the above examples. Similar functionality could also be combined with other features into more versatile mobile AR/MR applications.

#### 4.6. Lessons learned and notes about the survey

While some of the examples and devices presented in the survey are already in use with the general public, some examples are either scientific studies or prototypes of proposed augmented and mixed reality systems. The examples were chosen more or less randomly, with the aim to properly represent the wide range of possibilities of mobile augmented and mixed reality, and with slight emphasis on historic relevance or impact on the MAR/MMR platform, as well as on existing applications from the recent years. More recent examples were examined since some of them are available (or have been for a while already) for smartphones, making it possible for a very large audience to get acquainted with MAR and MMR applications. This should give us an idea of what currently exists, and what should be improved (considering all the possibilities of MAR and MMR) in the future. The majority of the examples were only mobile augmented reality applications, with mobile mixed reality being in the minority. This might be due to the simpler approach needed to develop AR when compared to MR, or the lack of possible applications that would benefit of the addition of augmented virtuality (or other concepts, such as mediated reality)

Some points that the survey may have suggested for discussion concerning possible future developments, features that would benefit users of MAR and MMR applications, as well as MAR and MMR environments in general, might include:

- providing users with novel ways to see the world, such as “x-ray vision” and interactive 3D models;
- allowing users to augment the virtual environment with objects and information from the real world in addition to augmenting the users view of his surroundings, i.e. providing a mixed reality experience to the users;
- MAR and MMR environments and virtual objects shared with multiple users, possibly also remotely;
- various approaches to aid in information retrieval (such as those mentioned in chapters 4.5.2 and 4.5.6) as well as navigation (such as the mobile mixed reality approach described in chapter 4.4.2);
- different ways to present an augmented view to the user, depending on the purpose of the application, as well as ways to add or information from the real world to the virtual environment;

Additionally, the survey was meant to present the diversity and possibilities of today's MAR and MMR equipment. The number of examples was considerably small; indeed, there is currently a large number of HMD systems available to users, and covering them all would require a survey focused on HMDs alone. Nonetheless we should now have an understanding of different options available to view MAR and MMR environments, such as head-mounted displays (or smartglasses), smartphones and tablets, as well as smartphones used as head-mounted displays.

We have now familiarized ourselves with the basic concepts of virtual, augmented and mixed reality, as well as the technologies used to implement mobile augmented and mixed reality systems. We also briefly examined related concepts such as spatial augmented reality, ubiquitous computing and smart objects. Usability and user experience issues concerning MAR and MRR applications and environments were also covered in some extent, as were technological limitations and possible information security and privacy issues. Hopefully all this, and the information gathered from the survey can provide some insight for the following discussion about the possibilities of mobile mixed reality as a platform.



## **5. Discussion, observations and possible future trends**

We have now learned about the basics behind augmented reality and mobile mixed reality systems, both technical as well as user-centered issues with implementing MAR and MMR applications, and also current features and limitations of the relevant technologies. The survey presented in chapter 4 demonstrated the use of mobile augmented and mixed reality in different application domains and on different platforms, and showed some of the possibilities that MAR and MMR can offer, as well as serves as a basis (alongside other topics, of course, such as the required technology) for discussion regarding possible future trends and possibilities for MAR and MMR environments and systems.

Currently, consumer-friendly mobile augmented and mixed reality applications consist mainly of systems such as those mentioned under chapter 4.5, and are mainly targeted to the mobile phone platform. Other promising mobile AR and MR displays, such as Google Glass (which, at the time of writing this, is no longer even available) or other HMD or smartglass systems, have not yet gained widespread usage, and the price of such devices may still stay relatively high for the average consumer. Nonetheless, such devices have shown potential as an interface to augmented or mixed environments (as mentioned in chapter 4.2.1, as well as other examples with other head-mounted displays), and research as well as development towards new smartglass systems, such as HoloLens (see chapter 4.1.3), keeps continuing. In addition, smartglasses are a natural platform for MAR/MMR systems, since the way we sense the surrounding world is very much based on what we see directly, and not through a screen of a hand-held device, while we move around in the world. Also, the relationship between ubiquitous computing and MAR/MMR was discussed earlier, and ubiquitous computing environments should be taken into account when considering future implementations of mobile augmented and mixed reality systems, since ubiquitous computing could allow much more pervasive MAR and MMR environments, and more flexible interaction with both real and virtual objects in such environments. However, despite the benefits of smartglasses as a mobile AR/MR platform, hand-held devices can perhaps be considered more important at the moment, due to their ubiquity, lower prices, and acceptance as everyday technology. Naturally, this does not diminish the significance of emerging smartglass technologies in any way, and one topic to consider could be how to design MAR and MMR environments that users can find satisfying to use and interact with using both hand-held devices and smartglasses as an interface, as well as how ubiquitous computing environments could enrich such MAR and MMR systems.

Other things to consider are whether “true” mixed reality applications and environments can provide users with more benefits and a more natural way to interact with digital information than using only the concept of augmented reality, and how interaction between real and virtual objects in

a mixed reality environment can be implemented in a way that is intuitive to the user. Different interaction modalities for different applications and environments should also be considered, since modern and emerging smartglass systems (such as HoloLens) allow the use of voice, gaze and gestures as a means of interaction. Additionally, some proposed (or even completely new) interaction methods, such as those briefly discussed in chapter 3.6, could be beneficial for users. These methods could perhaps make the same augmented environment easier to interact with using different mobile devices, for example, allowing interaction with most, if not all, features in an augmented environment with both mobile phone and smartglass interfaces (or with any other hand-held or wearable devices that can act as a mobile AR or MR display).

