The Historical Tour Guide
Augmented Reality

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Abstract

The purpose of this project is to investigate how historical pictures from Trondheim can be made available on a mobile platform. It was early on decided to research the use of mobile augmented reality. Feedback gathered during interviews with representatives from cultural heritage institutions in Trondheim guided the directions and the design of the final solution. The project work was carried out in accordance with the design-science research model and the living lab approach.

A tablet prototype, named "The Historical Tour Guide", has been developed and tested with prospective users. The application enables users to access information about historical images and view the images as overlays on the current landscape. A map and timeline is included to make it easier to navigate in the collection of images.

The project shows that the cultural heritage institutions in Trondheim are interested in a mobile augmented reality application with local historical pictures. Furthermore, it was discovered that the institutions want an application that is easy to use for people with limited technical experience and requires no maintenance. Initial tests with users indicate that the tablet is a suitable device for such an application, but further testing and development is required to verify both this and whether the general public have an interest in this type of application.

Preface

This report is a documentation of the project work performed by Anne-Cecilie Haugstvedt in the course TDT4501 “Computer Science Specialization Project”. The project counts for 15 units and is carried out in the ninth semester of the Master of Technology degree in Computer Science at The Norwegian University of Technology and Science (NTNU).

This research project would not have been possible without the support of many people. I wish to thank my supervisor John Krogstie at the Department of Computer and Information Science at NTNU for valuable feedback and advice throughout the semester. I would also like to thank the participants from NTNU University Library, the Regional State Archives in Trondheim, and Trondhjems Historiske Forening for their input and constructive feedback. In addition, I wish to thank my fellow students for their help with the heuristic evaluation.

Finally, I thank my parents, friends and family for supporting me throughout all my studies at the university. Without you, this project would not have been possible.

Trondheim, December 10, 2011

Anne-Cecilie Haugstvedt

Task

Through trondheimsbilder.no one have access to a large collection of historical pictures on an internet-platform. The task intends to investigate making these available on a mobile platform linked to the location of the user and the picture taken.

The student shall investigate the interest for such an application, including establishing the more concrete requirements of relevant users of such application.

A prototype shall be developed and evaluated in a rigorous manner. The project is expected to follow a design science research approach, producing and evaluating an artifact (e.g. as an App) in a scientifically sound manner. The task should use resources related to Wireless Trondheim Living Lab in an appropriate manner. Code to be produced should be made available under an open source license. It is preferred that the project report is written in English. The results from a good thesis should be possible to use as a basis for developing a scientific publication.

Supervisor: John Krogstie

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Introduction

1.1 Motivation

Through Trondheimsbilder.no one have access to a large collection of historical photographs on an internet-platform. The website is frequently visited by historians and members of the local historical organizations and new pictures are added regularly. Nevertheless, little has be done to update the functionality of the site since 2005. Students at NTNU have been involved in creating several location-aware mobile applications associated with the site [27], but those applications no longer work since the institutions behind the site have not had the resources to maintain or update the server.

At the same time, we now have access to a whole new range of methods for presenting images. One of the most striking is that of using mobile augmented reality. Other cultural institutions have successfully developed mobile augmented reality applications with historical photographs [9, 19, 28, 40]. However, the institutions that have released information on the structure of their solution have all chosen an approach that requires the use of a server. This project is motivated by the possibility of finding a solution for a mobile augmented reality application that fits the needs of the smaller organizations that lack the necessary technical staff and support to maintain a server and do not have the resources to hire someone to do so within their operational budget. A secondary goal is to find out if a tablet would be a suitable device for such an application.

1.2 Project Description

The goal of this project is to make historical images from Trondheimsbilder.no available on a mobile platform. To define the key features and requirements that must be supported by the system, interviews will be conducted with participants from cultural heritage institutions in Trondheim. A prototype will be developed and evaluated in a rigorous manner in accordance with the design-science research model and the living lab approach. The prototype will be evaluated using heuristic evaluation and an empirical study with users.

1.3 Report Outline

Below is a short overview of the different chapters in this document.

Chapter 2 Preliminary Study is a literature study of potential challenges within the field of mobile computing, the use of information and communication technologies in the cultural heritage sector, mobile augmented reality, existing solutions, and technologies facilitating the development of mobile augmented reality applications.

Chapter 3 Research Approach describes the research questions and the chosen research methods.

Chapter 4 Interviews presents the results from semi-structured interviews with participants from local cultural heritage institutions.

Chapter 5 Selecting and Preparing Materials presents the process of selecting and preparing images to include in the prototype.

Chapter 6 Prototype presents the final prototype, a mobile augmented reality application named the Historical Tour Guide. The chapter starts with user scenarios and requirements based on feedback gathered during the interviews and ends with a presentation of the features included in the final prototype.

Chapter 7 Evaluation gives an evaluation of the final system based on a heuristic evaluation and testing with users. The chapter describes how well the system conforms to the requirements specification.

Chapter 8 Conclusion and Further Work marks the end of the report by giving some concluding thoughts about the outcome of the project. The chapter also contains a discussion of possible further work.

Chapter 2

Preliminary Study

There are certain challenges in developing a mobile augmented reality application for a cultural institution. This chapter reviews some of the challenges of mobile computing and in using information and communication technology for cultural heritage. It presents the field of mobile augmented reality and mobile augmented reality in cultural institutions before it concludes with a review of the available technologies for the implementation part of this project.

2.1 Mobile Computing

There are today more than 5.9 billion mobile-cellular subscriptions [51]. Mobile computing has become an indispensable part of day-to-day life. Last year, the New Media Consortium [33] identified mobile computing and social media as two technologies that will have an impact on and use in education and interpretation within the museum environment on the near-term horizon. However, in order to take advantage of the technology and design and build efficient software for mobile computing there are a number of technical challenges that must be addressed.

In 1994, Forman [22] identified three essential characteristics of mobile environments that gave rise to most of the challenges in mobile computing at the time:

- mobility
- wireless communication
- portability

The technological advancement in mobile computing since 1994 has been breathtaking. Nevertheless, these essential characteristics continue to define areas that must be given extra attention when developing efficient software for mobile computers.

