Exploring context-sensitive collaborative augmented reality applications

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In smart spaces limited amount of physical resources are available. Also, system should be able to offer relevant information according to user's personal preferences. At the same time smart environments could serve many users with same requirement of relevancy and operate on limited resources. Sometimes it may not be possible to share resource in a way that respects all users without compromising collaboration.

This thesis is focused on solving the problem of shared resource from the perspective of augmented reality. Selected standpoint is on mobile collaborative augmented reality and context-awareness. A small user study has been arranged as part of thesis to bring out information about user's thoughts and emotions while using a simple prototype application. In addition, a small literature review about main concepts is conducted. There is a short analysis of some collaborative augmented reality applications presented based on recent literature.

Results of the thesis show that even with small experiments it is possible to discover new information from users. Results also provide tentative answers to presented research questions. Main findings are that users have high expectations towards context-awareness and augmented reality technologies. They also expect applications to offer relevant, validated and also surprising information in each situation. This thesis has some evidence about suitability of augmented reality in context-aware applications that are targeted to support human-to-human collaboration. With augmented reality it is possible to offer individual standpoints for users while they are inspecting limited, shared resources. Endorsement of user's ability to monitor their environment is one challenge in large smart environments. Finally, software engineer can take user's expectations into account when designing context-aware systems for smart environments. Also, developer could implement system that takes advantage of different human sensory modalities.

Keywords: augmented reality, context-awareness, face-to-face collaboration, shared resource, smart environment

TURUN YLIOPISTO
Tulevaisuuden teknologioiden laitos

Markus Konsti : Pieni tutkielma lisätyn todellisuuden soveltuvuudesta jaetun älyresurssin ja ihmisten välisen yhteistyön näkökulmasta

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Äly-ympäristöissä on useimmiten käytössä rajalliset aineelliset resurssit käyttäjien palvelemiseksi. Näiden ympäristöjen ajatellaan palvelevan käyttäjiä paremmin kuin tavalliset ympäristöt, sillä äly-ympäristöjen ajatellaan voivan ottaa käyttäjien yksilölliset mieltymykset paremmin huomioon tietoa tarjottaessa. Koska resurssit ovat rajalliset, voi esiintyä tilanteita joissa käyttäjien tarpeita ei voida täysin toteuttaa. Kun jokin resurssi joudutaan jakamaan monen käyttäjän kesken, kahden tai useamman käyttäjän mieltymykset voivat olla keskenään ristiriidassa.

Tässä työssä tarkastellaan lyhyesti jaetun resurssin ongelmaa lisätyn todellisuuden näkökulmasta. Esitettyä ongelmaa lähestytään tutkimuskysymysten kautta. Tutkielmassa esitetään lyhyt katsaus ongelmaan sivuavista teemoista: tilannetietoisuus, adaptiivisuus sovelluksissa ja lisätty todellisuus. Lisäksi esitellään muutama esimerkki ihmisten välistä yhteistyötä tukevista lisätyn todellisuuden sovelluksista kirjallisuuteen perustuen. Tutkimuskysymyksiin pyritään vastaamaan erillisen sovelluksen ja tutkimusta varten järjestetyn pienen käyttäjäkokeen avulla.

Työn tuloksista voidaan päätellä, että käyttäjäkoe antoi hieman uutta tietoa lisätyn todellisuuden sovelluksen käytöstä sekä vastaajien ajatuksista tilannetietoisista sovelluksista. Lisäksi esille tuli tietoa, joka voidaan vahvistaa olemassa olevan kirjallisuuden avulla. Työn tulokset antavat aiheen väittää, että lisätty todellisuus soveltuu jaetun resurssin yhtäaikaiseen tarkasteluun. Lisäksi kyseinen teknologia pystyy ottamaan jokaisen käyttäjän huomioon esimerkiksi hyödyntämällä ihmisen näkö-, kuulo- sekä tuntoaistia. Käyttäjillä on korkeat odotukset lisätyn todellisuuden sovelluksia kohtaan. He odottavat niiden tarjoavan relevanttia, tilanteeseen sopivaa tietoa sekä myös yllättävää, epätavallista tietoa. Sovelluskehittäjä voi ottaa huomioon käyttäjien odotukset lisätyn todellisuuden sovelluksista kehittäessään tilannetietoisia, lisätyn todellisuuden sovelluksia älyympäristöön. Näin ollen saadaan aikaiseksi sovelluksia, jotka kuljettavat käyttäjää mukanaan alati vaihtuvissa tilanteissa. Lisätyn todellisuuden käytännön sovellusten haasteena on tukea käyttäjän tarvetta seurata ympäristöään virtuaalisisältöä tutkiessaan.

Asiasanat: lisätty todellisuus, tilannetietoisuus, ihmisten välinen yhteistyö, älyympäristö, jaettu resurssi

Contents

1 Introduction

We all have had our frustrating moments with computers when they didn't do we wanted them to do. Underlying designs of computers and computing systems have created a barrier that is difficult to surpass. Interfaces to computing systems require us to understand complex jargon that has nothing to do with the task we are trying to do. They take our time and make us to invest a lot of money especially when there is some problem presented with complex technical jargon. And sometimes our anger and frustration remains after unsuccessful interaction session. It is no wonder why some people are unwilling to use such systems or any computing system. There are people who will continuously favour paper and pen instead of computer. Complex computing system interfaces may even be scary for professionals who are involved with developing them.

A new kind of thinking has emerged within software engineering communities. These information technology professionals want to create systems that are fast but also easy to use. Goal is to have interfaces that are easy to understand and won't require understanding of complex technical jargon. Computers are *desired* and *designed* to be hidden behind the scenes so that users are able to focus entirely on their tasks instead of time-consuming configuration. These systems offer interaction with humans while taking care of all the complex details. Actually, the role of human is to use the systems and set high-level policy how these systems should behave. Support for users being able to have full control over their private data is popular research topic.

One research area that tries to address described problems is *collaborative augmented reality*. This field of technology research is investigating possible uses of computers so that natural human-to-human interaction is supported. Collaborative augmented reality tries to remove artificial and complex barriers by bringing real and digital world together. However, this research field is also a sub field of greater area — *ubiquitous computing*.

1.1 The problem of shared resource

When dealing with intelligent environment software developer/engineer has to take a stand on the following problem:

In smart environment there is a service or device that provides some content to its users. Content is shared by all users who are present at the same time. It is expected that users *can collaborate with each other and they can operate on the same data while cooperating. The service could also provide filtered, context-aware content for individual user while user is examining the same object with others. This should be achieved without revealing personal content to other attendants without user's explicit consent.*

This is a non-trivial problem as in cooperation situations users also need to share information that is considered to be private for individual user. In addition, users could have preferences that are *opposite* to each other: one user may prefer to get notifications from smart environment while being there and another user may not want to get any additional information. Preferences could also be *conflicting*: one might want to get more heat out of heating system while another user might want to turn on cooling. This kind of system ought to be able to adjust its services according to every situation that may be totally impossible to achieve. Finally, transformation from a situation to another may occur very often and quickly. Thus, the system should be able to follow changes. Although computers can do all this rapidly and securely we humans have to be kept updated about these changes. We need to understand the reason for change of behaviour in order to be able to trust the system and not get confused.

Main research questions are build around question: "how can software support human-to-human cooperation and interaction while respecting user's custom preferences". The main research questions derived from the problem are:

1. What purposes of use augmented reality could be used?
2. What kind of solutions are there for collaborative augmented reality applications based on mobile devices?
3. How software developer could solve the problem of two or more users having opposite/diverging user preferences by using the context sensitive augmented reality technology?
    - How this could be achieved without disabling collaboration between users?

Since augmented reality is used for visualizing data it may be useful related to this problem. The overall focus is on mobile augmented reality and collaboration. Questions are mostly set by their relevancy and scope of this thesis. It is necessary to explore basics of related technologies in order to be able to find answers to presented questions. Hence, scientific literature is used to find answers to the questions 1 and 2. For the research question 3 a practical user study with custom software has been organised and analysed.

This thesis has the following structure: Introduction to next generation automation is presented in next chapter. The definition of augmented reality and enabling technologies are introduced in Chapter 3. Collaborative augmented reality is explained in Chapter 4. Actual research methodology and results are pinned down in Chapters 5 and 6 respectively. Discussion and conclusions are presented in Chapters 7 and 8 correspondingly.

2 Enablers of next generation automation

In order to understand position of the augmented reality technology it is helpful to acquire holistic view about evolution of modern computing systems. Naturally augmented reality is tightly connected to context and context-awareness. There is major effort to make computing systems transparent so that they would be used everywhere by everybody. And augmented reality applications are part of that effort. Today's computing systems are so big and complex that new approaches to develop and maintain such systems is needed. These concepts are also presented as part of this thesis because author took significant amount of time to come up with the final research questions and exploring these topics was important part of this process.

In Chapter 2.1 there is introduction to ubiquitous computation. In Chapter 2.2 there is a short overview of concepts "context" and "context-awareness" that are fundamental concepts of any ubiquitous environment. In Chapter 2.3 picture is widened a bit more to be able explain current status of adaptive software development. Last Chapter 2.4 presents the ideal goal of recent information technology research and ties up concepts explained in previous chapters.

2.1 Ubiquitous computing

Nowadays it is usual that we run into a situation where our personal computer requires our attention to solve some technical problem. Usually these situations forces us to switch focus from the task to technical problem. We have seen services in Internet that print error messages to our display although we are just using these services and have nothing to do with their technical properties. Blue screen errors related to one of the biggest operating systems are rare but not impossible. Information technology systems tend to require us to learn complex jargon they operate on. Hence, information processing systems are forcing their users to interact with them although it may be very irrelevant from user's point of view. Finally, these errors keep us away from focusing our main task while interacting with computers.

Weiser [1] was the first scientist to vision environment where computers would be totally hidden from human beings. Idea was to develop computing environments where users would be able to focus on their own task instead of computers themselves. Weiser envisioned genre of computing systems that were to assist humans in their daily activities. Emphasis were on human being instead of computing system. According to Weiser's vision computing system should be so invisible or ubiquitous that people would not recognise it any more. It would be weaved into environment and it would offer transparent interaction to human users. Thus system would be totally seamless. Weiser used term "ubiquitous computing" to designate system's transparency. He used writing as an example technology which has become so common that we are not able to distinguish it as a technology any more. Written information has spread to everywhere. Nowadays it is hard to find person who couldn't read or write. Hence, writing is a ubiquitous technology.

Salber et al. [46] extend Weiser's view about ubiquitous computing. They split the concept to two parts: interface transparency and user mobility. Traditional interfaces force users to understand how to use the interface before they can use it fluently. Understanding interface is conceptually different from the task user wants to do with the interface. Hence, learning to use one takes a lot of time. In order to make usage of computing systems easier and more intuitive these wrinkles has to be smoothed by making interfaces more transparent. This is achieved by hiding basic routines of interface use into background. This requires engineers to develop computing systems that can take care of complex details by themselves and also anticipate user's intentions and goals. User mobility addresses need for computing systems that can be accessed anywhere user is in. Idea in user mobility is also that user would be able to access computing system without need to have personal device to use the system. Shift from personal computing where users need devices to get tailored services to a paradigm where users do not need devices to get customised services is desired in ubiquitous computing ideology.

As a summary, ubiquitous computing takes advantage of notion "Internet of Things" in order to support users' intentions. The paradigm tries to make public or user-related interfaces as transparent and mobile as possible. This could be achieved by using advanced techniques such as wearable computing, context-awareness, visualization technologies and artificial intelligence.

2.2 Context and context-awareness

Context is fundamental concept in pervasive computing. Research of context and context-awareness began already in the 1990's and it was mainly focused on location and time. Research aimed to create context-aware devices that would collect data from its environment and consume it to support computer usage in varying physical environments. This meant giving birth to revolutionary devices — mobile computers.[2, 3]

Schmidt et al. [2] introduces a proposal of *context feature space*. There are two general categories "human factors" and "physical environment" which are both split to three sub-categories. These categories are listed in Table 1.

Human factors	Physical environment
User	Conditions
Social environment	Infrastructure
Task	Location

Table 1: Context feature space adapted from [2].

Information about the user could represent knowledge of habits, bio-physiological conditions or even emotions. Social environment related to context could describe co-location of others, social interaction or group dynamics. Information related to environment and especially infrastructure could describe surrounding resources for computation, communication or task performance. [2]

The Cambridge Dictionary defines context as *"a situation within which something exists or happens, and that can help explain it"*. Abowd et al. [3] defines context to be *any information that can be used to characterize situation of entity*. Entity can be person, place, physical or computational object. Floch et al. [4] describe context also to be any information that affects the interaction between human and computing system. Hence, context is dependent on situation and data. Rong and Liu [5] suggest that formal definition of Abowd et al. is too broad and general. It is not very applicable in practical applications. Consequently, they suggest that each domain should make their own definitions which would be more accurate and applicable.

Based on Dey [6] and Schmidt et al. one most important part of context is historical information. Thus it must be accessible as context data in applications. Computer programs could use historical data to predict future actions of users [6] or changes in data [38]. Table 2 presents some uses of the concept of context that Floch et al. used in their works to develop framework for self-adaptive systems.

Here is some explanation for data in Table 2. In order to make applications work more efficiently it is necessary to vary memory requirements. If, for instance, we

Context	How context is used?
Memory	requirements to size of memory is varied according to operation system platform
Network-related	stand-alone or connected mode in respect to network availability
Battery	application terminates due to low battery charge or it uses minimal configuration to reduce energy consumption
Location	navigation support, offers selection of special location dependent services
Application status	has impact on optimal configuration that depends on context
User Profile	user can turn on/off specific application features

Table 2: Examples of context according to Floch et al. [4]

have mobile device with low computing power and with low amount of RAM memory it is necessary to change application behaviour to use internal memory. Also if application runs on device which uses battery it is necessary to change application behaviour to more energy saving mode. It is well-known fact that mobile phones consume most of their energy when the device is connected to network or local wireless network. When there is low level of energy in battery it is necessary to turn wireless off and work in stand-alone mode with minimal network communication level. Adaptability of application behaviour based on battery is very common thing today. Location-based approach may offer special services to mobile devices that operate on certain area. For instance information about time tables could be offered when user is in a bus or ticket information could be downloaded to mobile phone when user is standing at bus stop. Navigation instructions could also be offered to certain devices in certain spaces [4]. Application status is related to communication with the system. Status could be "authentication successful", "task downloaded", "user preferred mode" or "installer priority"[4]. In order to create applications which user can easily understand and have certain amount of control user preferences are required. Also, user preferences can have significant role when application systems are trying to learn user’s behaviour [7].

Context-based software exploits data related to situations. Context data is mainly obtained by sensors. In order to have useful context information different levels have been considered. *Low-level context* means data obtained from sensors [44].

For instance low-level context could be battery voltage level, location but also more abstract data like some application event. High-level context is inferred from lower level [44]. If, for instance, we have low-level data that suggest our location is "lecture hall" and current time is same as in a calendar event "lecture of Object-Oriented Programming" we may infer that we have participated to lecture about programming. Because low-level context data can be very challenging to handle it makes sense to encapsulate data handling functionality and create reusable components that would be able to manage low-level data. For instance application frameworks for context-aware applications could help application developers to reuse ready components that master low-level context data [4, 44]. This way creating adaptive applications is far easier than from scratch.

Context-awareness is tightly related to context. Dey [6] defines a context-aware system to be *a system that is able to provide relevant information or services to user by using context data*. Context-awareness can also be interpreted as link between computation system behaviour and its environment [8]. Schilit and Theimer [9] defines context-aware computing to be *an ability of mobile applications to discover changes and react to them in specific situation and in particular environment*.