### **5.1. The potential of mobile mixed reality systems**

The survey in chapter 4 provided an overview what mobile augmented and mixed reality applications are capable of, and in what way it is possible to augment the users perception of the world, as well as how these applications provide an interface to the virtual world, and merge it with the real one. Already existing MAR and MMR systems, as well as some examples from earlier days, can provide the user with ways to view objects, places and information normally hidden from them (or even things that don't exist anymore, like detailed computer generated images of historical buildings at their original location). Mobile AR and MR environments and the virtual objects or data within can be shared among multiple users, and a specific location in such an environment can even be accessed by remote users from far-away locations (as shown in chapter 4.2.1).

Combining these features could provide users with an unprecedented way to interact with information, smart objects, and the environment as a whole. Features that could be considered to be a basic part of any mobile mixed reality platform, designed for diverse use and varied environments, might include:

**Enhanced and augmented vision and access to normally hidden visual information**, such as in the examples under chapter 4.3. These features could include “x-ray type” vision, showing occluded areas, or even occluded moving objects such as vehicles, to the user. Showing the location of nearby acquaintances or colleagues could also be considered. Displaying digital overlays on surfaces and areas of interest on virtually any subject, in many ways similar to the 2D digital tags displayed by applications such as HERE City Lens and wiktitude, but also on a larger scale and in 3D (displaying historical buildings that do not exist anymore, visualising the outcome of a project, building, or other physical object still under construction, or providing the user with personalized information, advertisements, and guides at various locations), also allowing real-time interaction with the information displayed. Providing the user with interactive, augmented manuals and guides to interact with different smart objects in the environment, with the information provided by the object, and not the MR application, allowing more efficient and versatile interaction in an ubiquitous computing environment. Additionally various other tools should be offered to the user

that could help with everyday tasks and activities, which would normally require the user to divert his/her attention elsewhere, in a mobile environment. Such tools could include, for example, translating foreign text in real time (visualized over the original language, similar to the already existing WordLens application, described in chapter 4.5.6), thermal infrared vision (with a thermal IR camera) or similar augmentation of a normally invisible view, the identification of objects and people, or navigation aids, which are discussed in more detail below.

**Enhanced navigation and pathfinding**, similar to current GPS navigating aids on mobile devices, but also extended to cover pedestrian use, and even indoor-navigation. Other features could include such as in the example on public transport tracking discussed in chapter 4.4.2 (which shows the possibilities of locating transport hubs such as bus stops, and of spotting the relevant vehicles in the environment). On hand-held devices, the user is required to share his or her attention between the device and the real world, but with a smartglass implementation, this would not be necessary. Concerning indoor-navigation, in addition to only displaying an augmented virtual map for the user on the MR display, such a system could, for example, allow a user to select a location on an interactive digital map overlaid on the real-world view, and the system could then direct the user to the location using non-distracting yet intuitive methods, such as rendering an unobtrusive line (similar to those found on traditional 2D maps that display specific routes) on the MR view, which would direct the user to the desired location (be it an outdoor locale or a specific room in a building). Granting the user visual access to occluded information, as described in the chapter above, could also provide additional navigation aid to the user.

**Sharing the user's view and environment with remote participants**, in similar ways as described under chapter 4.2. MMR systems could be used to share the user's environment partly or completely with remote colleagues or friends, either granting them access to the the user's view of the augmented environment, or allowing them to interact with the same virtual objects remotely. Real objects (such as smart objects, with built-in data about the object itself) could also be shared remotely by rendering them in 3D (based on the data known by the object) and augmenting the remote users' virtual environment with these representations of real objects, making the mobile environment follow the concept of mixed reality by including features of both AR and AV. The way environments and views are shared would obviously depend on the physical environment where the system is used, while 3D objects (real or virtual) could probably be shared more freely, more complex views (which distract the user from events occurring in the surrounding world) should perhaps be shared in controlled spaces only.

**Providing users with a pervasive and diverse interface to the real and virtual worlds.** Related to all of the features mentioned above, mobile mixed reality systems and mixed reality environments in general can provide users with completely new ways of interacting with their surroundings. Devices such as HoloLens are expected to contain features that allow users to place

virtual objects into the augmented environment, and these objects can act as interfaces to other devices, interactive screens showing various information or providing access to other interfaces, as well as granting access to complex 3D models the user can work and interact with. For example, acting as an interface to design items for 3D printing could be one application field [Microsoft, 2015]. One mixed reality environment could therefore contain a multitude of different applications (as opposed to one application being its own environment), such as with the concept behind the Argon AR browser (see chapter 4.5.1) in which the ability to view multiple applications simultaneously should increase the user's experience of immersion, and make the interaction with the augmented (or mixed) reality environment smoother [MacIntyre et al., 2011]. As we have already discussed, MAR and MMR environments can be used in a multitude of different fields, and the applications can be very diverse indeed, and users could be provided with various context- and location-aware applications, all functioning in the same MMR environment.

Combining the various features discussed above within a single mobile mixed reality environment that can be viewed and interacted with a variety of mobile devices and operating systems (i.e. making it more widely available for different users; comparable to the wide variety of available personal computer systems, for example), as well as shared with by multiple users, could change the way people interact with computers and their surroundings in general. The same thing has, of course, been (repeatedly) said before about emerging augmented reality technologies, but nonetheless: many of the predicted systems (such as mobile devices being a way to view an augmented version of the world) have become true already. Additionally, AR and MR are, in some forms at least, already becoming familiar concepts to a greater user base than before. Examples of this could be the existence of different public SAR environments and similar projection-based AR (such as the previously mentioned FogScreen [Rakkolainen and Palovuori, 2002]), and the variety of modern (even if still quite simple) mobile AR and MR applications for the smartphone platform, some of which are discussed in the previous survey (chapter 4).