2.1.1 Mobility

Mobile computers are expected to be transported during normal use. They will encounter more heterogeneous network connections than their stationary counterparts. As they change from one network to another, they may need to change network protocols and transmission speeds. While it may be OK to configure this information statically for a stationary computer, it has to be dynamically updated as a mobile computer moves to a new location. The users expect this configuration to take place with as little intervention from them as possible and they expect their applications to run regardless of the underlying network protocols and operational details. Furthermore, the users are probably not going to be so happy if an application makes them download a large file over a slow and expensive 3G connection instead of giving them the choice to wait until they can find a faster and cheaper Wi-Fi connection. In situations like these, it may be better to present the users with the alternatives and let them make an informed decision.

It is not only network configurations that must be updated as an user moves from one location to the next. Other location-dependent information have to be updated as well if mobile computers are going to answer queries such as "Where is the closest sushi restaurant?" or "How do I get to the main street from here?". Some systems and applications require that the users share his or her location and have legitimate reasons to do so. Examples span from systems for routing telephone calls at work to social applications like Foursquare. Ensuring that these systems and applications have access while protecting the users' privacy and protecting against misuse, is a challenge.

2.1.2 Wireless Communication

There are times when a mobile computer may remain stationary long enough to be physically attached to the network. However, most of the time it will require wireless network access to be able to communicate with other hosts. This is a challenge as wireless communication is characterized by lower bandwidths, higher error rate, and more frequent and unpredictable disconnections than wired communication.

There are a variety of techniques that can be used to mask and prevent network failures. Asynchronous operation, prefetching and delayed write-back all decouple the act of communication from the time the data is used and can thus mask short disconnections. Buffering and compression, either separately or in conjunction, can be used to increase the effective bandwidth by improving throughput. Nevertheless, it may still take longer to transfer the same amount of information via a wireless network than with a wired network and there will be situations in which you cannot avoid disconnections such as when the mobile computer move out of wireless communication range or run out of energy. In such cases, a good user interface can help by providing feedback about the progression of a download or about which operations are unavailable.

Another solution is to build a more autonomous application that do not rely on a network connection at all. There are several reasons why this may be a good approach for an outdoor application, even if it is location-based:

- Having a stand-alone application reduces the number of failure points. There are no servers that can go down and the application is not dependent on a stable network connection with sufficient bandwidth.
- There is no need for a network connection to find out where the user is if he or she is in the possession of a device with built-in GPS.
- Querying for data over the network introduces a latency that can negatively affect the user experience.
- Downloading large amounts of data over the cellular network can be expensive if the user does not have a data plan. It is often possible to connect to a nearby Wi-Fi network, but the user might not be willing to pay to do so. And, even if it is free, it is one extra step that has to be done before starting using the application.

2.1.3 Portability

Mobile computers are designed to be portable and easy to move or carry around. Consequently, they tend to be smaller and lighter than stationary computers. Having a device of limited size, such as a tablet or smartphone, is convenient for the user but the physical dimensions impose constraints on the type of hardware that can be installed and the size of the user interface. Compared to larger, stationary devices, portable computers have limited computing power and storage, and constrained battery life. Because of this, applications running on this type of devices should be efficient.

The small user interfaces of todays portable devices have motivated designers to come up with innovative interaction techniques. Touch screens with on-screen keyboards have already replaced the traditional keyboards and number pads on smart phones and tablets and voice recognition is supported on several devices. The software designers need to be aware of the limitations of these new techniques. On-screen buttons should not be so small that they are hard to tap with a finger and voice recognition should only be used if the advantages outweighs the disadvantages. An example of a justified use of voice recognition would be a voice controlled car navigation system. An example of an unjustified use of voice recognition would be any application that could make the user reveal personal information or disturb a meeting.

2.2 Information and Communication Technologies for Cultural Heritage

The use of information and communication technology (ICT) for cultural heritage has been growing very fast as part of the explosion in digital arts and humanities research driven by both public interest in heritage and the opportunity to enhance intellectual enquiry for arts and humanities researchers [18]. However, there are problems transferring prototypes and other research results relating to the use of ICT in the cultural heritage sector to working solutions for cultural institutions.

Figure 2.1, from EPOCH's Research Agenda for the Applications of ICT to Cultural Heritage [5], depicts why an effective transfer of research results and wider adoption of innovative ICT solutions is difficult to achieve in the cultural heritage sector:

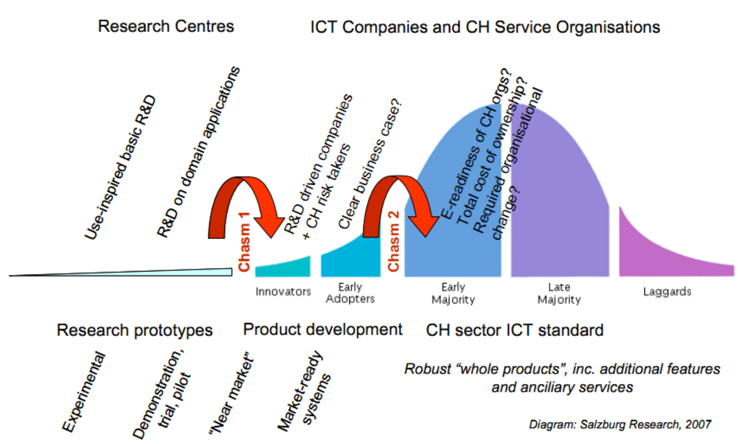

Figure 2.1: Chasms in the diffusion of ICT research results to the cultural heritage sector [5]

The figure shows two chasms in the diffusion of research results. The first chasm concerns the transfer of 'near market' ICT prototypes to innovators and other early adopters in the cultural heritage sector. The second chasm concerns the late adoption of mature applications by many institutions in the cultural heritage sector. The main problem here is that most cultural heritage institutions are small organizations that lack technical staff and support and are not able to cover the total cost of ownership for ICT applications from their operational budget [5].