To conclude the primary goal of designing context-aware applications is to get computer programs to do the right thing at the right moment [6]. Context-aware application should sense situation and act accordingly. According to Schmidt et al. [2] primary motivation to pursue context-awareness is derived from nature of mobile devices: We all want to use mobile devices when we are at some stationary location. But we'd also like to use mobile devices when we are on the move. This poses great challenge to designers of mobile devices and applications because it is impossible to know when context changes at design phase. It is also impossible to know what is the exact context where end-user uses the software. Nevertheless, user expects applications to act proactively in a fashion that doesn't confuse user.

2.3 Adaptive software

One challenge in software engineering is to design software that has enough flexibility to change in the future. There are many aspects that cannot be taken into consideration at design phase. Especially in long-living systems this kind of anticipation is impossible. Hence, adaptable software is a vital condition for these systems. As Floch et al. [4] express adaptability is pursued in order to maintain usefulness of application in changing environment with ever-changing requirements. Whatever is the reason for changes in requirements software systems should achieve those. Of course total transformation from one domain to another is not rational and it is not what is meant when talking about adaptability of software [see 39, chapter 3.2.].

Adaptability of software is other fundamental concept in ubiquitous software system in addition to context. Application is adaptable if it is capable of changing its behaviour on the fly when the application is running [8]. A change in requirements of the application should be the catalyst for these kind of dynamic changes. Concept of *behavioral variation* is also used in literature to refer to adaptability of software [10]. Because requirements tend to relate to context variables context-awareness and adaptability are tightly related. As Kephart and Chess [11], McKinley et al. [12] and Cheng et al. [39] have concluded in their own separate studies, in order to be able to change the behaviour application should be able to monitor itself and use inferencing as a tool. This requires acknowledgement of context and context-awareness.

According to Nierstrasz et al. [38] development tools and programming languages pose another great challenge from adaptive software engineering point of view. As change-enabled software systems require notion of context and context-awareness programming languages would have to provide means to achieve the key concepts. For instance current most used programming languages do not offer full reflection and even partial reflection is limited to granularity of functions or methods. Even if reflection is supported programmer runs into the problem of meta-object call recursion or ineffective constructs because of unawareness of context and naïve integration of reflection to dynamic run-time environment. Current programming languages don't embrace continuous evolution of software system well either.

Current integrated development environments (IDEs) do not let developers to inspect *dynamic information* of system. Instead they only offer static view of such system. According to Ko et al. (as cited in Nierstrasz et al.) a developer spends 35 % of the time to navigate source code when performing maintenance tasks. Source code itself does not reveal any dynamic aspects of software and it is connected to more low-level than high-level tasks. Yet developers are forced to use tools that enable low-level development while they pursue to represent system at all levels of abstraction. As Nierstrasz et al. point out, with current IDEs, there is no guidance to code refactoring, no view to actual code execution, no visualisation of dynamic information, no explanation why logical errors occur and no correlation between static structures and features derived from the structures. Hence today's IDEs play more passive than active role in practical programming. This way it is challenging building complete structure of adaptive system.

2.4 Autonomic computing

Current information systems are big and very complex. Installation, configuration, tuning and maintenance of such systems takes a lot of time and effort. Even development and installation of them takes time that is measured in months than weeks. When error occurs it is hard and time consuming to detect root cause and sometimes reason remains totally undetected. At times erroneous behaviour just disappears without knowledge about reason for error. For modern computing platforms it is common that they influence many stakeholders, not just groups inside companies but also many groups outside of enterprises. This makes development and maintenance even harder because many systems are affected. [11]

In order to make things better there is need for elementary building blocks that could take care of themselves automatically without human intervention. They could function in similar fashion than human body works [11]. Let's take an example and examine how heart works in human body: We can control it only for short time periods at a time but we don't have it under full control. Human body functions almost automatically and takes care of matters that will keep it alive. The human nervous system acts totally independently, regardless of human thinking and action. There is even switching between different activation levels between two separate nervous systems: the sympathetic and the parasympathetic nervous system. Even more desirable is the ability to adapt these systems. If, for instance, a person has a mild blockage in his vein his heart and the nervous systems will take several actions the person might not even notice - just to adapt to current conditions and let the body survive with new condition.

It could be desirable to have similar features in computing systems. This is the main idea of *autonomic computing* [11]. The term "autonomic" is used on purpose to illustrate source of inspiration which is tightly connected to biological systems. Kephart and Chess [11] state that self-management consists of four aspects: self-configuration, self-optimisation, self-healing and self-protection. In Table 3 these concepts are illustrated by their current status and desired state with autonomic systems.

Concept	Current computing	Autonomic computation
Self-configuration	Corporate data centers have multiple vendors and platforms. Installation, configuration and maintenance is complex and error prone.	Configuration is automated and it follows human governed high-level policies. Low-level actions would be done automatically without human intervention.
Self-optimization	Systems have several hundreds of manually set parameters that are hard to maintain by human being.	Systems could continually seek opportunities to tune and improve their performance.
Self-healing	In large complex systems problem detection and finding solutions for them is time consuming.	Problem detection, diagnosing and repair could be fully automated process.
Self-protection	Software security is handled manually and afterwards of security breach.	System could automatically take care of real-time attack detection and act both proactively and predictive ways.

Table 3: Current status and future vision by the four concepts of autonomic computing according to [11].

According to the vision Kephart and Chess the most simplest form of autonomic computing would be *an autonomic element*. This atomic structure could consist of two main parts: the element itself and its autonomic manager. Element would have different resources and services that it could provide for humans and other elements. Autonomic manager would consist of five distinct sets of functionality: monitoring, analysis, planning, execution and knowledge modules. Figure 1 illustrates this structure. There is no suggestion in [11] how these elements could be implemented but it is self-evident that autonomic computing relies heavily on notion of context-awareness and adaptive software.

By monitoring itself autonomic element could gather data about its state and actions. It could create plans through analysis of data gathered and execute the most appropriate plans. By processing these steps the element would be able to create knowledge about its state and fulfilment of goals. System would be able to make all the necessary adaptations and improve its behaviour. Being capable of making decisions and deducing all needed information it is evident that this kind of system has to have very sophisticated structure and thus the source code is likely to be complex. Element could represent hardware of software resource: storage, CPU, database, cache server, legacy system or some external device. By connecting and combining different autonomic elements it could be possible to derive complex computing platforms like we now have with the difference that autonomic computing platforms would take care all the technical details by themselves. Thus they could relieve humans from inspecting low-level source code and other micromanagement tasks. Human being could steer these systems with high-level policies and would have more time to focus on domain business rather than technical issues. [11, 44, 4]

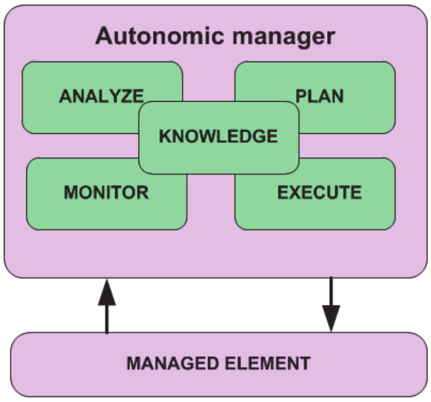


Figure 1: The MAPE-K loop after Kephart and Chess. Figure is taken from Gilman [44].

It is evident that there is multitude of challenges to be overcome before autonomic computing is a common thing. There is no mathematical theory for autonomic computing that relies on independence. Theory of robustness, machine learning, negotiation and optimisation need to be created or improved. Also, programming paradigms and techniques need to be improved greatly to support automating all significant tasks. Tools to develop automated systems need new perspective beyond their development that doesn't exist yet (cf. Chapter 2.3). The described autonomic system is assumed to be a distributed agent-based system which is hard to test completely with existing knowledge of testing. This is because autonomic system would create and maintain its low-level goals automatically and make necessary adaptations to source code that could be also distributed into several computing systems. Also, interaction between elements is a challenge and there is little knowledge about these kinds of multi-agent systems. [11, 39, 38]

3 Augmented reality and enabling technologies

This section provides a short description of theories that basic augmented reality applications make use of. Definition of augmented reality (abbreviated as AR) is the starting point for development and understanding of this concept. Reality-virtuality continuum maps augmented reality to other existing approaches to generate virtual content and be able to interact with it. Display and tracking technologies construct the core of all AR applications. As augmented reality is very new area of research there are also plenty of challenges that must be overcome before AR can be part of everyday life for everyone.

3.1 Definition of augmented reality

The original definition of "augmented reality" was composed by R. Azuma although the idea was developed in 1960s by Ivan Sutherland. According to this definition augmented reality is a technology that (1) combines *real* and *virtual* objects in a real world setting, (2) runs interactively in real-time and (3) incorporates alignment of virtual and real objects. [14]

According to Billinghurst and Kato [15] "augmented reality" is often used term when two or three-dimensional computer graphics are superimposed on real objects. These virtual objects can be seen and accessed through some sort of display. Also, there are some user studies that indicate that AR is mostly seen as a way to augment visual interaction modality by ordinary consumers [16]. However, the original definition of R. Azuma does not restrict AR to be used only in graphic space. AR application can possibly deal with aural, touch and smell as well as vision-based graphics. In accordance with this fact Grubert et al. [17] define augmented reality to be a technology which applies digital information to physical environment. Digital information can be text, graphics, audio or video. In the end, the original definition is also open for all technologies that could augment human sensory system. Maybe in future AR scenarios consist also applications that deal with taste and kinaesthetic modalities that help computers to track user's fine gestures and even feelings.

3.2 Virtuality continuum

Figure 2 represents "virtuality continuum" that describes relations of key concepts. The continuum were originally presented by Milgram and Kishino [18].

In the left side of virtuality continuum figure there is real world environment and in the right there is fully virtual environment.

Figure 2: Virtuality continuum. Figure is taken from Azuma et al. [14].

Real environment is the environment we are living in. All real objects or items follow the laws of physics that govern concepts like space, time and material properties. It is possible to view real world with electronic device like video camera. When displaying footage on computer display or television we see real world like video camera sees it. [18]

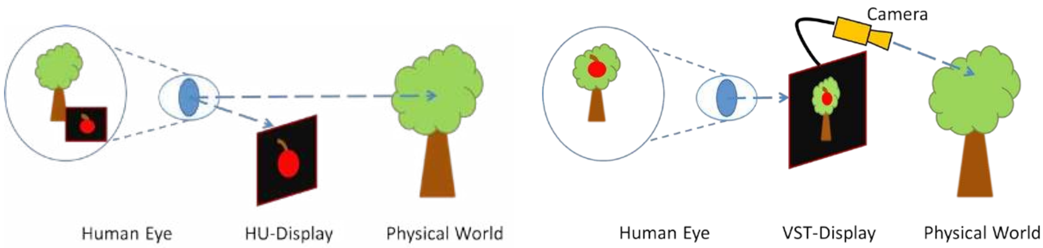
As opposed to real environment *virtual environment* is one that is entirely synthetic, that is, environment that doesn't have any real objects [18]. User is only able to interact with environment by using some electronic controller like computer mouse or keyboard. Virtual world may mimic real world but it can have features that does not exist in real world [18]. For instance some character in video game may hover or float over objects that is not possible in real world.

Augmented reality falls in between real environment and augmented virtuality. *Augmented reality* means that real world is superimposed with virtual content that does not exist in real. Thus, some content is real and some only lives in computer's memory. *Augmented virtuality* means virtual world that is overlaid with real world objects. What belongs to augmented reality and what belongs to augmented virtuality is somewhat grey area of the virtuality continuum. [18]

3.3 Display technology

Related to virtual continuum there are different classes of display technologies that are relevant part of virtuality-reality environments. According to Grubert and Grasset [40] main types of displays are optical see-through and video see-through display technologies.

In *optical see-through display* virtual content is superimposed to real object *optically*, that is, virtual content is projected on the lens of display. This is visualized in Figure 3a. Merging virtual content to real happens directly on retina of one's eye. If power fails with optical solution user can still see surrounding environment [19]. However, a separate tracking system is required to establish connection between virtual content and physical object [19]. Also, brightness and contrast are very poor in optical solutions [14].



(a) Optical display technology. (b) Video display technology.

Figure 3: Main principles of see-through optical and video technologies [40].

In *video see-through display* system's video camera observes real world and a computing system merges contents from real and virtual [40]. This is visualized in Figure 3b This kind of display is used for instance in mobile augmented reality applications. Benefit of using video see-through technique is ability to merge virtual content to real environment and also remove real objects on screen [19]. Since video content is digital tracking of movement can be more accurate than in purely optical solutions [19]. As disadvantages digital video resolutions are quite low in practice and manipulation of video stream requires high computing power [19]. There are also problems with depth perception [45].

It is also possible to *project* virtual content on physical objects in environment instead of optical lens or display. In projective systems field of view can be large and they can cover large surfaces. In addition, these systems don't require user to wear any kind of eye-wear. Since content is projected interaction with it is more complex. In order to interact special input devices are needed. Also, projectors need to be calibrated each time something changes in environment. Fortunately calibration can be automated. Projected systems are the best indoors due to properties of projection. Some materials and shapes require special attention because of physical properties of light. [19]

All the display types may be mounted on head like swimming goggles, held in hand or placed statically to certain position [19].

3.4 Tracking

In order to be able to follow real world object augmented reality system needs to have a system that tracks object's and viewing device's movement. Tracking of real item may be handled with sensors or computer-vision based methods [20]. Typically both systems are being used [14]. Tracking is used to observe position, orientation and movement of real world object relative to viewing system [40].

Sensor-based tracking. Device that is used to viewing of virtual content may be packed with different sensors. Sensor-based tracking takes advantage of these sensors. There are different types of sensors that can be used: magnetic, acoustic, inertial, optical and mechanical sensors [20]. For instance typical mobile phone has inertial sensors like accelerometer and gyroscope. They also have an interface to Global Positioning Systems that could also be applied for tracking purposes [19]. Likewise, radio waves can be utilized for tracking purposes.

Benefit of using sensor-based tracking is that it works relatively reliable in outdoor environment [40]. Sensors are also very cheap that most devices have them already. Disadvantage of sensor tracking is accuracy of sensor measurements and their inability to work indoor environment [40]. Fortunately, inaccuracy of sensors can be mitigated by using sensor fusion algorithm [40].

Vision-based tracking. Computer image processing algorithms may be used to provide tracking [20]. There are two types of techniques used in literature: feature-based and model-based [20, 45]. Vision-based approaches don't have jitter nor drift which are major advantages compared to sensor-based tracking [20]. But vision-based tracking methods are slow due to complex image processing techniques [20]. Also sudden and rapid movement can lead to tracking failures [20]. In some cases any obstacle that comes in between camera and real world target causes AR view to be lost since camera cannot see target any more [41].

In *feature-based tracking* image processing methods are used to find distinct details of pre-defined marker. Because markers suffer from differing lighting they are best used indoor. To be able to track large real objects it is not practical to use markers since they have to be placed on site. Also size of marker should be so large that they would be impractical. [45]

In *model-based tracking* a real 3D model is used to calculate translation and orientation of target. Tracking is done by using lines or edges of 3D model [20]. Zhou et al. [20] claim that model-based tracking is robust even when lighting changes. But as Forsman [45] points out certain lighting conditions may introduce false lines and edges that lead to tracking errors. Also a texture can be used to track 3D model [20].