If they gain popularity and become adopted by a wider audience, immaterial SAR displays and spatial augmented reality systems in general could perhaps be seen as a current predecessor to future multi-user mobile AR/MR systems which enable a shared MMR environment viewable by smartglasses (and thus be more immersive) where multiple users can interact with and within the same environment, just like in current interactive SAR environments. It is also possible that immersive MAR/MMR environments will break through on their own, since shared multi-user mobile augmented reality environments are something that, for example, Microsoft HoloLens already seems to promise (in some form or another). However, as mentioned earlier, SAR and MAR/MMR can be used in conjunction in same environments to provide more possibilities as well as enhanced immersion to the users. In other words, the two approaches (SAR and MMR) are not

exclusive, but can instead continue to develop and become adopted by the general public as platforms that complement each other and can also provide an augmented experience on their own.

There are also other emerging systems under some discussion which are intended to be viable MAR/MMR platforms. Magic Leap [Magic Leap, 2015] is another augmented reality display system, of which not much is currently known even though the company has received much funding, but the system is advertised as being able to provide immersive mobile augmented reality environments to the user, much like HoloLens. Bionic contact lenses might also be another platform which could perhaps be used as a possible AR/MR display in the future. If such lenses do become common, they would indeed make the system very lightweight, and probably almost undetectable to other people, probably lowering the social acceptability threshold to adopt such a platform, but bringing along various other (mainly privacy and usability) concerns.

The main issues with the emergence of MMR as an everyday computing platform are probably mostly concerned with the performance, price and future development of relevant technologies, and perhaps most importantly whether the proposed systems will ever become widely adopted by a larger user base. However, performance issues aside, the recent development of systems such as HoloLens, Google Glass, and the various configurations for smartphones as head-mounted AR displays (which offer a new level of immersion compared to a hand-held AR interface, with a reasonable price), as well as public spatial AR systems becoming more conspicuous, might possibly lead to a transition that makes immersive mobile mixed reality more common and more accessible to people who are not familiar with the concept, but might find it interesting, intriguing and even worthwhile to use. Additional incentives to adopt MMR devices could also include smart objects and ubiquitous computing environments becoming more widespread, assuming MMR systems will be designed to complement as well as act as an interface to UC environments.

## **5.2. Mobile mixed reality and ubiquitous computing**

The contrast between ubiquitous computing and virtual environments, as well as how UC and MMR can complement each other was already briefly discussed in chapter 2.5. As mentioned, MAR and MMR applications can be designed to use information provided by sensors or computing devices embedded in everyday objects, providing the user with an augmented interface to interact with ubiquitous environments. However, if the connection between UC and MMR is to be properly utilized and tapped into by developers and users alike, both environments need to be designed with the other in mind.

One way of achieving this could, at least in the early phases, be the addition of simple MAR applications launched alongside various UC systems or other smart environments, which could be controlled and interfaced with by the use of these applications (usable with common smartphones that people already have). This way, if smart environments become more common, the connection between MMR and UC might become accepted as a fundamental idea by users. More complex

systems (i.e. requiring more development, more expensive equipment, etc.) containing HMD or smartglass configurations could then be also adopted faster as an interface to UC environments once the basic concept is already familiar. Another approach, perhaps more inconspicuous to the user, would be to develop MAR/MMR applications that do not provide an actual interface to smart objects, but gather and use information provided by these objects, and display it to the user on the augmented overlay. The information displayed would obviously depend on the location, situation and application in question, but at the start it could be something as simple as displaying annotation tags that include information about a specific object on top of it (in a similar way that current commonly known MAR applications present annotation tags next to locations on a city view). Naturally, both approaches could be used in conjunction. The main point is, however, that such applications and systems should be developed as standard features alongside UC environments and smart objects, not just as specific curiosities aimed for a select few environments.

If we consider the potential of ubiquitous computing environments combined with mobile mixed reality, MMR could provide users with, for example, the following possibilities:

- diverse interfaces to control smart objects in the environment, including GUIs superimposed over specific objects and surfaces, remote operation of objects and devices with a virtual representation of said object as an interface, and localized control of an UC environment in general;
- concerning the interfaces mentioned above, multimodal interaction is possible, including touch-, gaze-, gesture- and speech-based interaction with various forms of feedback in addition to the visual interface (audio feedback should be provided as a default, but other forms could be viable too, especially since interacting with real objects in a mixed reality environment provides a natural tangible interface to the user as well);
- meaningful information gathered from smart objects or the environment can be displayed in real time to the user by an augmented overlay (such information could naturally be delivered by conventional user interfaces and computing devices, however, with smartglasses the information is displayed to the user instantly, which can be relevant in situations that require urgent response);
- a mixed reality environment would allow users to import data (which could range from location, object or person specific information to digitalized versions of real smart objects, along with their properties) from the real world to the virtual environment associated with a relevant UC environment;
- MMR could also increase the users' awareness of the surrounding smart environment (with certain limitations, since ubiquitous computing is by definition meant to be more or less unnoticeable to the user).

Combining spatial augmented reality with MMR and UC environments is also a possibility. SAR could provide stationary augmented interfaces on specific smart objects or locations, which could reduce information clutter on a user's personal mobile AR/MR display. This could be beneficial in situations where multiple users need access to an interface which is stationary in nature, and needs to be always accessible by any user at that location, even if personal mobile AR/MR displays are either turned off or otherwise occupied.

### **5.3. Limitations and other issues with mobile mixed reality systems**

As shown in the previous survey, mobile augmented and mixed reality applications can be used with hand-held devices to augment the environment in different ways. However, the limited screen size of mobile phones and tablet computers, as well as the fact that these devices do not offer a hands-free environment to the user, make smartglasses a much more viable platform to implement features such as the ideas described and proposed in the previous chapter, even though it could be quite possible to use hand-held devices in conjunction with smartglasses in a MMR environment. The reason for this is the freedom that smartglasses provide to the user, such as a hands-free environment, an augmented view that is “always on”, as well as better contextual awareness of the surrounding environment, and following from the previous three points: a more intuitive way to interact with the augmented world and surrounding smart devices. Regardless, smartglasses are still more or less an emerging platform, MAR and especially MMR environments are still relatively rare and mainly used with smartphones (or tablet PCs), and both the platform and the reality concepts themselves have some limitations that need to be addressed.