2.3 Mobile Augmented Reality

Augmented reality (AR) aims to enhance our view of the world by superimposing virtual objects on the real world in a way that persuades the viewer that the virtual object is part of the real environment [12]. It is a crossover between the real and virtual world, as illustrated by Paul Milgram's famous reality-virtuality continuum diagram shown in figure 2.2. Mobile augmented reality systems provide the same services as augmented reality systems without constraining the individual's whereabouts to a specially equipped area [32].

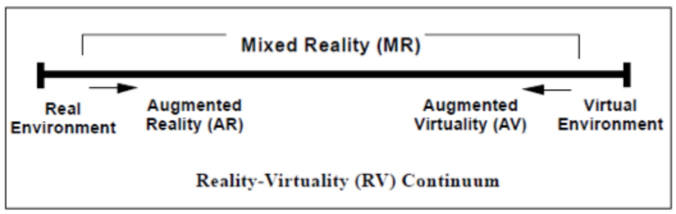

Figure 2.2: Reality-virtuality continuum diagram [38]

2.3.1 Historical Background

The term augmented reality (AR) was coined by Tom Caudell and David Mizell in 1992 [13]. The two were at the time were working for the Research and Technology organization of Boeing Computer Services and used the term to refer to a system that guided workers through assembling electrical wires in aircrafts by overlaying computer-presented material on top of the real world. The system used a head-mounted display. However, even though the term AR wasn't coined until the early nineties, augmented reality has been around for a while. Ivan Sutherland created the world's first augmented reality system 1968 [50]. The system, shown in figure 2.3, used an optical see-through head-mounted display to display simple wireframe drawings in real time.

In 1997, Ronald T. Azuma did a survey on the field of augmented reality [7]. He found that, at the time, AR systems was primarily found in academic and industrial research laboratories. While they were being put to use by a number of major companies for visualization, training, and other purposes, the head-mounted displays were too expensive for commercial purposes and the systems were not portable. 1997 was also the year when researchers at Columbia University presented the Touring Machine, the world's first mobile augmented reality system [21]. That system, shown in figure 2.4, required the use of a see-through head-worn display; a backpack holding a computer, differential GPS, and digital radio for wireless web access; a hand-held computer; and a battery belt to power it all.

In 2001, Vlahakis et al. presented Archeoguide, a mobile AR system for cultural heritage sites [52]. The system was built around the historical site of Olympia, Greece, and provided on-site

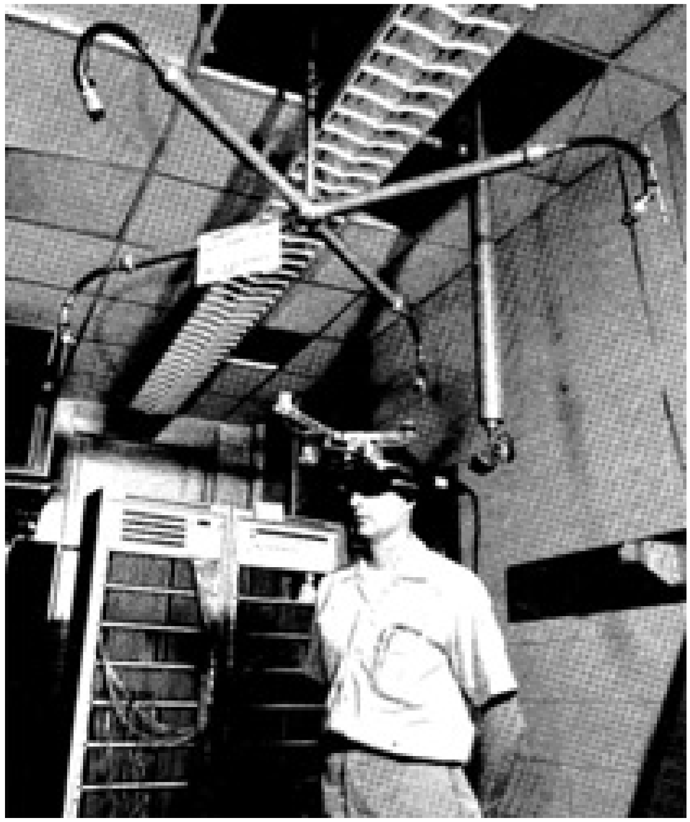

Figure 2.3: Early head-mounted display device developed by Ivan Sutherland [10]

help and augmented reality reconstructions of ancient ruins, based on user's position and orientation in the cultural site, and realtime image rendering. Three different mobile clients was supported within the system: a laptop, a pen-computer and a pocket PC. The laptop client was similar to the client used in the Touring Machine. It required the use of a head-mounted display; a backpack holding the GPS receiver and computer; and a bicycle helmet with a digital compass. The realistic AR presentations were highly appreciated by the users but objections arose on the size and weight of the equipment. The pen-computer and the pocket PC provided panorama views of the natural surroundings with augmented reconstructions rendered on top. This functionality is closer to what we today find in commercial AR systems for smart phones and tablet PCs. Both these systems were also appreciated for their smaller dimensions and weight, as well as the fact that they comprised a single unit. Their augmented panoramas received good comments.

Increased development of mobile augmented reality systems started with the introduction of the contemporary smartphone [9]. Suddenly, application developers got access to devices packed with sensors such as Global Positioning System (GPS) receivers, Wi-Fi sensors, cell tower radio receivers, cameras, compasses and accelerometers. With the release of a new version of the Android operating system for smartphones in summer 2009 they also got the ability to control the camera view and add graphics and other media to the display. A similar capability was added to the iPhone operating system shortly after.