According to Forsman [45] there are couple advantages and disadvantages for model-based tracking. 3D models can be large like real world buildings which is significant advantage in outdoor tracking scenarios. If model is complete tracking is possible from all directions. Moreover, if model is accurate also tracking is accurate. But accurate 3D models tend to also be very complex. This requires a lot of computing power and thus accuracy may also be a disadvantage. Moreover, good 3D modelling takes a lot time.

Hybrid tracking techniques are exploited to improve tracking accuracy and performance of sensors and vision algorithms. Basically they combine different sensor-based and vision-based techniques based on benefits of both approaches. Sensors are used to be able to track rapid motion and vision-based approaches are used to rapidly initialize AR content. [20]

3.5 User interfaces and interaction methods

The ultimate goal of augmented reality interaction is to be able to interact with real world objects in natural ways like by touching, manipulating physical objects and speaking. However, this is not easily achieved. Currently there are systems that deploy touch-based interaction. Especially mobile AR takes advantage of touch screen technology. There are methods that use haptic, visual or aural user interfaces. Haptic and visual interfaces require recognition of human gestures. Aural systems are based on complex speech recognition technology. [14, 19]

Haptic approaches are able to recognise gesture's force and motion as well as tactile sense. It is also possible to use special data gloves to provide haptic interaction but these gloves aren't very useful in practical scenarios. Visual user interfaces are based on camera technology. With cameras it is possible to track movement of human body and gaze. Advantage is that cameras may not necessarily need to be attached to user's body. Any occluding obstacle will disrupt tracking which is one possible disadvantage. Also, being able to track gaze user needs to be wearing AR glasses. Microphones and earphones may be used to provide aural interaction. They are easily hidden that makes using AR interfaces less awkward. With speech recognition aural interface provides a good addition to haptic and visual interfaces. [14, 19]

3.6 Application areas

The early applications for augmented reality were related to military, industrial, medical and scientific projects. Augmented reality has been used in navigational systems where user can inspect locations and get relevant guidance support to reach target location. Application development for these purposes started already in the end of 1990s. There has been developed applications for pedestrians, tourists and cars in this context. Another interesting application area are personal information systems that could integrate phone and email data with augmentations in locations and to related people. [19]

In corporate settings there have been developed applications that help people in design, manufacturing and maintenance tasks. In car designing there has been efforts to develop applications that makes it possible to inspect virtual models of car layout [19]. AR has also been used to comparison visual data of crash tests. In robotics sensor ranges have been visualized by custom augmented reality applications. Van Krevelen and Poelman [19] mention that working on large objects like aircraft has special challenges related to AR applications. Especially tracking is challenging because target objects are large. Forsman [45] points out that creation augmented reality applications for industry is hard because tracking has to be more accurate than in other application areas. Thus real industry use cases are rare. One application area in industry are applications that are targeted for maintenance tasks. According to Van Krevelen and Poelman there are applications that offer step-by-step instructions and are able to follow user's progress. Also, auxiliary sensors could be used to direct maintenance personnel's attention to problem areas.

There are efforts to develop AR applications for needs of medical domain. Fuchs et al. [21] presented already in 1998 application that simulates laparoscopic surgery. In the application real laparoscopes were augmented to visualize their position in life-sized foam model of human torso. According to Fuchs et al. [21] application was not used in real world case. There are also applications under development that overlay medical images on top of human body to help physicians in their work [19]. There have been efforts to develop applications to aid treatment of real world diseases. According to Weghorst [22] (as cited in Azuma et al. [14]) AR has been used to treat patients suffering from Parkinson.

Television broadcasting has taken advantage of AR to visualize hardly viewable objects like hockey puck. Also, augmented information about race car drivers and teams has been projected on television screen. There are also video games that utilize augmented reality. For instance Hakkarainen and Woodward [23] presents an AR table tennis application where users are able to play table tennis with each other by using regular mobile phones. The application was developed in 2005 when smartphones were still rare. Currently the Pokemon Go ([47]) is widely popular AR game where user ventures in virtual world by moving in real world. Augmented reality is also used in education. There have been efforts to build applications that visualize physical constructs in natural sciences [19].

Most application examples found in literature have been implemented with custom computing platform that has used large backpacks and custom displays [41]. But there are also applications that utilise regular mobile devices instead of expensive and bulky custom systems. Wagner et al. [41] present a simple multiplayer AR game where user is able to view and interact with virtual trains. Goal of this application was to experiment regular hand-held PDAs and their fitness to augmented reality. Henrysson and Ollila [24] created two test applications. One animates tram route maps with real data from progress of real trams. Another application plays videos in certain locations. User is able to view map and decide to which location to head. On location user can play video by clicking link appearing on screen. There are also mobile AR applications that enable users to view data and tag it to physical locations with textual or pictorial annotations. These applications represent genres of augmented reality browsers and AR image recognition.

Olsson and Salo [16] did extensive user study in 2011 by utilising questionnaire to find out which AR browsers and AR image recognition applications were most used by regular augmented reality users. There were 90 analysed responses that indicated most used augmented reality computer programs. Among the AR browser group respondents mostly used applications such as Layar, Wikitude and Junaio. Google Goggles were the most used AR image recognition tool. Excerpts from responses in Olsson and Salo [16] indicate that Goggles was popular because it could recognise almost anything.

3.7 Challenges in augmented reality research

Several articles (for example [14, 15, 17]) suggest that AR is mainly a visualization technology. It allows users to collaborate with each other interactively. It can reveal information that would not be visible or audible otherwise. Nowadays AR can be used to augment traditional media like newspaper or book. AR has been used in live television broadcasts to visualize real objects that are hard to see - like hockey puck or driver information in race. There is also potential to use AR for industrial purposes but this has been retarded because related technologies have significant scientific challenges.

Although augmented reality is available as well for software developers and end-users there exist many challenges that has to be solved. Table 4 summarizes main issues. There are challenges related to enabling technologies as well as challenges linked to social acceptance.

Challenge type	main issues
Display technology	poor quality in parameters: brightness, contrast, weight and size; lack of stereographic support in mobile devices
Registration technology	inaccurate readings from sensors, tools are tightly dependent on visual markers; markerless tracking requires lot of computation power
Social acceptance	there is no deep understanding of social impact

Table 4: Main challenges in the research field of augmented reality according to [14].

Display technology suffers from poor quality and performance in most parameters (brightness, contrast, weight, size). True AR displays tend to be bulky and heavy-weight. Sensing depth of scene is also one significant challenge. There are also challenges in object tracking. Especially in mobile applications performance of registration based on device's internal sensors tend to produce inaccurate results because of cheap sensors and other limitations of tracking technology. Currently AR tracking among development tools is mostly relying on physical markers. Marker-less tracking is mostly based on use of compass, gyroscope, GPS and video tracking. It is still suffering from great consumption of computing power that especially poses challenges to mobile AR applications. [14]

Visualization techniques pose challenges too: virtual content may not be aligned perfectly on real object because inaccurate mapping of virtual object. This makes virtual content to be seen as artificial rather than part of true world. Especially in gaming this is an important problem since low degree of immersion lowers creditability of game. Another interesting problem is occurring when AR system displays lot of data. While venturing on real world scenarios display may become cluttered by data. It may be difficult to read and see virtual objects because they are presented too closely. [14]

Final challenge is social acceptance. It is unknown how users will take augmented reality as part of their everyday life. There are aesthetic as well as privacy concerned challenges that has to be solved before AR can be part of everyday life [14]. According to Wikimedia Foundation, Inc. [48] there were lots of issues with the Google Glass - a optical head-mounted display product by Google. The fact that device used video camera to automatically record everything it viewed made people feel their privacy was violated. Although the idea of optical head-mounted display in everyday life is interesting the way it was implemented caused great anxiety among people. There were also difficulties with legislation and public authority in some countries. This proves that people are slow to adapt to new technological solutions and adoption may take a lot of time before these solutions become publicly accepted.

4 Collaborative augmented reality

The term "collaboration" means a situation where two or more people work together to achieve same goal [49]. Cooperation requires *intense ability to be present in the situation* to understand other people's intentions and speech. It requires us to see and interpret even subtle gestures and things that are not said: eye contact, movement of body, expression on face, mood, sensation of atmosphere etc. These are things that all humans observe during conversation with other human being to some extent. All material that extends collaboration process and is intended to shared by all participants requires attendants to be able to see the material in order to understand the situation.

Currently it is possible to have meetings with colleagues who don't share the same physical space. There are distributed teams working together - both are on different continents [25]. Modern software development is carried out by distributed teams [26]. The usual teleconference tools have granted us this privilege. But this privilege may also become a burden. Considering nature of cooperation or collaboration it is difficult to create application that would overcome problems of remote meetings.

According to Billinghurst and Kato [15] modern computer-supported collaboration technology is not perfect. Technology creates an artificial separation between real and virtual world: Audio-only technology leaves out important visual cues leading to overlapped conversations and difficulties to distinguish the speaker from other attendants. Even with videoconference technology it may be impossible to see subtle gestures: Resolution of video system may limit the amount of participants. Even eye contact may be lost. Real world documents are difficult to show in digital task space. Even if we leave out remote cooperation we have to deal with this artificial barrier. Consider common cooperation scenario described by Billinghurst and Kato [15]: other team members tend to gather around one member to see and have discussion about something on one's computer screen. Even if there is projector or multi-display system it is hard to cooperate smoothly and make use of digital task space seamlessly.

Another scenario could be the following: You are looking at the sky in beautiful evening with your friend. Suddenly you see some really interesting star constellation in the sky and you want to show it to your friend. How would you do that? Task becomes even harder if your friend is child. Even pointing at the moon may be hard. It is not easy to do this kind of practical demonstration even if all attendants are in the same physical place - not to mention remote conversations.

Since its nature of being a visualisation technology augmented reality can solve challenges mentioned previously. It is possible to build systems for face-to-face, remote, multi-scale and even command-and-control type of collaboration with support of presenting real world objects and sharing digital space at the same time. The Magic Book project proved this being possible by implementing a system where users could use immersive or AR mode [27]. Users were able to collaborate in real world and in virtual world. Users were able to review same data from individual perspectives. According to Billinghurst et al. (as cited in Billinghurst and Kato [15]) comparing traditional screen-based collaboration to AR-based collaboration with AR solution users were able to use speech, visual cues and non-verbal cues in similar fashion than in normal face-to-face cooperation. By using AR system it was easier to manipulate digital content than with screen-based system. With the Magic Book users were able to inspect same data with personal viewpoints that makes it a multi scale application. Magic Book is briefly presented in Chapter 4.2.

4.1 Characteristics of collaborative augmented reality application

According to Billinghurst and Kato during the Studierstube project researchers identified five key attributes of collaborative augmented reality environments: virtuality, augmentation, co-operation, independence and individuality.

Virtuality means that users have to be able to view and examine virtual objects. *Augmentation* is used to provide virtual content that may be context-sensitive and user-related. Augmented content is attached to virtual objects. *Co-operation* means that users have to be able to communicate and act together in natural ways. Technology should not be an impediment to achieve this. *Independence* and *individuality* refer to collaboration situations where users are granted with individual viewpoints of shared data. Individuality allows all users to have individual viewpoints. Independence refers users full ability to control their viewpoint. By taking into account these features it is possible to build environments that takes every user into account. [15]

Billinghurst and Kato also present *seamlessness* as another attribute of truly collaborative AR application. Spaces where communication and tasks take place should not be distinct. This way users are able to interact with virtual content by using familiar real world items. Value of seamlessness has been confirmed by several user studies by Billinghurst and Kato.

4.2 Sample applications on mobile collaborative augmented reality

It is reasonable to make a quick review about mobile collaborative augmented reality applications to build image of their most important characteristics. In order to build usable augmented reality applications for modern demanding collaboration conditions it is good to make this kind of review and inspect application's fundamental properties. This chapter is based on available literature of applications and none of them were really tried out by author since the applications were not available for public.

4.2.1 Hand of God

The Hand of God (HOG) application is targeted to command-and-control collaboration type where indoor user and outdoor user interacts with each other. The outdoor user could also be called as agent if desired. The indoor environment of the application has following features: a tabletop where projector's image is overlaid, cameras to capture user's gestures and mouse to scroll overlaid content. The indoor user uses the system by pointing area on the flat tabletop surface while surrounding cameras capture the gestures of hand. After that a custom computing system creates a 3D model of hand and attaches it to real world location. See Figures 4a and 4b for illustrations. A digital satellite image or anything else that can be used in this kind of scenario could be projected on the table. The outdoor user sees the modeled hand at appropriate direction on real world terrain. Outdoor user has a custom mobile AR computer system packed in a backpack. Besides this user wears see-through head-mounted display. [29]

Benefits of using the HOG system lie behind system's ease of use to provide navigation support in rapidly changing command-and-control environments. Indoor user can use any real world item on tabletop and the system will render it to AR view of outdoor agent. There is not need for preparation of suitable props to provide command-and-control tasks. Almost any real world object will

(a) Indoor specialist using interface of the Hand of God system.

(b) View for outdoor specialist with virtual hand of indoor specialist.

Figure 4: The Hand of God application views according to Stafford et al. [29].

do (cf. Figure 5). Indoor user can use items that are at disposal at any particular time. Also, moving prop on table makes AR object to move on real location which could be helpful for outdoor user. Collaboration between indoor and outdoor users is provided by light communication channel and AR properties. Both users can select certain object and refer to that in their discussion. Selection is visualized by highlighting the selected AR object. Both users are able to see each other's selections. In addition, outdoor user is able to manipulate AR objects by using special gloves. If outdoor user moves object to another location indoor user's map is relocated on tabletop surface respectively. It is also easy to create multiple copies of a prop and place them on map swiftly. [29]

Figure 5: Indoor user has added a signpost to help outdoor user to navigate [29].

4.2.2 Magic Book

With the Magic Book system user is able to read real book like any other book. However, user is also able to view AR objects attached to book pages and fly into virtual world at the flick of a switch of a controller. Besides all of this user is able to collaborate with other readers - locally or remotely. Users are able to view virtual world from AR and full-virtual perspectives. Users have their personal views to virtual word which is one most important feature from the collaboration point of view. AR users are rendered in the sky as immersed users' avatars are placed on the surface. This way AR users won't disrupt immersed users from exploring the world. Users are able to share their experiences and have rich conversations during reading book and flying in the virtual world. Because the system uses bioccular display that is held in hand in front of user's eyes it is easy to remove the display in front of eyes simply by moving it. This way users can easily to switch back from virtual worlds and have discussion with each other. This way the viewing system is less obtrusive than head-mounted displays. Because users can swiftly jump between the worlds the Magic Book supports human-to-human collaboration without creating artificial barriers. System's interface is illustrated in Figure 6. [15, 27]

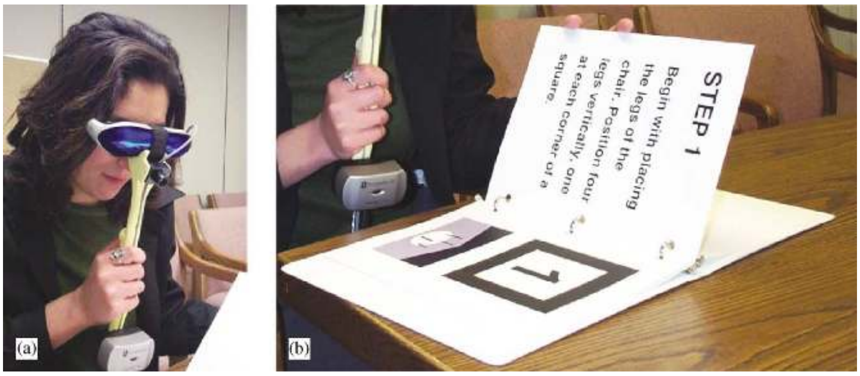


Figure 6: Main components of the MagicBook interface [27].