While current hand-held mobile devices, such as high-end smartphones, are capable of rendering relatively complex 3D data on the devices' screen, smartglass systems might require even more detailed and realistic graphical presentation of the augmented environment, since users would probably expect such a system to be as immersive as possible, as well as to offer realistic-enough graphics so that the augmented view wouldn't feel too “artificial” or “fake”. The graphics also need to be rendered exactly in real time, and not appear to be lagging to the user, even if the user is moving around fast or keeps focusing between different objects around the environment. Latency reduces user performance, and even delays as small as 10 milliseconds can make a statistically significant difference on certain tasks [Azuma et al., 2001]. Other issues with graphics and registration were already briefly discussed in chapter 3.

Apart from different performance issues, physical discomfort, such as eye strain, fatigue and headaches, are also concerns with emerging smartglass systems, even if the devices are designed to be lightweight and user friendly. The concept of mixed reality itself can also be seen as more complex than mere augmented reality, which might increase resources needed for development, but in return a mixed reality interface would probably offer more possibilities for interaction between the real and the virtual. By allowing augmented virtuality and, for example, mediated reality to be

part of the environment, the users would be provided with a wider range of functionality, which in turn would allow for a much more diverse application environment than just providing the user with mobile AR.

Usability issues, the connection with ubiquitous computing environments, and the existing technology all play a part in the possibilities and limitations that are part of mobile mixed reality environments. To summarize, the more prominent limitations and other problems with existing and near-future MMR interfaces could include:

- technical limitations and performance issues, such as processing power, camera image quality (on low-end devices), registration (accurate alignment) and realistic real time 3D graphics (especially with smartglasses);
- physical issues with the equipment used, especially with prolonged periods of use;
- compatibility issues, which might include some applications being device or OS specific and thus not accessible to some users;
- lack of smart (ubicom) environments which would allow more versatile mobile mixed reality systems, as well as developers not necessarily realizing the potential with combining UC and MMR;
- Possible negative user experience and usability issues with new devices and applications.

However, there are other very important issues which have a great impact in whether MAR and MMR systems will become widely adopted. These include more humane aspects, such as social acceptance, the price and availability of the required devices, and also successful marketing. But most importantly: will users actually consider it to be beneficial and useful to adopt and start using mobile mixed reality as a natural interface to the environment?

#### **5.4. Adopting MMR as an interface to the real and virtual worlds**

Following from the discussion in the previous chapters, the possibilities offered by mobile mixed reality systems would seem to benefit users in many different ways. As already mentioned, MMR environments and user interfaces would provide users with completely new means to view the surrounding world and interact with it and the objects within, be they mundane, smart or virtual. Additionally, the devices and related technology is becoming more readily available, as well as cheaper, making it widely available to different users; on the smartphone platform MAR and MMR applications have already gained at least some public attention, and emerging smartglass and HMD MAR systems are usually covered by the media, at least to some extent. Despite of all this, MAR and MMR applications have remained in a small niche, mainly attracting users who are already familiar with, or curious about the technology, or early adopters of emerging computing systems [Olsson, 2012]. So the question remains: why have mobile augmented and mixed reality applications or modern smartglass systems not gained widespread popularity, despite of all the promises and possibilities?



Reasons for this are probably numerous, including all the technological limitations discussed before, as well as the level of realism that can currently be achieved with virtual and augmented overlays (directly resulting from the limitations in processing power and graphical capabilities of the devices). Regardless, users did adopt smartphones in a relatively early phase, despite the devices offering much less than they do today, and found them to be useful and beneficial in everyday activities. So in theory users should also find MMR as a useful tool and concept, even if currently somewhat limited in regard to the promises and expectations; especially since MMR is also available on the devices users already own, i.e. smartphones, which in turn can be seen as a natural platform for MMR, as already described in chapters 2 and 3.

One reason for this might be found in the expectations of what MAR and MMR can offer, and in all the promises of what such systems might eventually deliver. Olsson [2012] points out that first-generation generation MAR applications (i.e. applications which have been available for early smartphones, some of which were included in chapter 4.5 of the previous survey) seemed not to fulfill the expectations of potential users. Olsson [2012] also mentions that these applications weren't often capable of encouraging or motivating users to be creative or find new ways in which to use the applications, granting users with a proper experience of unity with the environment or feelings of coherence with environment-related content, or creating a sense of user community. Creative use and the diversity of various smartphone applications, as well as the possibilities provided for social media and networking, are probably important factors considering the success of conventional smartphone apps and games. Perhaps this could be applied to MAR/MMR application development as well, using an approach where MAR/MMR would provide users with more social content, social networking possibilities, as well as more diversity and features in general within the applications and environments (instead of just developing niche applications which might gain some initial interest, but don't have much use on their own in the long run). This could be done by combining features of existing single applications into standard features of more comprehensive applications (as described in chapter 5.1), allowing better interaction with other users (including social networks) within the applications and better interfacing between different MAR/MMR applications themselves (similar to the concept behind the Argon example in chapter 4.5.1). Some focus should also be directed to making the applications more immersive (within the limits set by the performance of modern smartphones, of course), instead of merely providing 2D overlays on a view of the real world, as is the case with many existing smartphone applications. Additionally, Barba et al. [2012] mention that in addition to building possible future systems in isolation, researchers should also examine what is currently being built for consumers, and try to understand it and influence its direction. Similarly, developers of commercial MAR and MMR applications and systems should perhaps focus on a broader area of possibilities, instead of just a single application area.

While MAR/MMR could perhaps gain popularity on the smartphone platform with the improvements mentioned above, the threshold of adopting completely new devices, such as smartglasses or similar head-mounted systems (such as HoloLens) is probably much higher, and would require users to feel that such devices are actually needed and worth using, instead of just interacting with the environment and information in more traditional ways and with already established platforms.