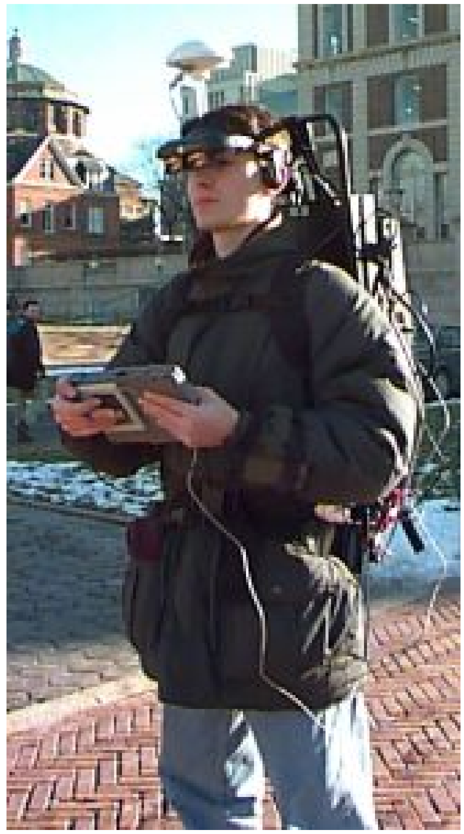

Figure 2.4: Fully equipped user of the Touring machine [21]

2.3.2 Tracking Techniques

Tracking is one of the fundamental enabling technologies for AR, and is still an unsolved problem with many fertile areas for research [54]. There are three dominant techniques: vision-based tracking, sensor-based tracking, and hybrid tracking. The vision-based and sensor-based tracking techniques are explained in detail below. The hybrid techniques combine elements from the other two techniques to provide a more robust result.

Vision-Based Tracking Techniques

Vision-based tracking techniques use image processing methods to calculate the camera pose relative to real world objects [54]. Applications that use the techniques analyzes the images coming in from a digital camera to determine what is visible in the world around the user and where those objects are in relationship to the user.

The available vision-based tracking techniques can be divided into two classes: marker-based and marker-less approaches. The marker-based approaches require that the systems identify an artificial fiduciary marker placed at locations or on objects in the real world in order to bring up the correct information while the marker-less approaches use natural feature detection to identify unaltered real world objects such as book covers, posters or landmarks that have no artificial makers to assist object recognition [12]. Marker-based approaches often use QR codes - essentially 2D bar codes which take the form of a pixilated square that can be read by mobile phones equipped with an appropriate software application [49]. A QR code that links to the url http://www.ntnu.no/ is shown in figure 2.5.

Figure 2.5: Example of a QR-code for http://www.ntnu.no/

Vision-based tracking is rather slow, and often turns out to be too fragile, especially in natural (e.g. outdoor) environments [47]. Furthermore, the marker-based approaches require that markers are placed in the real world. This can be a time-consuming process and it requires a certain control of the environment as the developers both must have permission to put up the markers and some way of replacing missing and vandalized markers. The marker-less approaches do not require the same control of the environment but are susceptible to slight variations in lightning and surrounding objects. Fast object motions will lead to rapid change of visual content and the vision-based tracking system will require time-consuming recovery of new landmarks with a temporary loss of real-time tracking abilities.

A marker-based tracking technique might be the easiest solution for companies and institutions that are looking for a way to implement augmented reality indoors [9]. For outdoor applications that covers a wide geographical area, it is better to go for a sensor-based approach.

Sensor-Based Tracking Techniques

Sensor-based tracking techniques are based on sensors such as magnetic, acoustic, inertial, optical and/or mechanical sensors [54]. Applications that use the techniques combine data from sensors to make a best possible guess at where the user is standing and what he or she is looking at.

The location-sensing technologies used for sensor-based tracking can be characterized according to whether they are fine-grained or coarse-grained [26]:

- GPS and cell tower or Wi-Fi triangulation are examples of coarse-grained systems. They exhibit modest accuracy, generally measured in meters. GPS is unsuitable for indoor positioning while triangulation can be used both outside and inside.

- Ultrasound is an example of a fine-grained system, achieving accuracies on the order of centimeters. Since audio is mostly bounded by walls, it can be used to resolve locations to the confines of a physical room. However, it does require the installation of sensors and that the users wears tags that can be tracked. There is no support for the approach in today's smartphones.

A common approach in mobile augmented reality systems is to get a basic geographic location from the GPS sensor of the device and augment this by Wi-Fi and cell tower locations. Whatever other sensors are present will then be used to determine exactly what the user is looking at. A compass provides information on the direction the device is pointing, a gyroscope will tell how far up or down the device is pointing and whether is it twisted vertically, and an accelerometer will indicate how the device is moving through space. Finally, the information of choice can be overlaid on the camera view.

The approach mentioned above is bounded by the accuracy and availability of the device's sensors. GPS is a global navigation satellite system and small timing errors can cause the GPS receiver to make different assessment of where it is located, causing a user's supposed location to bounce around while the user is standing still. These errors can be particularly bad in the city, where signals can bounce off buildings. It is also a problem that the signals does not penetrate indoors, making GPS unsuitable for indoor positioning [9]. Not all devices have a gyroscope and the other sensors have their limitations as well. Regardless of this, the approach is often the most suitable for mobile augmented reality applications, since is does not require the installation of any extra equipment.

2.3.3 Presentation of Image Overlays

Some definitions of augmented reality (AR), such as the one found in Ronald Azuma's survey of augmented reality [7], insist the virtual object is a 3D model of some kind. However, most people accept a looser definition where the virtual domain consists of 2D objects such as text, icons and images [12]. This is the approach taken in this project.

Given that it is accepted to use 2D representations in augmented reality, there are two possibilities for displaying image overlays:

1. display the photos as 3D objects in the scene (using absolute rotation)

2. display the photos as flat 2D overlays over the scene (using relative rotation)

When the user is standing directly in front of the photograph and have the same perspective as the photographer, the two methods produce identical results. If the user moves, the last option will result in the image still directly facing the user while the first option will result in an angled view of the photograph. At first glance, the second option might seem inferior. However, the promotional screenshots from successful applications that have used the first approach do not convey the difficulty in real world use [14]. Aligning historic images with 'reality' in 3D view can be an exercise in patience and, as a result, the 3D views ends up being a gimmick instead of a useful feature.

Due to the problems with use and the technical difficulties in developing an application with 3D objects, it was decided to display photographs as flat 2D overlays in the Historical Tour Guide.

2.4 Mobile Augmented Reality in Cultural Institutions

The last years advances in augmented reality and mobile technology have made mobile augmented reality applications more common and easily accessible. The 2010 Horizon Report: Museum Edition [33] identifies augmented reality as a technology that will have an impact on and use in education and interpretation within the museum section in two to three years.