4.2.3 MapLens

Morrison et al. [30] developed a mobile AR application, called MapLens, targeted to mobile augmented reality. They created software that is capable of showing points of interest and user-generated content superimposed on paper map (see Figure 7). They used smartphone as primary platform for their applications. As technology advances also calculation power has increased in mobile phones. But in the beginning of the 2000s smartphones didn't have so much power than now. Also, development platforms were very elementary. However, the researchers were able to develop the MapLens. User is able to take digital photos and add them to certain physical location on map. Users are able to view the photos of each other by inspecting paper map with smartphone.

Morrison et al. [30] conducted two field studies with the MapLens. During these user studies teams competed with each other. Goal was to find hidden "treasures" from different locations in Helsinki city centre. A typical treasure hunt

Figure 7: User view to the MapLens [30].

game then. Tasks were related to natural sciences. Teams were equipped with smartphone, map, notebook and pen and other necessities required by tasks. There were also teams that possessed multiple phones instead of one. Players used the application to find game clues and view images taken by other contestants. Usage of MapLens was also compared to fully digital non-AR solution, called DigiMap.

Results of the study show that MapLens teams collaborated more than DigiMap teams. Members of AR teams were able to follow progress and discuss more effectively than in DigiMap teams because team members could see contents on screen and follow phone's physical location on paper map. DigiMap users suffered from not being able to share digital map as easily as AR users did since they didn't have copy of physical map. Because the DigiMap application didn't have integrated camera users had to switch between applications. AR users didn't have to make any switching since camera was already in use by MapLens. Also, moving digital map with phone's keyboard was harder than map-device combination since map or device could easily be moved in AR version. In addition, MapLens teams did more work as a team than DigiMap teams both in single device and multi-device teams. There were more discussion about underlying task in AR teams. Only true advantage of the digital version was that it enabled users to use application while walking. The AR version suffered from not being able to track map if user was walking, map was trembling in wind or map was folded by user. [30]

4.3 Analysis of the sample applications against characteristics

The Magic Book is able to represent shared data from personal viewpoint of each user. Same applies to the Hand Of God that is able to provide personal view to data. Because the map view depends on smartphone's physical location related to paper map also MapLens offered personal perspective to shared data. In these solutions individuality was achieved by using client-server architecture with regular databases but also by using custom structures like multiple cameras in Hand Of God or custom computation system in Magic Book.

MapLens, Magic Book and HOG lets users to have control of their independent viewpoints by moving device or physical map. Thus, these applications fulfil requirement of independence. Additionally, in the Hand Of God indoor user can move virtual map by gestures. They can also add physical props to table that outdoor user will see instantly.

All these applications are able to conform virtuality and augmentation requirements. However, they do so in very different ways. For the HOG a special hardware and environment was created with multitude of digital cameras. HOG also requires a special software to be able to transform almost anything into virtual model. Also Magic Book employs custom hardware and complex virtual content. It also employed ability to switch between reality, augmented reality and full virtual environment. The system augmented physical book marked with AR image markers. The HOG augmented outdoor user's point of view while navigating in city. MapLens added virtual content to physical map processed with regular touch-based mobile phone.

HOG presents a very sophisticated model for remote collaboration. The system uses fast realtime voice communication and thus it connects users. Also, usage of interfaces is very intuitive and fast since indoor user interacts with system with natural gestures and voice. Users are also able to communicate by placing props on special table indoors. Props can be almost anything from paper notes to scale model sign posts. Using the Magic Book users are able to view same page of same book instantly and share the story while interacting with virtual content. Users are able to see each other in all modes and thus being able to have quite normal face-to-face discussion. However, user is not able to use natural gestures since they have to hold special display system in their hand. In addition, user is only able to switch between worlds by pushing a button attached to display stick. Using the MapLens users view physical map with phone. Attendants in user studies [30] had rich collaboration around the map and the application. They also shared contents of screen and physical location of phone on map just by looking things side-to-side. Thus, users were able to follow discussion and share information even if a group of users had only one device.

Finally, seamlessness of interface is explored at least in some degree in all solutions. In HOG it is achieved with a custom backpack-PC combined with data glasses. MagicBook utilizes bioccular display with video camera attached on metal bar to provide hand-held viewing device for AR content. Both HOG and MagicBook use custom software to provide smooth transitions between real and virtual worlds. In MapLens seamlessness is a bit more limited than in the other solutions since it uses mobile phone platform. There are no data glasses that would make transitions even smoother. But the solution successfully provides AR content to users despite of this matter. From the software engineering point of view mobile phone is good platform to deploy AR solutions since using AR application doesn't require any additional hardware from end-users.

5 Practical exploration about collaborative augmented reality

The main motivation beyond this thesis is to research as well context-aware as collaboration applications. In order to explore this field three research questions have been formulated. To be able to provide at least directive answers to research questions a small literature review and practical experiment has been orchestrated.

This thesis has emphasis on the augmented reality technology. There are reasons that support this kind of choice: Augmented reality is tightly bound to context through object tracking. Thus, every augmented reality application is providing context information and has some level of context-awareness in itself. Another interesting topic is building augmented reality applications that provide context-sensitive information and support collaboration. Cooperation between users should be achieved without creating artificial barriers between computing system and user. With augmented reality these objectives should be achieved with minimal effort.

5.1 Research questions

In order to explore context-sensitive and collaborative augmented reality three research questions has been formulated. The main research questions are:

1. What purposes of use augmented reality could be used?
2. What kind of solutions are there for collaborative augmented reality applications based on mobile devices?
3. How software developer could solve the problem of two or more users having opposite/diverging user preferences by using the context sensitive augmented reality technology?
    - How this could be achieved without disabling collaboration between users?

The first question 1 is general by its nature but answering to it is necessary because answers provide significant information about the application area of augmented reality technology. A literature review has been done in order to answer to this question. The second question 2 narrows down the wild area of AR to theme of collaboration with mobile devices. Third question with sub question 3 focuses on human-to-human collaboration and preferences that users share when they operate on shared data locally or remotely.

5.2 Research methodology

In this research literature review, questionnaire and interview has been used as primary methods. Literature review has been focused on scientific articles and most relevant books about main themes. Websites has been used to complement information gained from more accurate and appropriate literature. In References every article or book is grouped by type of material to make it more readable. Goal for literature review has been to find out current status of AR and related technologies. Review has been done also to find out most recent research methods of scientific studies in related fields. The review is presented in Chapters 2, 3 and 4. Questionnaire and interview have been used as main components of small user study. They are explained in more detail in next sub chapters.

5.2.1 Questionnaire

Questionnaire is most applicable research method for basic studies like Master's Thesis. It is effective and fast. It is possible to have multiple questions for multiple themes in effective way. Survey can also be targeted to wide audience. It is easy to analyse results with computer if questions are carefully planned and clearly written. But survey has also downsides. There is no guarantee that respondents have answered to questions seriously and their answers are truthful. It is hard to design a good survey that could capture good answers. This means that researcher has no control to avoid misunderstandings. Also questions may be too general or specific which may lead to problems in analysis stage. [42]

Despite these disadvantages survey has been chosen to this thesis as one method to find out answers to research questions because of limited time. As part of this thesis author designed a questionnaire with different statements. There were eight questions altogether in questionnaire. Two of the questions was targeted to find out basic information like sex and age. Two consisted of four to five statements. Rest were simple multiple choice questions. There were none open-ended questions in questionnaire to minimize high risk of empty answers. Questionnaire was supposed to give information about user's previous and current experiences about augmented reality. Please read actual questionnaire in the Appendices for more detail. Questionnaire is written in Finnish.

5.2.2 Interview

According to Hirsjärvi et al. [42] interview is an appropriate choice for context that is not familiar for researcher. In addition, when it is desired to see respondents non-verbal expressions interview is a good choice. It is possible to ask further questions or clarifications for interviewee's answers during interview. Hirsjärvi et al. point out that participants get chance to involve with research and it is also possible to reach interviewee later if needed. They also state that interview has some disadvantages. Interviewee may experience a social pressure when answering and thus he may answer to questions like it is socially expected. Also interviewee may answer to wrong question to avoid answering questions that are being asked to represent himself as a good citizen or a person with high moral. It is interviewer's challenge to find out which answers are valid. Hirsjärvi et al. claim that time used for interview should be measured in hours rather than in minutes. They claim that in order to have successful interview it should last at least one hour. Interview lasting only half an hour could be replaced by questionnaire and results would be better. Interviews can be organized to individuals, pairs or groups. Interview can be structured, semi-structured or informal.

To provide more detailed information an interview was utilised as another tool to understand user's behaviour during experiment sessions. Interview was structured and designed around three main questions:

1. What are attendants' thoughts about context-sensitive software?
2. What are attendants' thoughts about augmented reality software?
3. What kind of feelings did attendant experience during use of prototype software?

The first question was supposed to give information about what ordinary people that may have no experience of context-aware software think about context-awareness in conceptual level. This question was explained by giving an example where users were able to view a restaurant listing web page related to their preferences and day of time: In the morning listing would provide information about restaurants that offer breakfast filtered according to each user's preferences. Same thing would happen when user views listing at noon to seek a good lunchroom or in the evening when user would prefer a good dining room.

The second question was formulated to find out general information about how users received simple test prototype of this experiment. The third question was addressed to reveal general information about user's feelings when they used test software during experiment. Since this area is not explored much it seemed to be a good idea to make a question about feelings.

All questions were explained in great detail. For instance question 1 was presented as prototype would be expanded towards context-awareness. Questions 2 and 3 were also connected to test application and current situation in order to be as tangible as possible and to get better answers. According to Jyrinki [43] users may have difficulties to present their thoughts if they are asked to imagine unknown things that may happen in future. Users can provide better answers the closer question is tied to user's own recent experiences. Please read actual questions in the Appendices for more detail. Questions are written in Finnish.

Goal of interview was to make sure most important questions would have reasonable amount of answers. If users had any questions they could ask them during the interview. Goal of observation was to capture information how users used prototype and what their facial expressions were during session. These goals were not revealed to attendants. Author acted as interviewer in the experiment. Because he took part of test sessions and provided help the experiment utilised as well *participating observation* as *interviews for pairs* methods. Despite the recommendation from literature interview was planned to take 10 minutes of time and answering to questionnaire five minutes. The entire experiment session was supposed to last only half an hour.

5.2.3 Recruitment of participants

The experiment of this thesis was mainly advertised in Facebook. Information was also shared as a flier that was shared in Turku city centre. Author also met a lot of people in campus area and told about experiment. Fliers were also shared to these people. Author also asked his friends, family members and other acquaintances to join. The only prerequisite for attending was that a participant should be able to use regular touch-based mobile device. Recruitment lasted two weeks before planned time of experiments. Idea was to get 10 to 20 persons to join.

To give general information about augmented reality primary material was created. All enrolled participants received a slide show by email. In the preliminary material characteristics of the augmented reality concept was explained in common, non-technical language. Goal was to give required information for all participants to guarantee they would be able to answer the planned questions. In this material it was explained what AR is and how it is currently used. Perspective was in mobile applications since test prototype was utilising mobile device platform. Moreover, mobile devices are familiar for most of the people. It was also explained how AR differs from reality and how virtual content can be viewed. Also role of marker image in AR technology was explained because it has important role in augmented reality. Another goal was to demonstrate with image marker for all attendants that AR is tightly connected to reality through image markers. In slide show there was given some typical application areas based on scientific literature. As part of preliminary material the goal and methods of experiment were explained. Also responsible person and exact place for experiment were mentioned. Material consisted of text and self-explanatory images freely available from Internet. Material was written in Finnish since all participants were Finnish. It is included in Appendices of this thesis.

5.3 Experiment

In order to answer research questions an experiment was planned and executed. Ordinary people was considered as target audience for this experiment. The goal for experiment was to introduce augmented reality to people who may or may not have any technical background. Another goal was to monitor how participants used related application prototype and third goal was to find out how related software prototype supported face-to-face collaboration.

5.3.1 Test scenario

The experiment consisted of two parts. In the first part two attendants used a prototype software in a very simple fictitious scenario. In the beginning of test session users were demonstrated main functionalities of the prototype. This took about five minutes on average. After this imaginary scenario was revealed to attendants both in spoken and literal form:

"You work at an advertising company that has personnel of total 10 persons. You primarily work in pairs and you meet your colleague daily in pair meetings. Now a chocolate manufacturer has asked your company to develop a wrapper for their newest chocolate product, a chocolate bar. The product is targeted for consumers that are under 40 years old. Wrapper of chocolate product should be attractive but practical in use.

You and your pair have now a meeting about important features that wrapper should have according to you.

Now I ask you to create at least one note each by using the prototype application. You could write something about your ideas about this assignment to note. You could also make list of features that wrapper should have. It is also possible to write some question to other pairs."

In other words attendants were asked to write down any thoughts they had about new package. They used prototype software to create notes. As part of this task participants were encouraged to collaborate with their pair. Interviewer acted as an instructor for experiment and his role was to give guidance if any technical issues occurred. Interviewer read aloud the scenario description to participants. Users were given 10 minutes for this small task and after that interviewer asked the open-ended questions. In the end of each session participants were asked to fill in questionnaire statements. Voluntary nature of the experiment was underlined to attendants in every phase. The middle phase where users were asked open-ended questions was recorded in all sessions. Permission to record was asked from each attendant verbally.

5.3.2 Test room and used devices

Experiment took place in a small room sized for from four to six people. Environment situated in University of Turku at the Department of Future technologies. Please see Figure 8 about experiment environment. This kind of space was chosen because it guaranteed a peaceful environment to carry out the scenario. Room also provided isolated space where participants would be able to express their thoughts freely without being heard by outsiders.

Significance of technical specifications of test devices was not important. Idea was to use any available devices targeted for consumers. Devices used during experiment sessions are listed in Table 5. Nexus 9 tablet PC saw its end after serving first two sessions and it was replaced by LG K10 smartphone.

The experiment used image target as augmented reality tracking method. Marker-based approach was used due to its simplicity and its availability in all commercial augmented reality libraries. Henrysson and Ollila [24] argues one benefit of image marker is that it clearly indicates location of virtual content. According to Rekimoto et al. (as cited in Olsson and Salo [16]) point out that marker should

Figure 8: Room used for experiment.

Test device	Specifications
HTC Nexus 9	Processor: 64-bit NVIDIA Tegra K1 Dual Denver 2,3 GHz, RAM: 2 GB, display: QXGA 1 536 x 2 048, camera: 8 MP, autofocus, BSI-cell, f/2.4, 1080p video, Operating system: Android 5.0
Huawei M2-A01L	Processor: Hisilicon Kirin 930, Quad 2.0GHz + Quad 1.5GHz, RAM: 2 GB, display: 1920X1200 FHD, camera: 13MP, auto-focus, F2.0, 1080p-video, Operating system: Android 5.1
LG K10 K420N	Processor: Quad-core 1.2 GHz Cortex-A53, RAM: 1.5 GB, display: 720 x 1280, camera: 13 MP, f/2.2, auto-focus, 1080p video, Operating system: Android 5.1.1

Table 5: Devices used in experiment.

not be totally replaced by markerless methods even if it would be technically possible. They have discovered that marker helps user to identify virtual content from the rest of the environment. The Vuforia Unity extension library supports image tracking as main tracking method. Thus, this approach was chosen. In addition, non-technically oriented user would probably be able to understand experiment better while he would be viewing a tangible object through mobile device screen. Image target was attached to cardboard stand in order to make it appear clearly and give some room for table.