Early head-mounted AR display systems were never really introduced to consumers on a larger scale, and their size, weight and obtrusiveness would have very likely prevented any natural or comfortable use of such systems. Modern head-mounted systems, however, are more lightweight, allow many interaction modalities, and higher levels of immersion, and in some cases can even be designed to be relatively inconspicuous (such as the Google Glass or Sony SmartEyeglass devices which were briefly covered in the survey). The high price of such devices may also be one reason why the technology is not yet widely adopted, since unlike smartphones, which remain useful even if the user is disappointed with the quality-price ratio, smartglasses will offer very limited use if the consumer is initially disappointed with the quality of AR (or any other important feature), which probably raises concerns should one acquire such a device in the first place. Other reasons why such devices and more immersive MMR systems have not yet gained wider interest might include some of the following:

- Social acceptance, i.e. is using the device viewed as acceptable or positive by other people. This could include aspects such as privacy (would other people feel that their privacy is at risk in an environment where others use MMR systems), or how using such devices could affect a person's image (would the user, for example, be viewed as a “geek” or “nerd” by others). User studies performed by Olsson [2012] showed that users with a positive orientation and attitude towards technology also regard MAR in a more positive way, this would also indicate that users who are not interested in technical devices are less likely to find MAR/MMR systems interesting, even if such systems would provide some benefit to the users.
- Usability of smartglasses, including both user interface and physical issues. Physical issues may include the obtrusiveness and weight of the device (even though modern devices are designed to be relatively small and comfortable, as mentioned above), as well as the general design of the system, i.e. what does it look like (which can also be seen as a social issue). User interface issues could include, for example, disparity between the design of user interfaces of different applications (perhaps making the adoption of new applications a nuisance), as well as poorly designed or lacking interaction choices (that might lead to the lack of creative use and impede finding new uses for applications).

- Information overload or lack of important information available to the user. If users are not provided with what they need and what they would find useful, they are probably less likely to use such an applications if other, more established, options for retrieving information from the surrounding world exist. Likewise, offering too much information to a user might only result in confusion, especially with smartglasses or other immersive MMR systems.
- Usefulness and benefits of using such devices and MAR/MMR in general. Barba et al. [2012] point out that it is impractical to use many existing MAR applications, and so people simply do not use them. Olsson [2012] mentions that current MAR applications are still far away from the ideal that visions of augmented reality have created, which is a result of, not only technological limitations, but also of the lack of suitable content for such applications and environments. Users will only adopt modern MMR devices (headsets and smartglasses) and applications on a larger scale if they find them useful and beneficial in their everyday activities. Without a doubt, MAR and MMR have very much to offer, as discussed earlier in the above chapters, and MMR environments have the potential to deliver completely new experiences of interaction and immersion, but the user needs to be convinced that this is truly the case. Focus on marketing MAR, MMR and related devices might aid somewhat with these issues, but what mostly matters are probably the personal views and needs of different user groups, and will the users find MAR/MMR applications that actually suit their needs.

To summarize, MAR and MMR promise a lot, and could probably be able to deliver many of these promises in the near future, but this would require more focus on making MAR and MMR applications more diverse and more versatile, and combining features of many applications into one. If ubiquitous computing environments and other smart devices keep evolving and become a consumer standard, MMR applications and environments have the opportunity to provide an interface to UC, blending the real and virtual worlds even more so than augmented reality currently does. Even now, MAR and MMR have much to offer: users are able to download applications to their smartphones when and where needed, the applications can be very useful (such as translating foreign text in real time), and these applications provide users with a completely new way to view the surrounding world. If the relevant technologies keep evolving, applications keep becoming more versatile and broad in scope, and the problems and other issues discussed earlier will be addressed, MMR has the potential to be all that has been expected from augmented environments in the recent years.

## 6. Conclusion

This thesis has provided a concise overview of the concepts related to virtual, ubiquitous, and augmented environments, how these concepts relate to each other, and why the mobile platform is ideal for augmented and mixed reality applications. The concepts of augmented reality and mixed reality were clarified according to the definitions first presented by Milgram and Kishino [1994] and Azuma [1997], and later expanded in many other researches and studies. The technology behind MAR/MMR was also briefly discussed to provide the reader with an understanding of what is needed to implement MAR/MMR applications and environments. Other relevant topics included user needs and expectations as well as privacy and information security regarding MAR/MMR systems. Following the definition and description of the concepts and technology, this thesis presented a survey of existing and emerging MAR/MMR applications and devices, to demonstrate what is already available to users, how the technology has evolved, and in what ways a user's perception of the world can be augmented. Finally, this thesis discussed the possibilities of MMR environments, how MMR can complement ubiquitous computing (UC) environments, how spatial augmented reality (SAR) and MAR/MMR can be combined, and additionally examined some of the reasons why MAR and MMR have not yet been widely adopted in everyday use, despite of their vast potential.

The purpose of this work was to provide some insight into mobile augmented and mixed reality systems, how the real and virtual worlds can be combined, and how MMR could be used to further enhance our perception of the surrounding world as well as to allow new ways to interact with objects and interfaces, real or virtual. While MAR and MMR applications are currently not in everyday use, and they seldom can deliver what all the media hype has been promising, such applications are still readily available to anyone who is interested in augmented or mixed reality applications, and has access to a smartphone. Similarly, spatial augmented reality and ubiquitous computing environments already exist, and are accessible to users, but environments combining SAR, UC and MAR/MMR have not yet been emerging. Combining these technologies in the same environments (i.e. having UC, MAR/MMR and SAR all complementing each other), would probably have much to offer, but also probably includes many issues that are yet to be solved. These issues include, for example, the design, development, usability as well as the overall success of such systems. In addition to all the possibilities and pitfalls, perhaps the most important question here is, that even though the technology has much to offer, and could benefit users in a variety of ways, how should the technology be designed and implemented that users actually realize the possibilities and find it beneficial in their everyday activities.