In fact, cultural institutions are in a sense already in the augmented reality business [33]. They readily understand the need to augment the reality of objects in a museum in order to help visitors better understand and connect with collections. Artifacts are often accompanied by extra material such as descriptions, pictures, maps, movies and so on. The museums' use of audio guides show that they are no stranger to using digital and mobile technology to provide contextual information to the viewers. Mobile augmented reality applications takes the technology a step further and lets the institutions provide information to the user, where the user is. They also create publicity and help institutions reach out to new audiences who might not have known of the images' existence [9, 19].

Several cultural institutions have begun experimenting with mobile augmented reality. The rest of this section presents some of the major projects.

2.4.1 Augmented Reality by PhillyHistory.org

The Augmented Reality by PhillyHistory.org application [9] was developed as a joint project between Azavea, a software company specializing in Geographic Information Systems, and the City of Philadelphia Department of Records. The application is built on top of the Layar platform and is available for both Android and iPhone devices. It enables users to view historic photographs of Philadelphia as overlays on the camera view of their smart phones.

The application contains almost 90.000 geo-positioned images. 500 of these can be viewed in 3D while a selection of 20 contains additional explanatory text developed by local scholars. The entire development process is thoroughly documented through a white paper and numerous blog posts covering technical and cultural challenges they have met on their way.

2.4.2 Streetmuseum

The Streetmuseum [19] is an augmented reality application for iPhone developed by the Museum of London. The application contains over 200 images from sites across London. Users with a 3GS iPhone can view these images in 3D as ghostly overlays on the present day scene. Users with a 3G phone cannot access the AR functionality but are still able to view the images in 2D. Streetmuseum is different from the applications built by the other cultural institutions as the Museum of London built their own system instead of using an existing AR browser. The result is an application that offer a far better experience than Layar but only works on a limited number of devices [14]. They still had more than 50.000 downloads the first two weeks.

Netherlands Architecture Institute's UAR application

UAR [28] is a mobile architecture application developed by Netherlands Architecture Institute. The application is built on top of Layar and is available for both Android and iPhone devices. It uses augmented reality to provide information about the built environment. It is similar to the Streetmuseum and the Augmented Reality by PhillyHistory.org application but unlike those systems, UAR also contains design drawings and 3D models of buildings that never were built or still are under construction or in the planning stage.

The Powerhouse Museum's AR experiment with Layar

The Powerhouse Museum's AR application [40] allows visitors to use their mobile phones to see Sydney, Australia as it appeared one hundred years ago. The Powerhouse Museum did not develop a custom application but have implemented their experiment as a channel in Layar. It is thus available on all devices with a Layar browser. Their web page contains detailed instructions on how to download Layar and search for the Powerhouse Museum channel.

2.4.3 iTACITUS

The iTACITUS (Intelligent Tourism and Cultural Information through Ubiquitous Services) project [48] was an European research project funded under the Sixth Framework Programme for information society technologies. The project commenced in September 2006 and finished in July 2009. During this time the researchers explored ways of using augmented reality to provide compelling experiences at cultural heritage sites and encourage cultural tourism.

One of the systems developed under the iTACITUS program, was Zöllner et al's Augmented Reality Presentation System for Remote Cultural Heritage Sites [36]. The system has been used to produce several installations, among them the 20 years of the Fall of the Berlin Wall installation at CeBIT 2009. In that installation, users could use Ultra Mobile PCs (UMPCs) to see images of Berlin superimposed on a satellite image of the city laid out on the floor. By touching the screen, they could switch through visualizations from different decades, thus recognizing the situation in Berlin before and after World War II and the construction of the Berlin Wall. The installation also consisted of an outdoor part where users would take a photo of a building and receive overlays from the server that were overlaid on the current view.

Culture and Nature Travel

Culture and nature travel (kultur- og naturreise) is a project whose goal is to present cultural heritage and natural phenomena in Norway using mobile technology [6]. The project is done in collaboration between the Arts Council Norway (Kulturrådet), the Directorate for Cultural Heritage (Riksantikvaren), the Norwegian Directorate for Nature Management (Direktoratet for naturforvaltning) and the Norwegian Mapping Authority (Statens kartverk).

The first pilot experiment in the project used augmented reality and QR-codes to present information from the historical river district in Norway. Further pilot projects will be conducted to identify what is needed to present information from archives, museums and databases on smartphones, tablets and other mobile devices.

2.5 Mobile Augmented Reality Frameworks and Technologies

Mobile augmented reality development is still in its infancy and the field is characterized by rapidly changing technologies. Nevertheless, there are two dominating approaches to development:

1. Use an existing AR browser to show the points of interest
2. Do custom application development with or without the use of existing libraries and software development kits

This section contains an evaluation of a variety of technologies that covers both approaches to development.

2.5.1 Criteria for Choice of Technology

The best choice of technology for a particular project depends on a number of criteria, including the need for customization, the number of clients that must be supported and the type of information to display. The criteria presented in this section are the result of the initial interviews with stakeholders (presented in chapter 4) and experiences from other mobile augmented reality systems for cultural heritage (presented in section 2.4). The criteria have been used to determine which technology is best suited for the implementation part of the project.

T1 Sensor-based tracking The technology must support sensor-based tracking, i.e localization using GPS, gyroscopes, compasses and accelerators.

T2 Support for image overlays The technology must support customized views or 3D-models in order to implement a transparent image overlay.

T3 Embedded POIs The maintenance costs should be as small as possible as there will be little or no resources available for maintenance after the end of the project. For this reason, it is preferred to have embedded POIs rather than a web service.

T4 Custom application The photographs in the application belong to cultural institutions in Trondheim. It is therefore preferred to have a custom application that makes it easy for the end-users to identify the augmented reality prototype as being connected to the cultural institutions rather than to launch the prototype within another application associated with an external, commercial company.

T5 Tablet support The technology must be available for iPad or Android tablets.

T6 Pricing structure The technology should preferably be available for free.