5.4 Test application

With the test application user is able to create, delete and update his own virtual notes on virtual desktop. Users are able to see their own private notes and ones published by other users. However, content is not actually made available for the general public outside the system. Notes can be arranged manually by each user. Idea of application is to support human-to-human collaboration so that all collaborators are present in same room. With application they can make notes as part of their work and have also rich face-to-face conversation. Application is designed for mobile devices like smartphone or tablet PC that have integrated camera and touch screen.

5.4.1 Architectural overview of the prototype

Test application consists of client and server applications. Server application is basically a set of web services that provide information about notes and users. Client application consists of AR tracking, rendering and touch-screen interaction functionality. Figure 9 illustrates main functionalities of test application.

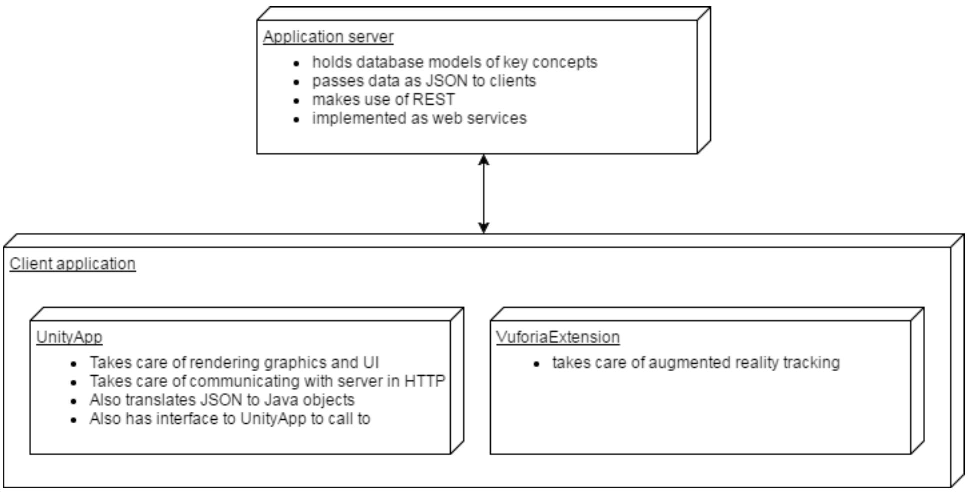


Figure 9: Deployment diagram of test application.

Key concepts of this application are Note and User. Class of User holds user-related information like user name, created content, authentication and authorization. Note class holds data about:

- title
- description
- User who has created Note

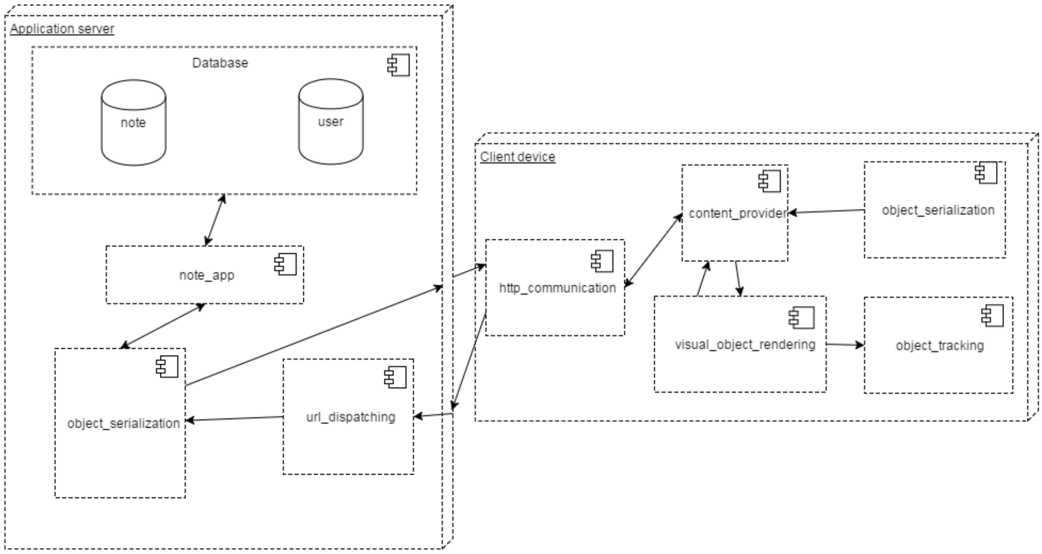


Figure 10: Overview to test application. Arrows represent typical data flows.

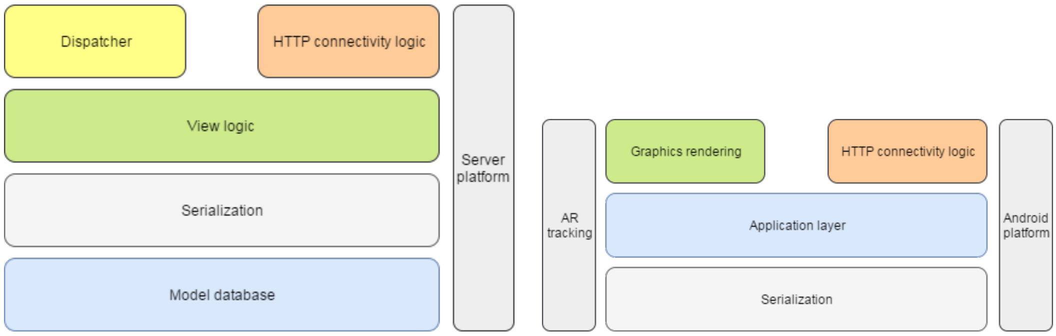
- sharing mode, private or public

Title and description can be used as user wishes. It is possible to create two similar notes that have identical title and description. Each Note has information about its owner and sharing mode. If Note has sharing mode set to "private" only its owner is able to see and modify it. If Note is tagged as "public" all system users are able to view it but not modify.

Figure 10 shows overall structure of test application. Both server and client applications make use of Model View Controller design pattern that is almost standard way to build interactive applications. Server contains dispatcher that is responsible for routing HTTP requests correctly to views.

5.4.2 Implementation

Test application has been implemented with several frameworks that offer significant benefits over custom framework. Server-side application has been designed to make use of the Django framework [50] that is general purpose web development framework. Web services have been implemented with the Django REST Framework [51] that is fully compatible with Django. It also conforms the Representational State Transfer architectural pattern. With the browsable Application Programming Interface feature developer of other web services or applications can examine web service API by Internet browser. This relieves need for using command line interfaces. Client application is build upon the Unity game engine and library [52]. Unity was chosen because it offers solid ground



(a) Server viewpoint. (b) Client viewpoint.

Figure 11: Main layers of test application.

for building 3D applications. The Vuforia library [53] was used that provides augmented reality extension to Unity. This way using AR in application would be as easy as possible.

The server application has different architectural layers (Figure 11a). This is mostly achieved by following Django framework's API guides. Also the Django REST Framework makes heavy use of Django's class-based views and serialization but it also provides a powerful way to control serialization in great detail. For each model there exist one serializer class that has instructions of serialization process. Since both frameworks have internal implementations of HTTP communications developer does not need to build own structures to handle communications. This gives developer time to focus other more relevant matters. Since the prototype application has authentication and authorization features all communication is performed using HTTPS protocol. This means that hosting server has to implement SSL certificate and maintain it. For this purpose the Heroku Platform was used. For more information about Heroku please see [54].

Server application makes use of generic class-based views that provide a way to reuse view functionality. This makes development relatively easy and rapid because in web development views almost always have basic Create Read Update Delete (CRUD) functionality set. Serialization takes care of transforming data from objects to JavaScript Object Notation format and back. Django REST Framework maps serialized data to Django models which simplifies model code greatly. All important concepts are represented as Django models that encapsulate characteristics of the key concepts. Django provides a way to reuse application functionality by creating distinct application structures. This way applications are reusable with limited amount of overlapping program code.

Web service application provides information about each user and Notes taken by users. Service holds information about Django models that basically are Python classes. Django has its own database that is implemented with SQLite.

Web service requires all users to be authenticated when retrieving data. Server application responds to valid HTTP request and passes data as JavaScript Object Notation (JSON) format. When user requests authorized information server application fetches information from database and serializes it from Python object format to JSON text format.

The client application has slightly different layers (Figure 11b). Unity has its own classes for HTTP communication. These classes are designed to represent needs of game developers. Thus HTTP classes are also able to transform entire Unity GameObjects into JSON. Unity GameObjects represent graphical and functional instances in any Unity application [52]. They are derived from C# Object class. All Notes, background, HTTP communication and dynamic storage objects are represented as GameObjects. Capability to serialize entire GameObjects was not used because the web server applications did not support it.

Client application takes care of de-serialization of JSON data to usable format. It also takes care of rendering virtual environment and augmented reality related tracking. Client does not have any specific database to temporarily store retrieved and possible modified data. The application is implemented in C# that is the main language of the Unity game engine.

Augmented reality tracking was implemented by using the Vuforia library Unity extension. It makes use of computer-vision based tracking (see Chapter 3.4) that seems to be major tracking method in commercial AR products according to Mixed Reality group at University of Turku [55]. Original idea was to make use of wall-sized virtual desktop but because image tracking has its limitations this was not possible. Problem with wall-sized image is that computer vision-based tracking is dependent of clear detail-rich marker that is very expensive to produce at wall-size scale. Vuforia has also more basic limitations that computer-vision based tracking methods have (see Chapter 3.4). Vuforia offers also model-based tracking but it was considered to not to be applicable in this case. Other tracking methods do exist but they are rarely implemented in commercial products like Vuforia [55].

5.4.3 Main features of the prototype

When software starts it arranges notes from the upper left corner of virtual desktop towards right side. System arranges notes to multiple rows if necessary. Test application consists of virtual environment and graphical objects, named

Notes (Figure 12). Notes are overlaid of the desktop that is in turn overlaid on top of image target. All items in the environment are effectively geometrical planes.

Figure 12: Main view of test application. Virtual environment is overlaid on image target.

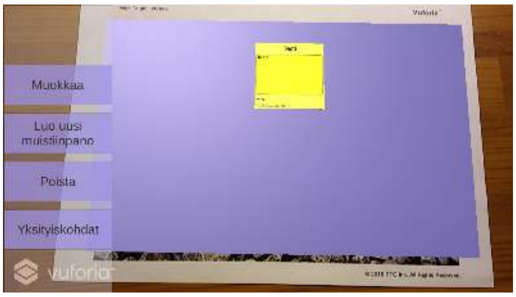
User is able to review and create Notes, that represent traditional notepad. In Detail view (Figure 13a) user can inspect details of any Note that user is authorized to see. In Edit view (Figure 13b) user can specify Note's title, description and whether a Note is private or public.

(a) Detail view. (b) Edit view.

Figure 13: Detail and edit views of application.

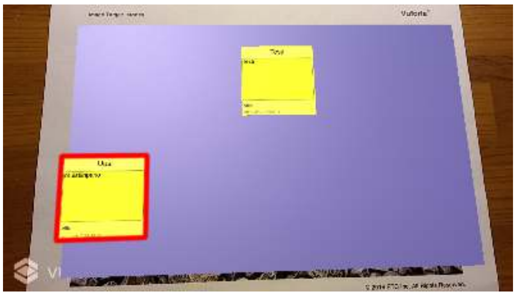
When user wants to create or edit Note they have to tap any existing Note twice to open main menu (Figure 14a). Contents of menu are determined based on user's rights. If user has created the selected Note he is able to do any CRUD operation to it. Else user is only able to view details of selected Note. Thus, menu is basically context aware. If there are none Notes on desktop user sees main menu on left side of screen.

After viewing the main menu user might create new Note like in Figure 14b. As soon as user pushes the "Save" button new Note will appear in lower left corner of virtual desktop (Figure 14c). If some other user either creates or edits Note it will appear on lower right corner (Figure 14d). As it can be seen from figures all created Notes will cumulate onto virtual desktop.

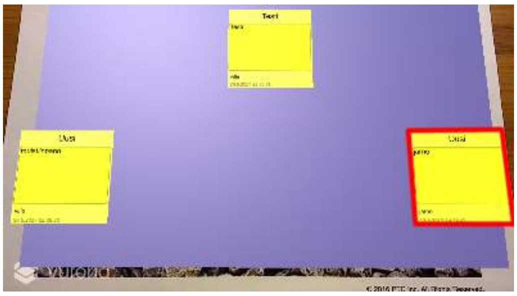


(a) Main menu.

(b) Edit view.



(c) After user has created Note it will appear in lower left corner. New Note is marked with red borders just for demonstrative purposes.



(d) After some other user has edited or created Note it will appear in lower right corner. New Note is marked with red borders just for demonstrative purposes.

Figure 14: Work flow with the application.

6 Experiment results

As part of the experiment participants answered to both open-ended questions and to questionnaire. Open-ended questions were analysed by summarising most common themes based on notes and audio records. Questionnaire was produced with the Webropol survey tool [56].

There were total of ten participants in the described experiment which was orchestrated at week 20 in May 2017. Participants were grouped into five distinct pairs. Only rule for forming pairs was attendants' own wishes about date and time to participate. Only two pairs of five knew each other before the experiment. There were five females and five men. All participants were over 12 years old and under 45 years old. Most of them (5 of 10) were between 25 and 34 years old.

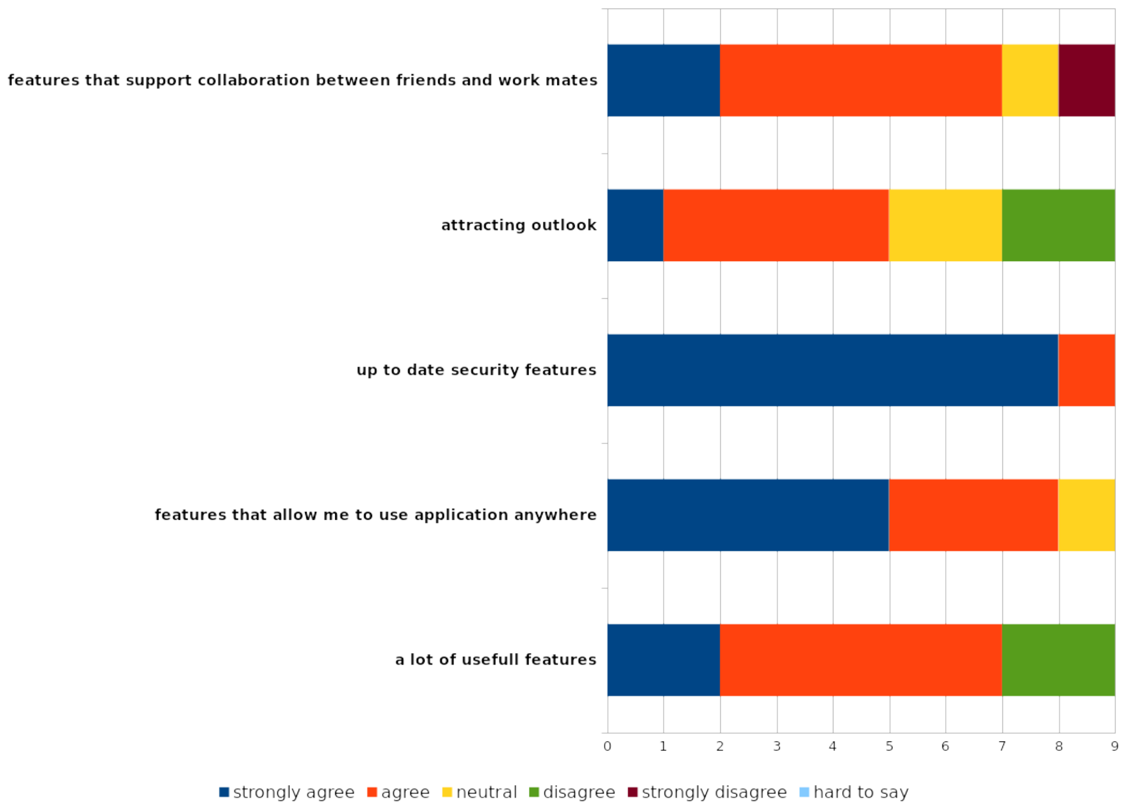


Figure 15: Answers to statement *"For me its important that the mobile applications I use have..."*.