Despite the challenges, limitations, as well as other issues discussed in this work, providing users with new MAR/MMR applications with more flexibility and creativity could increase the popularity of MAR/MMR systems, and eventually lead to more widespread adoption of MMR applications and devices that provide much more immersion than a smartphone. The possibilities to fundamentally change our view of the world, and to blend real and virtual together, already exist, but it remains to be seen will this mixing of realities eventually take place on a larger, much more immersive and interactive, scale.

## References

- [Aquino Shluzas et al., 2014] Aquino Shluzas, L., Aldaz, G., Pickham, D., Sadler, J., Joshi, S., & Leifer, L. (2014, August). Mobile Augmented Reality for Distributed Healthcare: Point-of-View Sharing During Surgery. In *AMBIENT 2014, The Fourth International Conference on Ambient Computing, Applications, Services and Technologies* (pp. 34-38). IARIA.
- [Azuma et al., 2001] Azuma, R., Bailiot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *Computer Graphics and Applications, IEEE*, 21(6), 34-47. IEEE.
- [Azuma, 1997] Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments* 6(4), 355-385. MIT Press.
- [Bane and Höllerer, 2004] Bane, R., & Höllerer, T. (2004, November). Interactive tools for virtual x-ray vision in mobile augmented reality. In *Mixed and Augmented Reality, 2004. ISMAR 2004. Third IEEE and ACM International Symposium on* (pp. 231-239). IEEE.
- [Barba et al., 2010] Barba, E., MacIntyre, B., Rouse, R., & Bolter, J. (2010, October). Thinking inside the box: making meaning in a handheld AR experience. In *Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH), 2010 IEEE International Symposium On* (pp. 19-26). IEEE.
- [Barba et al., 2012] Barba, E., MacIntyre, B., & Mynatt, E. D. (2012). Here we are! Where are we? Locating mixed reality in the age of the smartphone. *Proceedings of the IEEE*, 100(4), 929-936. IEEE.
- [Billinghurst et al., 2009] Billinghurst, M., Kato, H., & Myojin, S. (2009). Advanced interaction techniques for augmented reality applications. In R. Shumaker (Ed.), *Virtual and Mixed Reality* (pp. 13-22). Springer Berlin Heidelberg.
- [Bimber and Raskar, 2005] Bimber, O., & Raskar, R. (2005). *Spatial Augmented Reality: Merging Real and Virtual Worlds*. A. K. Peters, Ltd., Natick, MA, USA.
- [Caudell and Mizell, 1992] Caudell, T. P., & Mizell, D. W. (1992, January). Augmented reality: An application of heads-up display technology to manual manufacturing processes. In *System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on* (Vol. 2, pp. 659-669). IEEE.
- [Chen et al., 2011] Chen, D., Tsai, S., Hsu, C. H., Singh, J. P., & Girod, B. (2011, July). Mobile augmented reality for books on a shelf. In *Multimedia and Expo (ICME), 2011 IEEE International Conference on* (pp. 1-6). IEEE.
- [Cruz-Neira et al., 1993] Cruz-Neira, C., Sandin, D. J., & DeFanti, T. A. (1993, September). Surround-screen projection-based virtual reality: the design and implementation of the CAVE. In *Proceedings of the 20th annual conference on Computer graphics and interactive techniques* (pp. 135-142). ACM.

- [Cutting, 1997] Cutting, J. E. (1997). How the eye measures reality and virtual reality. *Behavior Research Methods, Instruments, & Computers*, 29(1), 27-36. Springer-Verlag.
- [Dhir et al., 2012] Dhir, A., Olsson, T., & Elnaffar, S. (2012, March). Developing mobile mixed reality application based on user needs and expectations. In *Innovations in Information Technology (IIT), 2012 International Conference on* (pp. 83-88). IEEE.
- [Drascic and Milgram, 1996] Drascic, D., & Milgram, P. (1996, April). Perceptual issues in augmented reality. In *Electronic Imaging: Science & Technology* (pp. 123-134). International Society for Optics and Photonics.
- [Dünser et al., 2008] Dünser, A., Grasset, R., & Billinghurst, M. (2008). *A survey of evaluation techniques used in augmented reality studies*. Human Interface Technology Laboratory New Zealand.
- [Engel et al., 2014] Engel, J., Schöps, T., & Cremers, D. (2014). LSD-SLAM: Large-scale direct monocular SLAM. In *Computer Vision—ECCV 2014* (pp. 834-849). Springer International Publishing.
- [Feiner et al., 1997] Feiner, S., MacIntyre, B., Höllerer, T., & Webster, A. (1997). A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. *Personal Technologies*, 1(4), 208-217. Springer-Verlag.
- [Feiner, 2002] Feiner, S. K. (2002). Augmented reality: a new way of seeing. *Scientific American*, 286(4), 34-41.
- [FLIR, 2015] FLIR ONE, <http://www.flir.com/flirone/> (retrieved on 22.4.2015). FLIR Systems (Wilsonville, OR, U.S.).
- [Google, 2014] Glass, <https://www.google.com/glass/start> (retrieved on 12.11.2014). Cardboard, <https://www.google.com/get/cardboard/> (retrieved on 25.4.2015). Google Inc. (Mountain View, CA, U.S.).
- [Henderson and Feiner, 2009] Henderson, S. J., & Feiner, S. (2009, October). Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In *Mixed and Augmented Reality, 2009. ISMAR 2009. 8th IEEE International Symposium on* (pp. 135-144). IEEE.
- [HERE, 2015] HERE City Lens, <https://help.here.com/fi/wp8/citylens> (retrieved on 15.3.2015), <http://company.nokia.com/fi/news/media-library/image-gallery/item/here-city-lens-viewfinder> (retrieved on 15.3.2015). Nokia HERE (Finland).
- [Homido, 2014] Homido Virtual Reality Headset, <http://www.homido.com/en> (retrieved on 25.4.2015). Homido (Lille, France).
- [Höllerer and Feiner, 2004] Höllerer, T., & Feiner, S. (2004). Mobile augmented reality. In Karimi, H. (Ed.), Hammad, A. (Ed.), *Telegeoinformatics: Location-Based Computing and Services*. Taylor and Francis Books Ltd., London, UK, 21.