2.5.2 Development Using an Existing AR Browser

AR Browsers like Junaio, Layar, Mixare and Wikitude are applications that can be downloaded to a smartphone or, in some cases, a tablet. The browsers display information like text, pictures, videos and audiofiles overlaid over the camera at certain locations. To publish content in one of the browsers, the developers have to create a channel consisting of one or more geo-located information services that contain points of interest (POI). The points of interests will then be displayed in the browser of those who select to view the channel.

Junaio

Junaio [29] is an advanced AR browser from the German company Metaio. The browser supports 3D object rendering, location based tracking and both marker and marker-less image recognition. The latter is an advantage in areas with poor GPS accuracy or for indoor campaigns where the GPS-signal won't work.

A problem with the most basic use of all AR browsers is that the users cannot search for the application that shows the POI they are interested in, but have to download an external application and search for the specific channel [37]. Junaio has provided a solution to this problem for anyone willing to pay. The Junaio Plugin allows 3rd party applications to display Junaio channels. It uses the same code-base as Junaio and therefore has the same features. XML is used for development, so programming is not required. The cost of the plugin is 10.000 Euro.

Normal use of Junaio requires the use of modeling tools to convert images to transparent models in order to implement transparent image overlays. Furthermore, in order to set up a channel, it is necessary to set up a server and build a data service using php. Initial testing also showed that there might be a problem with displaying Norwegian characters. On the positive side, there is both an iPad and an Android tablet version of the browser.

Layar

Layar [34] is a prominent AR browser from a company based in Amsterdam. The application comes pre-installed on several smartphones and is the browser used in the augmented reality applications by Philadelphia Department of Records, Netherlands Architecture Institure and the Powerhouse Museum (presented in section 2.4). The browser supports 3D object rendering and location based tracking. It is also possible to add features using Layar Vision, an extension of the Layar platform that uses computer vision techniques to augment objects in the physical world.

To build a new channel in Layar, it is necessary to build a web service. This can be done manually, but it is also possible to use any number of online web services and content management systems that have specialized in providing content for Layar. The pricing structure varies, but most require a monthly fee for hosting and/or a fee for publishing. Layar does not demand any money for publishing basic channels, but there is a monthly fee for channels that use Layar Vision. There is not yet any Layar browser for iPad or Android tablets.

Mixare

Mixare [39] is a free open source augmented reality browser. The basic application displays Wikipedia POIs of the surroundings. However, it is also possible to launch the application from a link on an HTML site or a launcher-application and make it use a data source of choice instead of Wikipedia. The application is freely expandable and can even be modified into an individual application. The browser in itself only supports location based tracking and 2d images. There is not yet a tablet version of the browser.

Wikitude

Wikitude World Browser [53] is a general purpose browser from the German company Mobilizy. The browser only supports location based tracking and 2D images. However, its open publishing model makes it one of the most accessible browsers for developers. It is possible to create new worlds by uploading ARMLs (augmented reality markup language files) or by registering Hoppala or external user-defined web-services. The browser can be customized with HTML and JavaScript using Wikitude ARchitect and there is a version of the browser available for the iPad and Android tablets.

2.5.3 Custom Application Development

Custom application development is more flexible than using an existing AR browser but requires a more technical background. However, there are software development kits and libraries that can be used by a software developer to speed up the development of an augmented reality application.

Unfortunately, most of the these either requires a licensing fee, does not support the use of sensor-based localization and/or does not support tablets.

OpenCV

OpenCV [16] is is an open-source library of programming functions for real time computer vision, launched as a project by Intel in 1999. The library is released under a BSD license and is free for both academic and commercial use. However, it provides no support for development of augmented reality applications with sensor-based tracking.

ARToolKit

ARToolKit [46] is a software library for building computer vision-based Augmented Reality (AR) applications. It was originally developed by Dr. Hirokazu Kato and its ongoing development is being supported by the Human Interface Technology Laboratory (HIT Lab) at the University of Washington, HIT Lab NZ at the University of Canterbury, New Zealand, and ARToolworks, Inc, Seattle. The library is made available for free for non-commercial use under the GNU General Public License and commercial licenses are available. Unfortunately, as with OpenCV, this library provides no support for development of augmented reality applications with sensor-based tracking.

Wikitude SDK

The Wikitude SDK [53] is an an open source framework for developing standalone AR applications. Developers have full access to the source code and some skeleton applications to get started. Wikitude do support tablets but for the time being it is only possible to download the Android SDK from their home page. For evaluation of the iPhone SDK, developers have to contact Wikitude directly.

Custom Development Without the Use of a Framework

It is also possible to develop an AR application without the use of any SDK or library. The advantages of this approach is that it is free and that the application can be branded and customized as much the developing organization wish. Furthermore, there are no restrictions on how the POIs are published so the developers can decide if it is most suitable to embed the POIs in the application or make them available through a web service.

On the negative side, custom application does require that the developer implement overlays, navigation systems and views. The application will most likely have to go through several iterations of usability testing before it even gets close to the level usability in the ready-made applications. It is possible to build an application for iPad or for Android tablets, but it is necessary to develop two separate applications if it is desirable to support both types.

Chosen Solution - Development on Top of CroMAR

As can be seen from table 2.1, custom application development without the use of an existing framework was the only technology of those evaluated that satisfied all the criteria at the time this report was written.

Criteria	**Junaio**	**Layar**	**Mixare**	**Wikitude World**	**Wikitude SDK**	**OpenCV**	**ARToolKit**	**Custom**
T1 Sensor-Based Tracking	yes	yes	yes	yes	yes	no	no	yes
T2 Support for image overlays	yes	yes	no	no	yes	yes	yes	yes
T3 Embedded POIs	no	no	yes	yes	yes	yes	yes	yes
T4 Custom app	no	no	yes	no	yes	yes	yes	yes
T5 Tablet support	yes	no	no	yes	Android only	yes	yes	yes
T6 Pricing structure	free	free	free	free	free	free	free	free

Table 2.1: Comparison of AR Technology

Since custom application development requires significant development expertise and not be possible within the timeframe of this project it was decided to implement the prototype on top of CroMAR [2], an open source mobile augmented reality application developed by Alessandro Boron and Simone Mora from the Norwegian University of Science and Technology (NTNU).