6.1 Questionnaire

There were nine answers to the questionnaire. Surprisingly none of respondents were familiar with the concept "augmented reality" before taking part to the experiment. From Figure 15, it can be seen that seven respondents of nine agreed or fully agreed on opinion that mobile applications must have lot of useful features. Eight respondents also agreed or fully agreed opinion that mobile applications must support usage anywhere. All respondents wanted to use application that have security features up to date. Only one respondent fully agreed that mobile application has to have appealing outlook. Four agreed, two had neutral opinion and to disagreed this statement. There were total of seven people who fully agreed or agreed that mobile application must have support for communicating with friends and colleagues.

Figure 16 illustrates statements about ease of use of the prototype. Overall six respondents had opinion that the prototype application was relatively easy to use. Only two participants stated that using the application was relatively hard. One user argued that the software was very easy to use. It was also asked about how attendants conceived the operating principles of the test application. Three participants stated that software was very easy to comprehend. Four of nine answered that it was relatively easy to understand functional principles of the prototype. Only two persons had opinion that the software was relatively hard to understand during 10 minutes test session.

There were statements about support for communication and collaboration. In the questionnaire these two terms were used as substitutes. As the Figure 17 illustrates seven out of nine respondents stated that the prototype was able to support communication between two users. Two attendants disagreed on this. Most attendants stated that the used prototype was able to provide something new to face-to-face collaboration they had not experienced before. One agreed fully and six just agreed. Two participants disagreed. The statement *the application improved the quality of collaboration between attendants* received the following answers: three attendants agreed, three disagreed and three had neural opinion.

6.2 Open-ended questions

All participants were really active to provide answers to presented questions. If some attendant didn't understand question they asked additional information to be able to answer.

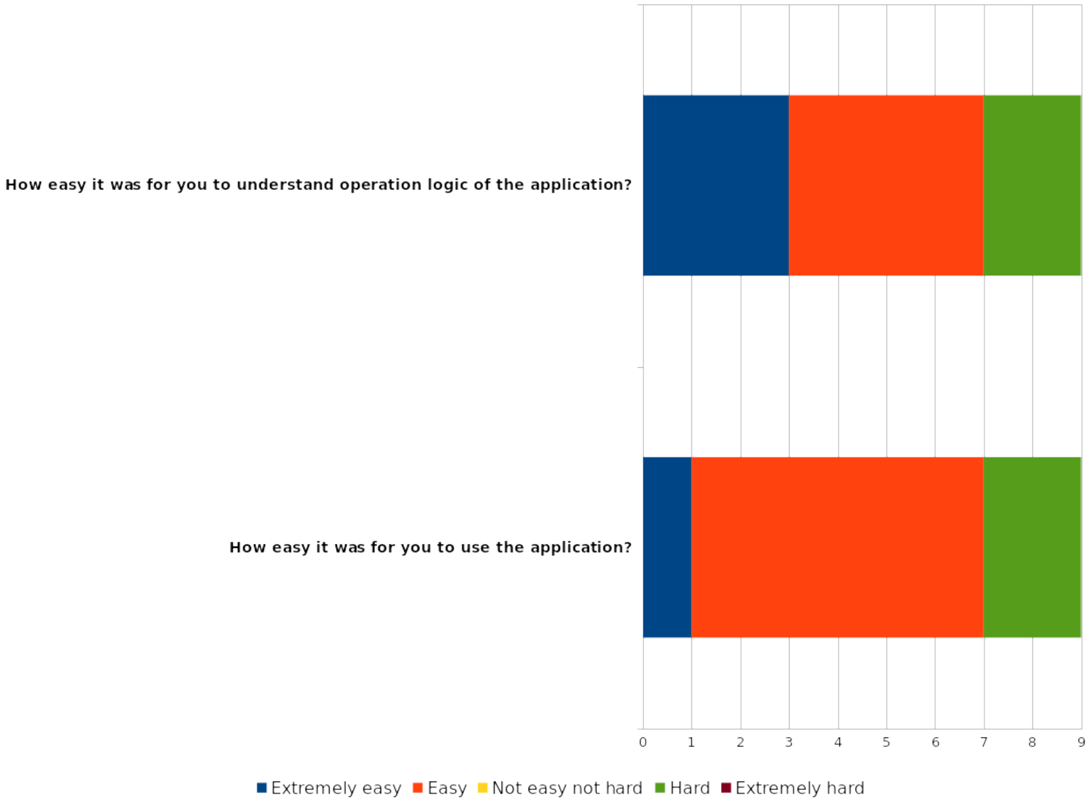


Figure 16: Questions about ease of use.

6.2.1 What were attendants' thoughts about context-sensitive software?

When asked about context-aware software most participants saw them to be interesting. They saw that context-aware software would be nice to use because preference learning features would make application easy to use. If software would be able to learn user's preferences it would relieve user from configuration tasks and also satisfy user's informational needs. Some users argued that context-aware applications could increase performance of individual. For example, learning user's travelling paths context-aware system would be able to suggest more effective paths for individual.

Some participants pointed out that currently existing services provide lots of information that users do not need at all. Some participants worried if this redundant information was likely to increase with context-aware applications. Some attendants immediately thought the opposite: One participant pointed out that with context-awareness there is high risk of user not being able to view information outside of one's preferences. If user would like to have new information about something interesting that is unusual for him it could be very hard to get that kind of information.

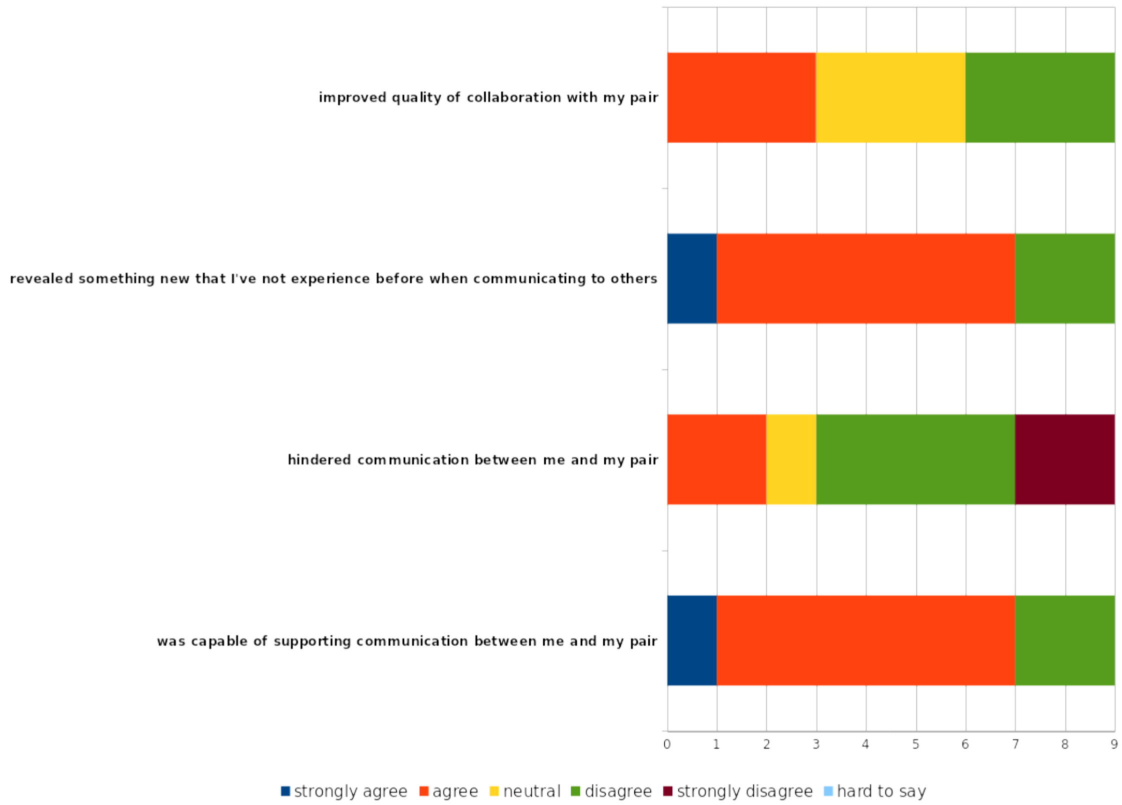


Figure 17: Answers to statements that began with *"The application that I just tested..."*.

Some interviewees were also worried if context-aware systems would be able to track user constantly and continuously. These participants found this kind of behaviour very disrupting if they would not be able to control it. Also, source of provided information was important to some participants. They were worried if provided information would be biased somehow by some external factor: one participant raised a question *"If information is sponsored by some company does it mean it is considered to be necessary and relevant by end-user?"*.

6.2.2 What were attendants' thoughts about augmented reality software?

According to questionnaire results in Chapter 6.1 none of participants had used any augmented reality application before participating to the experiment. This was supported by the answers of open-ended questions. There were two respondents that clearly had some technical background or they were interested in information technology in general. They were able to compare their current situation at work to the prototype application. One of them had opinion that if prototype was developed further it would provide useful environment to data visualization compared to current available methods. This particular interviewee currently uses screen-shots that has to be overlaid with explanatory drawings or highlighting. Then he sends screen-shots with some commercial instant messaging application.

Some participants pointed out that augmented reality application like the prototype would be able to provide a relatively large amount of information among users. They had opinion that AR applications could easily provide more information than physical object could ever do. Some participants saw augmented reality as a way to customize applications to satisfy different needs.

Augmented reality was unknown technology for most interviewees. Although participants were suggesting different general application areas they had hard time to come up with practical applications that *they would need* in their everyday life. Also viewing image target with mobile device was found very disrupting. Participants were used to have access to necessary information regardless of the location. Thus viewing image marker with mobile phone was considered to be very old fashioned and impractical. At least three attendants pointed out that in order to use the prototype users would need to carry the image target with them. One participant had opinion that AR applications in general would disrupt communicating and collaborating with other people because either mobile device or AR goggles had to be carried along.

6.2.3 What kind of feelings did attendants experience when using the prototype?

Some participants experienced *bewilderment* during test session. They explained that feeling of bewilderment was due to unfamiliarity of the augmented reality concept. Two pairs *suspected* their own ability to use the prototype software. Users described that they had this feeling before they used the actual prototype. After using the test application these same participants experienced *feeling of success* and they were really *confident* of using software. This is somewhat remarkable because attendants were not be able to familiarize themselves with the application before experiment session.

At least three pairs stated that the experiment and the prototype evoked *feeling of curiosity* in them. These attendants were enthusiastic to know what kind of experiment this was and what it required from participants. So some answers were mixed with similar question 'What did you think about the experiment?'

although it was not asked. One attendant said that he felt *frustration* because the prototype did not work fluently and mobile device suffered graphical lag. Participant used his own mobile device because one of the test devices was broken. Performance issues caused misbehaviour because system did not respond to every touch input user made.

Participants felt that although prototype was really simple and immature it provided functionality that supports distributed co-operation. Although users have slightly different viewpoints to data they would be able to share also similar viewpoint. This was highlighted by one attendant that had some technical background. This feature evoked experience of *surprise* according to two pairs. These attendants explained they were surprised the way system allowed them to communicate in virtual environment. One participant stated that communication by using mere Notes was an interesting option. He argued that communication through virtual environment by writing notes would be possible with remote connections too.

6.3 Perceptions about experiment

Presented points are result from observing attendants while they did the assignment. These points are purely qualitative since it was not possible to measure any part of behaviour by using some gauge under prevailing conditions.

Attendants created total of 16 Notes to virtual desktop. All users were able to produce at least one Note which was the goal of given task. All pairs tested switching sharing mode from "public" to "private" or vice versa with at least one Note. This was encouraged by instructor to demonstrate primitive context-awareness of system.

The way how attendants used given prototype reminded author of previously experienced usage patterns of smartphones: During experiment sessions all users spent most of their time to look at mobile device's screen. Some were able to communicate with their pair as expected but some were more focused on using application. There were two pairs who actively compared their views of devices. Others shared information through virtual environment. No device sharing occurred. However, all participants were able to give ideas to given task and also produce content to system. Some were even able to give assistance to their partner when they encountered technical problems or did not know how to use certain feature. All pairs shared given task and related ideas to their team mate.

Attendants were interested in augmented reality and context-awareness at conceptual level. They saw plenty of valuable uses of presented prototype and some were interested to have it in real working-life related scenarios. Everyone had opinion that presented augmented reality application was still immature: It lacked appealing outlook, video feed had disrupting lag, moving virtual objects was considered to be hard and application's data synchronization was thought to be slow. All attendants had opinion that prototype has to be developed further to better fulfil user's expectations.

Below is list of all application areas that attendants came up with. It's worth noting that participants were not asked to provide any list during the experiment.

- accident situations
- daily reporting at work
- tracking individual's location
- product and building design and construction
- note taking tool in meetings
- personal tourist guide
- personal travelling assistant
- entertainment for kids

In summary, all participants were really eager to take part to experiment although none had been used any augmented reality application. Nevertheless, users were able to give good answers to questions and provide relevant information about usage of prototype and feelings that usage evoked. None of attendants refused to take the simple task and empathize as the assignment required. Some pairs discussed more lively than others but all five pairs had relevant discussion related to given task.

7 Discussion

In this chapter main results of the research are discussed and validated against relevant literature related to collaborative context-sensitive augmented reality applications.

7.1 User study

The user study revealed a lot of information about how attendants received the test application. It also revealed data about participants' opinions about context-awareness and augmented reality as general concepts. Some attendants were also able to elaborate possible uses for context-awareness and augmented reality with help of the presented prototype and detailed description of those concepts. Interviewer used examples to describe some possible uses for context-awareness and augmented reality based on literature review (cf. Chapters 2.2). In order to make experience more tangible preliminary material was sent to all attendants. Some users reported that it helped them to understand definition of AR and its possible use cases. Still some attendants were not able to figure out how they could benefit of AR in their everyday life. During interview the information that was presented in pre-material was repeated verbally. Thus, first goal to introduce augmented reality to participants was achieved.

Another goal for the user study was to monitor how participants used or received given prototype application. Information about this was acquired by observation and inspection of user-created content. There was not any gauge used to evaluate content because goal was more to explore than to test some predefined hypothesis. Idea was to see what things would be uncovered by the small experiment.

Generally attendants had positive attitude towards the prototype application. They were interested about its functionality and capabilities as well as about the entire experiment. One participant was really interested in seeing this kind of early stage project. Some attendants had suspected their abilities to operate prototype software before they took part. But after having tried the application they felt more confident or even surprised of their own capabilities to interact with application.