- [Ishiguro and Rekimoto, 2011] Ishiguro, Y., & Rekimoto, J. (2011, March). Peripheral vision annotation: noninterference information presentation method for mobile augmented reality. In *Proceedings of the 2nd Augmented Human International Conference* (p. 8). ACM.
- [Kato and Billinghurst, 1999] Kato, H., & Billinghurst, M. (1999). Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *Augmented Reality, 1999.(IWAR'99) Proceedings. 2nd IEEE and ACM International Workshop on* (pp. 85-94). IEEE.
- [Klein and Murray, 2007] Klein, G., & Murray, D. (2007, November). Parallel tracking and mapping for small AR workspaces. In *Mixed and Augmented Reality, 2007. ISMAR 2007. 6th IEEE and ACM International Symposium on* (pp. 225-234). IEEE.
- [Kriesten et al., 2010] Kriesten, B., Tünnermann, R., Mertes, C., & Hermann, T. (2010, September). Controlling ambient information flow between smart objects with a mobile mixed-reality interface. In *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services* (pp. 405-406). ACM.
- [Kurz, 2014] Kurz, D. (2014, September). Thermal touch: Thermography-enabled everywhere touch interfaces for mobile augmented reality applications. In *Mixed and Augmented Reality (ISMAR), 2014 IEEE International Symposium on* (pp. 9-16). IEEE.
- [Kurze and Roselius, 2011] Kurze, M., & Roselius, A. (2011, March). Smart glasses linking real live and social network's contacts by face recognition. In *Proceedings of the 2nd augmented human international conference* (p. 31). ACM.
- [Lee et al., 2009] Lee, R., Kwon, Y. J., & Sumiya, K. (2009, September). Layer-based media integration for mobile mixed-reality applications. In *Next Generation Mobile Applications, Services and Technologies, 2009. NGMAST'09. Third International Conference on* (pp. 58-63). IEEE.
- [MacIntyre and Feiner, 1996] MacIntyre, B., & Feiner, S. (1996). Future multimedia user interfaces. *Multimedia systems* 4(5), 250-268. Springer-Verlag.
- [MacIntyre et al., 2011] MacIntyre, B., Hill, A., Rouzati, H., Gandy, M., & Davidson, B. (2011, October). The argon AR web browser and standards-based AR application environment. In *Mixed and Augmented Reality (ISMAR), 2011 10th IEEE International Symposium on* (pp. 65-74). IEEE.
- [Mackay, 1998] Mackay, W. E. (1998, May). Augmented reality: linking real and virtual worlds: a new paradigm for interacting with computers. In *Proceedings of the working conference on Advanced visual interfaces* (pp. 13-21). ACM.
- [Magic Leap, 2015] Magic Leap, <http://www.magicleap.com/> (retrieved on 26.3.2015). Magic Leap Inc. (Dania Beach, FL, U.S.).



- [Microsoft, 2015] Microsoft HoloLens, <http://www.microsoft.com/microsoft-hololens/en-us> (retrieved on 14.3.2015), Microsoft Corporation (Redmont, WA, U.S.).
- [Milgram and Colquhoun, 1999] Milgram, P., & Colquhoun, H. (1999). A taxonomy of real and virtual world display integration. In Ohta, Y. (Ed.), Tamura, H. (Ed.), *Mixed reality: Merging real and virtual worlds*, (pp. 5-30). Ohmsha Ltd., Tokyo / Springer-Verlag, Berlin.
- [Milgram and Kishino, 1994] Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, 77(12), 1321-1329.
- [Milgram et al., 1994] Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented reality: a class of displays on the reality-virtuality continuum. In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* (Vol. 2351, pp. 282-292).
- [Mountain and Liarokapis, 2007] Mountain, D., & Liarokapis, F. (2007, July). Mixed reality (MR) interfaces for mobile information systems. In *Aslib proceedings* (Vol. 59, No. 4/5, pp. 422-436). Emerald Group Publishing Limited.
- [Müller et al., 2013] Müller, L., Aslan, I., & Krüßen, L. (2013). GuideMe: A Mobile Augmented Reality System to Display User Manuals for Home Appliances. In *Advances in Computer Entertainment* (pp. 152-167). Springer International Publishing.
- [Nokia, 2009] Mobile Mixed Reality, The Vision (2009). available online in pdf-format at: [https://research.nokia.com/files/NTI\\_MARA\\_-\\_June\\_2009.pdf](https://research.nokia.com/files/NTI_MARA_-_June_2009.pdf) (retrieved on 25.8.2014). Nokia Research Centre (NRC) (Finland).
- [Nurminen et al., 2014] Nurminen, A., Järvi, J., & Lehtonen, M. (2014). A Mixed Reality Interface for Real Time Tracked Public Transportation. Helsinki Institute for Information Technology (HIIT), of Aalto University and University of Helsinki, Finland
- [Nurminen, 2012] Nurminen, A. (2012, November). Mobile mixed reality interface developments. In *SIGGRAPH Asia 2012 Symposium on Apps* (p. 4). ACM.
- [Olsson and Salo, 2011] Olsson, T., & Salo, M. (2011, October). Online user survey on current mobile augmented reality applications. In *Mixed and Augmented Reality (ISMAR), 2011 10th IEEE International Symposium on* (pp. 75-84). IEEE.
- [Olsson and Salo, 2012] Olsson, T., & Salo, M. (2012, May). Narratives of satisfying and unsatisfying experiences of current mobile augmented reality applications. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 2779-2788). ACM.
- [Olsson et al., 2009] Olsson, T., Ihamäki, P., Lagerstam, E., Ventä-Olkkonen, L., & Väänänen-Vainio-Mattila, K. (2009, September). User expectations for mobile mixed reality services: an initial user study. In *European Conference on Cognitive Ergonomics: Designing beyond the Product---Understanding Activity and User Experience in Ubiquitous Environments* (p. 19). VTT Technical Research Centre of Finland.