Figure 2.6 shows a screenshot from CroMAR. The application was developed to show how mobile augmented reality can be used to support reflection on past events. Features include the possibility to view points of interest (POIs) over the camera feed, find POIs on a map, share screen shots or filter POIs using a timeline. The application is developed specifically for the Apple iPad.

Figure 2.6: Screenshot from the CroMAR application

Chapter 3

Research Approach

This chapter describes the chosen research approach. It starts out with a presentation of the research question in section 3.1 and continues with a discussion of selected research models and methodologies in section 3.2.

3.1 Research Questions

The following questions guided the work during the project:

1. Is there an interest in developing a mobile augmented reality application with historical images from Trondheim?

2. What requirements do smaller cultural institutions have for a mobile augmented reality application?

3. Is a tablet a suitable device for an augmented reality application where historical images are presented as overlays?

3.2 Research Methodology

Three requirements in the task description determined much of how the work was structured in this project:

- The project should follow a design science research approach, and

- The project should use resources related to Wireless Trondheim Living Lab in an appropriate manner

- The prototype shall be developed and evaluated in a rigorous manner

This section describes Living Labs and the design science research approach and presents the semi-structured interview method used for collecting requirements. It ends with a section on methods used for usability design and testing.

3.2.1 Living Labs

Living Labs are built upon the notion of using external resources as a resource in innovation. Researchers work together with firms, users, public partners and stakeholders to create new solutions, products, services or business models in a real-world setting.

There are five key principles that should permeate all activities in a Living Lab: openness, influence, realism, value and sustainability [8]:

Openness Open collaboration between people of different backgrounds, with different perspectives will stimulate creativity and thereby strengthen the innovation process. For this to be successful one need an open mindset on an individual, team and organizational level as well as stakeholders that are motivated to and have incitement to share knowledge inside and between organizations. In this project, openness was achieved through cooperation with existing research groups at NTNU and participants from local cultural heritage institutions. In addition, the code produced is open source.

Influence Users and other stakeholders are competent partners and domain experts. Their involvement in innovation and development processes contribute to high quality products. Furthermore, users have a moral right to influence technological decisions that affect their personal and professional life. They are a heterogenous group and their needs and ideas should be clearly traceable in concepts, prototypes, and the finished product. The stakeholders influence in this project was ensured by conducting semi-structured interviews before writing down the requirements and by conducting usability tests with prospective users at the end of the project.

Realism Innovation activities should be carried out in a realistic, natural, real life setting to generate results that are valid for real markets. Products and services should be tested in users' real world environments or in environments that are created to be similar to the real world. The realism of this project was ensured by developing an application for a commercial device that is widely available and performing the usability testing in downtown Trondheim.

Value Living Labs activities should produce value both for the end-users and for the different stakeholders. In this project, where no product was released to any end-users, the value is in the collected requirements, the feedback from the users and the assessment of relevant technologies and types of applications. This is the first step on the way to produce a professional mobile augmented reality application with historical pictures from Trondheim.

Sustainability Sustainability in a Living Lab refers both to the viability of the lab and to its responsibility to the wider community in which it operates. In order to achieve a viable lab the stakeholders must be willing to put in the time and effort required to build up and maintain a network. The research component of each lab also have a responsibility to transform the everyday knowledge generated into models, methods and theories. This project have helped sustain a viable living lab in Trondheim by building and maintaining the network between research groups at NTNU and between NTNU and the wider community.

3.2.2 Design Science

The design science paradigm is fundamentally a problem-solving paradigm that seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts.

It involves a rigorous process to design artifacts to solve observed problems, to make research contributions, to evaluate the designs, and to communicate the results to appropriate audiences [4].

Figure 3.1 illustrates the design science research process model for conducting design science research in information systems. It is the result of work done by Peffers et al. [30, 31]. The process is structured in a nominally sequential order; however, it is possible to start at almost any step in the process. After evaluating the artifact in step 5, the researchers can decide whether to iterate back to design and development to improve the effectiveness of the artifact or to continue on to communication and leave further improvement to subsequent projects.

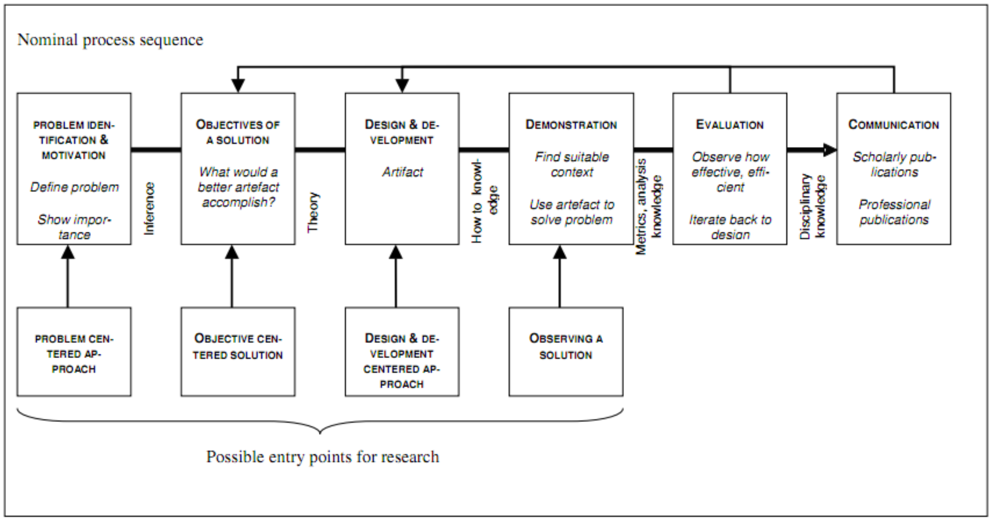

Figure 3.1: Design science research process model [30]

This project was carried out using a problem-centered approach starting with problem identification and motivation. More specifically, it started with two observations:

1. Little has been done to take advantage of new technology and the geographical nature of the photographs when conveying historical images from Trondheim to the public

2. Other institutions with historical image collections that have developed mobile augmented reality applications for smart phones suggest further research to determine if tablets are more suitable for the task [9]

The objective of the project was to develop a prototype mobile augmented reality application for tablets that use image overlays and the location of the user and the picture taken to present historical pictures in downtown Trondheim. The prototype was designed and developed in a rigorous manner, using the results of a study of similar projects and initial interviews with stakeholders to develop user scenarios and elicit a set of system requirements. These were in turn used to determine which features to include in the final prototype. The appropriateness of the system have been demonstrated and evaluated through usability testing and the final results are communicated through the depth study.