From the answers to the questionnaire it can be concluded that most participants thought that prototype was quite easy to use. There were some technical problems that may have influenced the feel of ease. Olsson and Salo [16] had similar results related to ease of use when they enquired users of commercial AR browser or AR image recognition applications. They used statement *"Learning to operate the application is easy for me"*. According to the report users experienced usage of the AR application to be relatively easy on average. It's worth noting that in the research of Olsson and Salo users were evaluated to be early adopters and experienced augmented reality application users.

Third goal was to find out how participants evaluated prototype's capability to support face-to-face collaboration. It wasn't easy to measure this aspect since research papers about user studies related to the field of collaborative augmented reality are very rare. In addition, research articles that describe entire question sets used are extremely rare, virtually non-existent. However, Morrison et al. [30] tried to measure and describe collaborative use of augmented reality on mobile phones. Similar user studies have been performed in Olsson and Salo [16], Arhippainen and Tähti [32] and Olsson et al. [33]. Although being very representative research articles they fail to provide enough details about performed user study and about exact question sets. Since there isn't any better material for this purpose these articles are used as ground point for evaluation results of the experiment.

Participants mostly supported the statement *"The application that I just tested was capable of supporting communication between me and my pair"*. Also, most attendants had the opinion that the prototype didn't hinder communication between members of each pair. Statement about quality of collaboration was not very successful since respondents got to use their own perceptions about quality. Maybe some reference examples would have been necessary to capture more information about quality.

Morrison et al. [30] measured collaboration level in their user study by observing turn-taking, team placemaking, how well team build common ground to their working and device and task sharing. The main details of their research is presented in Chapter 4.2.3. Researchers concluded that users shared their devices only in teams that had only one device. In multi-device teams sharing was not needed in order to take underlying tasks. Instead, team members worked more in teams than as individuals by using one device as main device and others as supplementary info sources.

The conducted experiment confirms these observations: Users did not need to share device because they both had own device to interact with. Users got to see virtual desktop with their own device and follow the progress. Task sharing was common in the experiment: each pair shared information and ideas of underlying task. They also shared content through to virtual environment. Some were even able to help their counterpart. Attendants shared information through to virtual environment but also verbally. In Morrison et al. [30] users shared more information verbally and with gestures when they had to share mobile device. Among the multi-device team sharing users shared more through virtual system. Comparing to Morrison et al. [30] these results are well in line with the experiment.

Morrison et al. [30] conclude that augmented reality on mobile phones offers a natural platform for collaboration. Researchers noted that AR teams had more versatile conversations and more collaborative activity than non-AR teams. Members of AR teams were more able to follow progress than in teams who had fully digital version of the application. In addition, using the application was significantly easier and more effective than with digital version. Morrison et al. [30] believe that collaboration level was mainly dictated by personalities of attendants than amount of available devices although they didn't prove it. In the test setting of this thesis only few participants had versatile discussions during test session. Some were only able to focus on the application and it's usage. These attendants remained silent as they performed. This variation in ability to cooperate may have been caused by given task or personalities of test subjects. Also, technical problems may have caused low level of collaboration.

The prototype was capable to bring something new to collaboration that attendants had never experienced before. This is probably due to fact that augmented reality was new thing to all participants. So in this context maybe the question about this matter was naive. However, it was big surprise that none of attendants had ever used any AR application before. This must be result of the fact that augmented reality is immature technology that still seeks its place.

There were three attendants that questioned need for context-aware application and augmented reality applications. Attendants had the opinion that AR requires them to carry along either mobile device or AR glasses. And they were no very enthusiastic to do so. One participant had also opinion that using AR applications could hinder her from collaborating with others. Applications could prevent user from observing surrounding environment. The participant also provided reasons for her opinion: She described herself as non-technical person who isn't familiar with technology in general. Thus, using any software would take more attention than she would like in social situations.

Olsson et al. [33] had similar results in their user study that indicated some attendants didn't want to carry mobile device all the time. However, researchers also mentioned user statements that indicated positive attitude towards data glasses. They were seen as most suitable method for interacting AR systems during long-lasting sessions. Respondents saw data glasses as useful interface to AR systems.

According to Olsson et al. [33] user's had high expectations towards augmented reality applications. Participants expected them to be able to provide always-relevant and valid information according to each situation. Users expected these applications also to be able to surprise them with some positively new information in similar fashion than some video games present new data to players. Respondents also stated that AR systems should be easy and intuitive to use. The user study of this thesis was also able to confirm that users expect applications to be easy to use. Most attendants emphasized ease of use since they presented themselves as non-technical people who do not easily want to learn complex applications. One participant had opinion that usage of mobile device should not be anything else than tapping and touching. He stated that users are so used to these functions that they cannot imagine any other interaction techniques.

In this user study attendants expressed their thoughts about contex-awareness at conceptual level. Results from the test setting were very similar than in Olsson et al. [33]: Most attendants saw context-awareness as interesting and useful field. It could help them to get relevant information but also to get rid of time-consuming configuration of devices. Context-aware applications were seen as possible time savers that may give user time to focus on more important tasks. There were also some worries about privacy and inability to see unusual and surprising information expressed. Some were also restless about chances that context-aware system would offer totally useless or even biased information. Attendants were also uneasy about inability to control data collection. Some stated that they do no want to be under surveillance by such system all the time.

Additionally, users in study Olsson et al. [33] also argued that context-aware AR system would need to have explicit user control and privacy management. User were concerned about what information could be collected and where the data would be stored. They were also concerned about who is able to see their personal AR content and how public is interaction with such system. Olsson et al. found out that users would like to have the system under their total control. Users also stated that they were worried about information leaks. Participants expressed their worries about validity of information in case where data changes frequently (e.g. daily lunch menus and temporary offers). Attendants were questioning user generated content instead of official institutions.

Emotions of users are not researched in great detail in related literature. They are mostly ignored and defeated by more technical approaches. The test setting revealed some emotions users experienced while using the prototype. Mostly mentioned feeling was interest or curiosity about the experiment itself and about the AR application. For some participants it was interesting to watch progress of virtual desktop while other user was adding or modifying notes. Use of the application and invitation to the experiment also invoked suspicion of user's own abilities to perform. Augmented reality and technical issues of software evoked bewilderment or frustration in some users. They didn't realize how AR works or what they should do with the application while exercising the assignment. This could be explained that AR was new concept to all users and with the fact that users only had very limited amount of time to act. Maybe more related image marker that would have hinted the theme of the application to users would have lessened level of bewilderment. There was also feeling of surprise mentioned by users. They were positively surprised how virtual content was viewed by using just image and mobile device. Some were also surprised about the possibility of sharing. One participant was astonished how effortlessly notes were shared to other users.

7.2 Revisiting the research questions

Main motivation beyond the research questions was to get familiar with the augmented reality technology and study implementation of such application. In addition, research about context-awareness seemed to be good investment for future. The research questions presented in Chapter 5 will have to answered. Questions were quite laborious since there are information about basics but not very much about the problem of shared resources.

1. What purposes of use augmented reality could be used?

In Chapter 3 augmented reality was defined. There was also a short presentation about the technologies that *enable* augmented reality as practical application instead of being just theory. These technologies are very important since without them augmented reality could not exist in practice. Main reason for this research question was to review augmented technology from technological point of view but also from practical point of view. Understanding of basic concepts of Augmented Reality and developed AR applications is necessary to be able answer to the other research questions.

There are plenty of research papers about different applications that have been studied from AR point of view. This thesis brought out just some of them. There are some very popular applications like Pokemon GO, Layar and Google Goggles. Unfortunately there aren't any scientific evaluations about them or any commercial AR applications in general. The most appropriate evaluations have been published about applications that have been build to serve one or more research projects. This means that these applications may not have been released as products for ordinary consumers. Thus, they aren't available for public audience.

An answer to the research question is that augmented reality exists almost in any field that could be imagined and that offers some kind of business opportunities. There exist AR applications for custom hardware and also for commercial mobile devices. General application areas and some collaborative AR applications have been presented in Chapters 3.6 and 4.2.

As a final note, it is interesting to contemplate about range of AR applicability. Derived from results of the experiment some users stated that the prototype was not usable in mobile contexts. They had the opinion that generally image marker is not practical solution. High-educated early adopters and also non-technical consumers do know AR as technology and they are very interested to use it. Users have high expectations towards AR applications since they desire features like context-awareness spiced with proactivity. Usage of AR application should be easy, intuitive, secure and natural for users. These are not trivial tasks to achieve in practical applications. Although there are many applications augmented reality is still considered to be immature and most applications are seen as "pseudo-AR" [16]. In addition, enabling technologies are also immature. This came out clearly in the experiment as the prototype application suffered from technical issues like image jitter and slow updating of video stream. Forsman [45] argues that video camera quality has also its effect on tracking problems.

To sum up, as augmented reality is a visualization technology it could be utilized in any project where visualization is needed. But, as mentioned in Chapter 3.7 there are lot of challenges virtually in all enabling technology fields. These obstacles have hindered AR from being used in everyday situations and in large scale industry.

2. What kind of solutions are there for collaborative augmented reality applications based on mobile devices?

Collaborative augmented reality investigates how AR could be applied to support human-to-human communication and collaboration. It also studies ways AR applications could be developed to optimize support for collaboration. As stated in Chapter 4 an artificial barrier exists between computing systems and humans. This leads to issues that won't allow merging virtual content to reality. In remote meetings merging physical space into digital space is very hard. Also, inspecting shared data from personal perspective may be totally impossible without any assistive technology. During the experiment one participant admitted having significant trouble in sharing information in working environment. He also saw the presented prototype as could-be solution to his problem. Although this thesis is just one sample it could be stated that AR can solve collaborative problems.

In Chapter 4.2 there have been presented some very representative samples of collaborative augmented reality applications. Most of them have been implemented with custom hardware to address specific scientific issues. However, they are good samples since they possess vision what kind support AR could offer. Also user study by Morrison et al. [30] offered a solid information about user's experiences while they used the application. There are six characteristics proposed that collaborative mobile applications should have: virtuality, augmentation, co-operation, independence and individuality and seamless nature of AR interfaces. By applying these features application should offer a good starting point for collaborative use. This conclusion is based on the literature review and performed user study.

3. How software developer could solve the problem of two or more users having opposite/diverging user preferences by using the context sensitive augmented reality technology?

Problem of shared resource (see Chapter 1.1) is related to asset that may be a physical object or environment. There has been research about physical shared resources like information displays [34] and smart houses [35]. The problem of shared resource is tightly connected to smart environments that are able to detect their users and offer services according to user's specific needs or preferences.

There are lot of resources that are not easily to be shared according to users' different needs. When two or more users have colliding or conflicting preferences context-aware system has to resolve conflict. E.g. when one user wants to listen country music and other wants to listen rock music there is conflict.

From a technical point of view there is need to have services that can share resources. If resource is related to some object like lighting system it may not be easily shared in conflicting situation. If resource is related to software then it may be shared in certain degree. Client-server architecture plays critical role from technical point of view. By combining this type of architecture with layered architecture it is possible to offer very different services derived from some main service. With client-server architecture it is possible to take user's preferences into account. All presented samples from literature and the prototype used client-server and layered architectures. However, this is just a partial solution. Since users are human beings use of some service is tightly related to social and psychological aspects.

Users have high expectations towards context-aware systems. Users desire proactive features that offer relevant information based on user's preferences. Systems would need to be able to offer positively surprising information like recommendations. Users expect these systems be able to adapt to constantly changing needs of themselves. As the attendants of the experiment stated context-aware systems need to be easy to use. They need to have intuitive interfaces that users can use naturally while interacting with their environment.

However, there are certain user-related problems when dealing with information systems. According to Olsson and Salo [16] users are worried about information flood in augmented reality systems. Users are also worried about their ability to have full control over data about themselves [16]. Users also question relevance and validity of offered data. Currently users are not aware how data collected about them is being used and how often data collection occurs when using any software.

Since augmented reality is visualization technology its use on situations like shared resource may be useful. AR is able to connect virtual data to physical objects in very natural way. Also, users' experiences about AR technology are better than other visualization technologies (video projecting and screen-based solutions) since collaboration between human beings is experienced in more natural way [15, 30].

The experiment presented also brought out user opinions that augmented reality could be used to share common data and also to provide personal viewpoints to users. Participants were really interested in new context-sensitive systems that could learn user's preferences and offer relevant information from situation to another. Users also had high expectations towards discussed software systems like in studies of Olsson and Salo.

In order to be able to offer services for users with conflicting preferences context-awareness is required. In order to achieve true awareness of situation developers need to investigate the concepts *context*, *adaptability*, *autonomic computing* and *ubiquitous computing*. It is necessary to also study user's expectations and map situations where preferences could be colliding. User's expectations are a necessary supplement in software engineering since not everybody wants to use wearable devices or even be part of smart environments.

In AR systems information flood could be solved by using different types of augmentations. As some users mention in Olsson and Salo [16] more urgent data could be offered as auditory augmentation and less relevant data as visual cues. This could also be applied to private and sensitive data. Using multiple human sensory modalities even shared devices could present private data by channelling it as different augmentations to different users. Of course this would not solve issues related to hardly shareable situations like different preferences of lighting system. But maybe data glasses with certain lighting device could solve this issue. Clearly augmented reality is one solution to problem of shared resource in software systems.

Anyway, the best results are achieved by including end-user in product development. During the experiment some attendants argued correctly that users are not taken into consideration while developing software. Thus totally useless information is offered to them on daily basis which is experienced as major problem. This is confirmed in Olsson and Salo [16] by regular users and also researchers behind of concept Internet of People [36].

3.1. How situation in question 3 could be achieved without disabling collaboration between users?

To answer this question 3 let's take a look at the sample applications presented in Chapter 4.2. These collaborative augmented reality applications are able to share common resources and offer also different perspectives for user with full control over viewpoints. These applications make it possible to *enable* collaboration while users may have colliding preferences. They excel on cooperation situations because they apply the six characteristics: virtuality, augmentation, co-operation, independence, individuality and seamlessness of interfaces. The characteristics with augmented reality technology provide a solid ground for enabling solutions for sharing resources without sacrificing collaboration.

7.3 Analysis of utilized research methods

In retrospect, it is good to analyse suitability and applicability of the used methods related to user study. User study was split into three sections: use of the protype, discussion and answering to the questionnaire. Interview and observation were used to find out users' thoughts and non-verbal behaviour.

As Arhippainen and Tähti [32] note user study needs to be planned beforehand to get most appropriate results. They report that human behaviour is so multifaceted that it is very hard to observe. Many non-verbal gestures occur in short period of time. Hence, it would be good to have video recording while performing interview.

As part of this thesis a user study was carried out. Observation focused on interpreting user's facial expressions and body language while using the test application. Goals of interview and observation were not mentioned to participants since it could have had too large impact on their behaviour during test session. This was also the reason why sessions were not video recorded although literature suggests it. Audio recording was used to capture verbal expressions as accurately as possible. It would be interesting to have another experiment with video recording and compare results.

Arhippainen and Tähti [32] used questionnaire as part of their user studies. They sent questionnaire after interview sessions to each participant. Authors claim that user has to be able to reflect their thoughts about participation to test experiment. Thus, it could be useful to give user time to process their experiences of experiment and send questionnaires afterwards to users. These are very good points and they are well rationalized. However, amount of responses to post questionnaires has been proved to be much less than in-present questionnaire [43]. It is all about how much researcher wants respondents to reply to questions asked. It may be worth to ask questions that aren't in top priority and send them by post. But in order to have significant amount of valid responses in-present questions have to be asked.