- [Olsson et al., 2012] Olsson, T., Kärkkäinen, T., Lagerstam, E., & Ventä-Olkkonen, L. (2012). User evaluation of mobile augmented reality scenarios. *Journal of Ambient Intelligence and Smart Environments*, 4(1), 29-47. IOS Press.
- [Olsson et al., 2013] Olsson, T., Lagerstam, E., Kärkkäinen, T., & Väänänen-Vainio-Mattila, K. (2013). Expected user experience of mobile augmented reality services: a user study in the context of shopping centres. *Personal and ubiquitous computing*, 17(2), 287-304. Springer-Verlag.
- [Olsson, 2012] Olsson, T. (2012). User expectations and experiences of mobile augmented reality services. *Tampereen teknillinen yliopisto. Julkaisu - Tampere University of Technology. Publication; 1085*.
- [Orlosky et al., 2014] Orlosky, J., Kiyokawa, K., & Takemura, H. (2014). Managing mobile text in head mounted displays: studies on visual preference and text placement. *ACM SIGMOBILE Mobile Computing and Communications Review*, 18(2), 20-31. ACM.
- [Papagiannakis et al., 2008] Papagiannakis, G., Singh, G., & Magnenat-Thalmann, N. (2008). A survey of mobile and wireless technologies for augmented reality systems. *Computer Animation and Virtual Worlds*, 19(1), 3-22. John Wiley & Sons, Ltd.
- [Poelman et al., 2012] Poelman, R., Akman, O., Lukosch, S., & Jonker, P. (2012, February). As if being there: mediated reality for crime scene investigation. In *Proceedings of the ACM 2012 conference on computer supported cooperative work* (pp. 1267-1276). ACM.
- [Quest Visual, 2014] Word Lens, <http://questvisual.com/> (retrieved on 19.12.2014). Quest Visual Inc. (San Francisco, CA, U.S.).
- [Rakkolainen and Palovuori, 2002] Rakkolainen, I., & Palovuori, K. (2002, April). A Walk-thru screen. In *Electronic Imaging 2002* (pp. 17-22). International Society for Optics and Photonics.
- [Raskar et al., 1998] Raskar, R., Welch, G., & Fuchs, H. (1998, November). Spatially augmented reality. In *First IEEE Workshop on Augmented Reality (IWAR '98)* (pp. 11-20). IEEE.
- [Roesner et al., 2014] Roesner, F., Kohno, T., & Molnar, D. (2014). Security and privacy for augmented reality systems. *Communications of the ACM*, 57(4), 88-96. ACM.
- [Samsung, 2015] Gear VR, <http://www.samsung.com/global/microsite/gearvr/index.html> (retrieved on 25.4.2015). Samsung (Seoul, Republic of Korea).
- [Schall et al., 2013] Schall, G., Zollmann, S., & Reitmayr, G. (2013). Smart Vidente: advances in mobile augmented reality for interactive visualization of underground infrastructure. *Personal and ubiquitous computing*, 17(7), 1533-1549. Springer London.
- [Sony, 2015] SmartEyeglass, <https://developer.sony.com/develop/wearables/smarteyeglass-sdk/api-overview/hardware/> (retrieved on 2.5.2015). Sony Corporation (Tokyo, Japan).

- [Sutherland, 1965] Sutherland, I.E. (1965). The Ultimate Display. In *Proceedings of IFIP 65* (vol 2, pp. 506-508).
- [Sutherland, 1968] Sutherland, I. E. (1968, December). A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I* (pp. 757-764). ACM.
- [Ventä-Olkkonen et al., 2012] Ventä-Olkkonen, L., Posti, M., Koskenranta, O., & Häkkinä, J. (2012, December). User expectations of mobile mixed reality service content. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia* (p. 52). ACM.
- [VTT, 2009] ALVAR, A Library for Virtual and Augmented Reality. VTT Technical Research Centre of Finland, <http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/index.html> (retrieved on 28.4.2015) and [http://virtual.vtt.fi/virtual/proj2/multimedia/media/ALVAR\\_busi\\_tech\\_v3.pdf](http://virtual.vtt.fi/virtual/proj2/multimedia/media/ALVAR_busi_tech_v3.pdf) (retrieved on 28.4.2015).
- [Weiser, 1991] Weiser, M. (1991). The computer for the twenty-first century. *Scientific American* 265(3), 94-100.
- [Wikitude, 2014] Wikitude, <http://www.wikitude.com/> (retrieved on 19.12.2014). Wikitude GmbH (Salzburg, Austria).
- [Wither et al., 2011] Wither, J., Tsai, Y. T., & Azuma, R. (2011). Indirect augmented reality. *Computers & Graphics*, 35(4), 810-822. Elsevier.
- [Yohan et al., 2000] Yohan, S. J., Julier, S., Baillet, Y., Lanzagorta, M., Brown, D., & Rosenblum, L. (2000). Bars: Battlefield augmented reality system. In *NATO Symposium on Information Processing Techniques for Military Systems*.
- [You et al., 1999] You, S., Neumann, U., & Azuma, R. (1999). Orientation tracking for outdoor augmented reality registration. *Computer Graphics and Applications, IEEE*, 19(6), 36-42. IEEE.
- [You et al., 2008] You, Y., Chin, T. J., Lim, J. H., Chevallet, J. P., Coutrix, C., & Nigay, L. (2008, September). Deploying and evaluating a mixed reality mobile treasure hunt: Snap2play. In *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services* (pp. 335-338). ACM.