In case of this thesis users were asked to answer to questionnaire right after the experiment. There were several reasons for this. First of all, questionnaire was planned to take little time as the entire session was planned to take really short period of time. Thus, users would be able to respond after prototype testing even if they felt exhausted. Secondly, risk of having too many inadequate answers or not getting responses at all was not tolerable with small sample.

When looking at the results question set layout was quite successful. Answers revealed new information as well as they confirmed existing results. Though any kind of information about level of difficulty of the questions was not collected. Users were not asked about their thoughts of asked questions either.

Olsson and Salo [16] note that their research was not able to test user experiences with real augmented reality application. They mentioned this fact to be another source of error. As part of this thesis a prototype was designed and implemented. However, the application is really simple and it cannot be used in real situations yet. Also, it lacked sophisticated context-aware features to be truly context-aware. It is hard to know how much its technical features or lack of them affected on results. Olsson et al. [33] did not use any existing applications since they rate them to be too naïve as AR is still in its infancy. Nevertheless, they were able to get very representative results about participant's thoughts about AR. When evaluating outcome of the experiment from this perspective it is reasonable to assume that the test setting was able to reveal true information about users' experiences that can be confirmed by the findings of the existing scientific literature.

The user study of this thesis was not able to give users any time to learn application operation since resources were really sparse. It would be good idea to replicate this study and give users time to learn application usage before attending. In the other hand features of this application were very similar with most existing applications. Thus impact of unfamiliarity to results can be considered to be very low. It is also good to ponder if it is possible for end-users to imagine full-fledged version of application prototypes. It may not be possible to have clear image of finalized products since participant may not have any understanding of information technology or software engineering. However, nowadays users have several applications they use on daily basis. Even non-technical people have some experience of these software applications. They certainly have experiences about good and bad features of software in order to be able to have a decent view about ideal computer applications.

Finally it is good to analyse existing literature of augmented reality and context-awareness. Most research papers are focused on fascinating technical issues like algorithms, user interface design and tracking techniques. There are many papers (e.g. [37, 35]) that classify themselves to be user studies but actually they describe technical rather than any aspects of psycho-social issues. This reflects problem of poor and immature definitions of concepts. There are also papers about methodology of performing interviews and observation in the field of information technology (e.g. [32, 30]). However, these research reports lack of description about user's thoughts or emotions. If some article manages to report any of psychosocial issues results tend to be very short and too concise.

While papers that would have appendices about *exact questions* of user studies or summarized results of question sets are virtually non-existent there is not much information to reuse. During planning this thesis and its test setting author had to rely solely on his own experiences about using applications and his vision about goals of this thesis. It is not trivial task to design question set to user studies since it cannot be anticipated how participants will respond. As many research projects utilize pilot studies the experiment would also have benefited from testing the presented question set with pilot user group. Also, it would be good idea to share more additional material that is used for analysis of scientific research. Many authors are only presenting related material if it serves some purpose of reporting results. This is a major issue that makes repetition of scientific studies practically impossible.

8 Conclusions

This thesis has contribution to augmented reality in offering real opinions and experiences from real users. This have been done already in Morrison et al. [30] and Olsson et al. [33]. Former research group was able to provide rich description about researchers' observations during collaboration tasks with sample test group but not exact results to questions. Latter research group was not able to provide user experiences related to real augmented reality system but succeeded at conceptual level by using fictitious scenarios.

This thesis presented main contributors for next generation automation. Findings were based on existing scientific literature. Goal for designing and implementing ubiquitous system is to make human-computer interaction easier and more transparent. These systems are based on context-awareness and adaptive software. Also, augmented reality will have its own role for the automation since it can significantly fade away artificial barriers between human and computing system.

The presented research questions focus on problem of shared resource. Selected perspective was on context-sensitive collaborative augmented reality. Some answers were presented to problem by interpreting results of the user study and from literature. There were also statements presented that based on author's experiences about designing and implementing the prototype. Results of the user study have been reflected on the existing literature to get some reference point of validation. The thesis described a small but real experiment with real prototype application based on mobile augmented reality. The test setting was able to provide useful information about regular consumers' thoughts about augmented reality and context-aware applications.

This thesis studied augmented reality and its applicability for collaboration scenarios. There were three sample applications evaluated against five characteristics found in literature. Samples are able to provide vision about future state of affairs. It was concluded that the samples have all five characteristics and they support collaboration very well. These applications were also tested with real users and real scenarios. As a merit, all user studies has been reported in scientific articles. The reports indicate that the applications were making user's life easier and they supported human-to-human collaboration.

Software developer can support user's personal preferences and collaboration by using augmented reality as main visualisation method. It is possible to share limited resource by using multi-modal augmented reality. By channelling urgent content to aural modality and leaving rest of content to visual modality it is possible to share resources to some extent. However, techniques to achieve this are currently very rare. From technical point of view all samples presented use at least client-server architecture to deploy viable software in context of shared resources. Although augmented reality offers possibilities to share common data between users and retain individuality of each user these characteristics are not easily achieved. Future will most probably reveal new sets of characteristics that could bring collaborative solutions even closer the human behaviour. Also, reaching true context-awareness is still under development also in many research projects not to mention consumer products.

Another aspect software engineer could focus on is users' expectations. This thesis presented some results of user studies that indicate users having very high expectations towards modern computing systems. Users expect software systems to be highly proactive, context-aware and secure. Some users are not willing to use such systems if they cannot control their own data and storing process of it. This thesis expressed some thoughts about validity of context-sensitive data. Although users demand proactive systems they still want systems that are also able to offer unusual but positively surprising information. Some users may want to get information to expand their knowledge or just to satisfy their curiosity.

The research brought out some development areas of augmented reality. It is not easy to use AR application while user is moving. Users face significant challenges when image marker is used because marker has to be on flat but stiff surface in order to useful. Based on the findings it could be concluded that in order to have usable augmented reality application hybrid tracking methods have to be used. Although some user studies indicate that users are not able to follow their environment while using AR also other technologies have this same issue. Maybe future AR glasses and more natural ways of interactions offer users better ways to utilise AR than it is possible currently. Maybe ubiquitous computing and augmented reality will also alter the ways we use computing systems in general.

The existing literature and the user study indicate that social acceptance of ubiquitous systems is still in its infancy. Users are not aware of these concepts in the extent they should be. There will be great challenges when ubiquitous systems are deployed to real scenarios. Maybe changes to legislation are required in certain countries before these proactive systems can be part of everyday life.

The thesis provided also some introspection about methodology and the achieved results. Some findings were confirmed by the existing literature and some were not. The literature review was not very exhaustive so some articles may have been left out. However, the most recent and the most representative articles and their results were used to validate the outcome of the practical experiment. Although the results were well in line with existing literature about context-awareness and collaborative augmented reality they are not complete in any way. More research is needed to get deeper understanding of collaborative AR effectiveness.

This thesis provides a good ground point for next user studies for other students and researchers. It could be useful to replicate the performed user study and compare results. This is possible because used materials are attached to this thesis as appendices. It would be helpful to measure opinions of information technology professionals to get more fruitful results about shared resources. In order to fully understand issue of shared resource new user studies are needed. In addition, more functional, truly context-aware software prototypes are required as well as smart environments to be able to study social aspects of computing systems. Hopefully more user studies with complete question sets will be reported in the future.

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9 Appendix A: Open-ended questions used in experiment

Every question included some kind of introduction to main question. Explanation was read aloud for attendants and repeated if necessary. In addition, there was couple of examples provided in order to be able to describe each situation more.

Millaisia ajatuksia tällaiset ominaisuudet teissä herättävät?

Järjestelmä pyrkii antamaan yksilöllistä tietoa kullekin käyttäjälle siten, että kaikki yksityiset muistiinpanot pysyvät tekijänsä tietoisuudessa ja vain julkiset muistiinpanot jaetaan muiden kanssa.

Mitä, jos prototyyppisovellusta laajennettaisiin niin, että se pyrkisi ottamaan huomioon teidän kulloisenkin paikan ja ajankohdan päivästä. Millaisia ajatuksia tällaiset ominaisuudet teissä herättävät?

Millaisia ajatuksia sovelluksen käyttö teissä herätti?

Käytitte juuri hyvin yksinkertaista lisätyn todellisuuden sovellusta. Millaisia ajatuksia sovelluksen käyttö teissä herätti?

Millaisia tunteita sovelluksen käyttö teissä herätti?

Ihminen reagoi asioihin tunteella. Myös tähän sovellukseen liittyi tunteita. Millaisia tunteita sovelluksen käyttö teissä herätti?

10 Appendix B: Questionnaire with statements

Kysely lisätyn todellisuuden antamista mahdollisuuksista ihmisten väliseen yhteistyöhön.

1. Mikä on sukupuolesi? *

- Nainen
- Mies

2. Minkä ikäinen olet? *

- 12-17-vuotias
- 18-24-vuotias
- 25-34-vuotias
- 35-44-vuotias
- 45-54-vuotias
- 55-65-vuotias
- 65-74-vuotias
- 75-vuotias tai vanhempi
- en halua ilmoittaa ikääni

3. Oletko käyttänyt aikaisemmin jotain lisätyn todellisuuden sovellusta? *

- En
- Kyllä

4. Missä yhteydessä käytit sovellusta?

- Käytin sovellusta vapaa-ajan harrastuksessa
- Käytin sovellusta työssäni
- Käytin sovellusta tutustuakseni lisättyyn todellisuuteen
- Muussa tarkoituksessa, missä? ______

5. Minulle on tärkeätä että mobiilisovelluksissa, joita käytän, on... *

	täysin samaa mieltä	jokseekin samaa mieltä	neutraali kanta	jokseekin eri mieltä	täysin eri mieltä	ei osaa sanoa
paljon erilaisia hyödyllisiä toimintoja						
ominaisuuksia, joiden avulla voin käyttää sovellusta missä tahansa						
tietoturva ajatasalla						

vetoava ulkonäkö						
ominaisuuksia, jotka tukevat kanssakäyntiä ystävien ja työkavereiden kanssa						

6. Kuinka helppoa sinun oli käyttää sovellusta? *

- Erittäin helppoa
- Kohtalaisen helppoa
- Ei helppoa eikä vaikeata
- Kohtalaisen vaikeata
- Erittäin vaikeata

7. Kuinka helppoa sinun oli ymmärtää sovelluksen toimintaperiaate? *

- Erittäin helppoa
- Kohtalaisen helppoa
- Ei helppoa eikä vaikeata
- Kohtalaisen vaikeata
- Erittäin vaikeata

8. Vastaa vielä seuraaviin väittämiin juuri kokelemasi sovelluksen antamien kokemusten kautta. *

	täysin samaa mieltä	jokseekin samaa mieltä	neutraali kanta	jokseekin eri mieltä	täysin eri mieltä	ei osaa sanoa
Juuri kokeilemani sovellus pystyi mielestäni tukemaan minun ja parini välistä kommunikointia						
Sovellus haittasi minun ja parini välistä kommunikointia						
Sovellus toi ihmisten väliseen kommunikointiin kommunikointiin jotakin uutta, mitä en ole kokenut aiemmin						
Sovellus paransi mielestäni parityöskentelyn laadukkuutta						

11 Appendix C: Preliminary info for participant

Tervetuloa osallistumaan tutkimukseen!

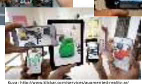
tietoa lisätystä todellisuudesta

Mitä tarkoittaa “lisätty todellisuus”?

- lisätty todellisuus tarkoittaa teknologiaa, jolla reaalimaailmaan lisätään jotakin sellaista, mitä siinä ei tavallisesti ole

kuva: http://bgr.com/2017/02/13/iphone-8-specs-augmented-reality-features/

Kuva: https://www.youtube.com/watch?v=5OK2xxjI5MY



Kuva: http://www.klickar.com/services/augmented-reality-ar/

Miten lisätty todellisuus toimii?

- tietokoneohjelma käsittelee videota ja erityisen kuvan avulla se tunnistaa, missä kohtaa virtuaalisen sisällön tulisi sijaita reaalimaailmassa

Esimerkki markkerista. Kuva on otettu Forsmanin (2016, 25) työstä *“Applying Augmented Reality to Outdoors Industrial Use”*.

Miten lisätty todellisuus toimii?

- kuvamarkkerin lisäksi voidaan käyttää esim. kännykän sensoreita reaalimaailman ja virtuaalimaailman yhdistelyyn sekä virtuaaliobjektien sijoitteluun
- kuva voi olla myös tavallinen kuva, jos siinä on riittävästi yksityiskohtia
- koetilaisuudessa käytetään alla olevaa kuvaa

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Miten lisätty todellisuus sitten eroaa virtuaalimaailmasta?

- lisätyn todellisuuden sovelluksessa reaalimaailman ilmiöt, esineet ja tapahtumat ovat pääosassa
- reaalimaailmaan on lisätty jotakin virtua

Kuva:

Miten virtuaalista sisältöä voidaan tarkastella?

- periaatteessa virtuaalinen sisältö voi tuoda lisää siihen, mitä nähdään, kuullaan tai tunnetaan
- yleensä sovellukset rajoittuvat visuaaliseen lisättyyn todellisuuteen, jota voidaan tarkastella:
  - läpikatsottavalla näytöllä, kuten puhelimen videokamera
  - erityisillä laseilla

kuva: http://bgr.com/2017/02/13/iphone-8-specs-augmented-reality-features/

Kuva: https://www.microsoft.com/en-us/hololens/hardware

Miten lisätty todellisuus toimii?

- kun laitteella, jossa on lisätyn todellisuuden sovellus, katsotaan kuvamarkkeria, sovellus sijoittaa markkerin paikalle virtuaalikomponentteja
- kuvassa on havainnollistettu asiaa, markkeria ei näy kuvassa

Kuva: Grubert & Grasset 2013, sivu 8.

Tyypillisimpiä lisätyn todellisuuden käyttökohteita

- mainokset ja televisio
- navigaattorit
- tietokonepelit
- koulutus
- laitteiden asennukset

- ehkäpä tulevaisuudessa
  - terveydenhuolto
  - teollisuus

Lähteet:

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Tietoa ja ohjeita tutkimukseen osallistuvalle

Missä tutkimus järjestetään?

- tutkimus järjestetään Turun yliopiston Tulevaisuuden teknologioiden laitoksella, joka sijaitsee Agora-rakennuksessa 4.kerroksessa. Rakennus sijaitsee osoitteessa Vesilinnantie 5, 20014 Turku.

Agora

Tutkimuksen tarkoitus

- tutkimus on osa opinnäytetyötä, jossa tutkin lisättyä todellisuutta ja sen antamia mahdollisuuksia lisätä/parantaa ihmisten välistä yhteistyötä työympäristöissä
- tarkoituksena on selvittää, miten lisätty todellisuus voisi palvella ihmisten välistä kanssakäymistä työssä

Tutkimuksen toteutus

- tutkimus toteutetaan siten, että jokainen osallistujapari tekee ensin 2-3 tehtävää tablettitietokoneella
- tehtävissä käytetään tekemääni yksinkertaista sovellusta
- kukin pari vastaa yhdessä kysymyksiin ja tehtävät tehdään yhteistyönä parin kanssa
- tutkimuksen lopuksi osallistuja voi halutessaan vastata kyselyyn
- tutkimus vie aikaa noin 20-30 minuuttia
- koetilanne äänitetään, mikäli osallistujilla ei ole mitään sitä vastaan
- käytän äänitettä lähinnä muistin tukena analyysivaiheessa