The seven guidelines for conducting and evaluating good design-science research developed by Hevner et al. [4] was used to ensure that the prototype was developed and evaluated in a sound manner. The guidelines are summarized in table 3.1.

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contribution	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Table 3.1: Design Science Guidelines

Guideline 1 states that design science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation. The Historical Tour Guide application is the instantiation that constitutes the artifact for this project. The relevance of the problem is covered in the motivation section of the introduction and the solution is thoroughly evaluated in chapter 7. The comparisons of technology in the preliminary study, the results of the interviews with the stakeholders and the feedback gathered during the usability testing are all contributions of this project that satisfy guideline 4. Rigorous methods have been applied in all parts of the development, from semi-structured interviews and development of use cases in the construction of the artifact to the use of the system usability scale in the evaluation. The methods are discussed later on in this chapter. The research has been carried as a continuous search, where we start out with a description of the problem, and arrive at the solution by making informed design decisions. Finally, the results are communicated through this depth study in accordance with guideline 7.

3.2.3 Semi-Structured Interviews

The semi-structured interview is a method of research in the social sciences that allow for focused, conversational, two-way communication [17].

Unlike the structured interview or questionnaire, which has a formalized, limited set of questions, the semi-structured interview is flexible, allowing new questions to be brought up during the interview as a result of the answers to previous questions. The interview can be used both to give and receive communication.

However, even though it is a flexible research method, the semi-structured interview still requires preparation. An interview guide with topics or questions that should be covered during the interview should be prepared beforehand.

The semi-structured interviews was chosen as a research method because it encourages two-way communication. Both the interviewer and the person being interviewed have the flexibility to probe for details or discuss issues. The information collected during the interviews will often provide not just answers, but also the reason for the answers.

The method has it weaknesses. A lot of extra information may surface during the interviews and it can be hard to find the balance between open-ended and focused interviewing. The method is time-consuming and require some skill of the interviewer, who must listen closely and avoid asking leading questions.

Interviews was conducted with relevant stakeholders at the beginning of this project. A discussion of the interviews and the feedback gathered can be found in chapter 4.

3.2.4 Designing for Usability

Both the design science guidelines and the living lab principles stress the importance of evaluating the system to demonstrate its value and utility in a real-world setting. In addition to this, the initial interviews uncovered the need for a system that would be easy to use for people with limited technical background. As a result, it was decided to design and evaluate the system for usability. The results of the evaluation will be used to guide further improvements to the system. This section describes the theoretical foundation for the methods used. The result of the usability testing are covered in chapter 7.

Definition of Usability

ISO 9241 [1] defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use." Nielsen [42] defines usability in terms of five quality attributes:

Easy to learn - so users can go quickly from not knowing the system to doing some work.

Efficient - letting the expert user attain a high level of productivity

Easy to remember - so infrequent users can return after a period of inactivity without having to learn everything all over.

Relatively error-free or error-forgiving - so users do not make many errors, and so those errors are not catastrophic (and are easily recovered from)

Pleasant to use - satisfying users subjectively, so they like to use the system

Both definitions help identify information that is necessary to take into account when specifying requirements for usability or evaluating the usability of the system.

Principles of Usability Design

Not even the best usability experts can design perfect user interfaces in a single attempt [42]. For this reason, interface designers should build a usability engineering life cycle around the concept of iteration.

Gould and Lewis [25] propose early focus on users and tasks, empirical measurement, and iterative design as three principles for system design that can help designers attain a useful and easy to use computer system. They recommend interviews and discussions with potential users prior to system design, early empirical tests where intended users use simulations and prototypes to carry out real work, and an iterative cycle of design, test, empirical measurements and redesign, repeated as often as necessary.

Nielsen [42] recommend an iterative development of user interfaces, involving steady design refinement based on user testing and other evaluation methods. It is possible to perform rigorous evaluations, with a large number of test subjects measured carefully in several different ways while performing a fixed set of tasks. However, the principal outcome of a usability evaluation is not a collection of quantitative measurement data but a list of usability problems and suggestions for interface improvements. In many practical usability-engineering situations, we can gain sufficient insight into the usability problems with only a few test subjects and no collection of quantitative measurement data.

Evaluation of Usability

Nielsen and Molich identifies four ways to evaluate a user interface [45]:

Formally - by some analysis technique, (for example a cognitive walkthrough)

Automatically - by a computerized procedure

Empirically - by experiments with test users

Heuristically - by inspecting the user interface and judging whether it follows established usability principles (heuristics).

The list above is not exhaustive. Inquiry methods, such as focus groups and surveys, can also be used to collect subjective feedback from the users.

When choosing one or more evaluation methods, cost, time constraints, and appropriateness must be considered. Formal analytical methods are for example less successful than the other methods at estimating error rates and are unable to address the “pleasant to use” dimension of usability [42]. Setting up an environment for automatic testing takes more time than what can be justified for the evaluation of a prototype, and the method is unsuited to measure the subjective satisfaction of the users.

The best results of usability testing can often be achieved by combining several methods as one method might find usability problems overlooked by another and vice versa [41]. For this reason, empirical testing with users is often done in conjunction with heuristic evaluation to thoroughly evaluate a system.

An heuristic evaluation is an informal method of usability analysis where a number of evaluators are presented with an interface design and asked to comment on it [45]. Ideally, the evaluation is conducted according to certain rules, such as those listed in a guideline document. Nielsen [43] have developed a list of ten heuristics, general principles for user interface design, that he recommends to use during heuristic evaluations. The heuristics are more in the nature of rules of thumb than specific usability guidelines. However, they explain a very large proportion of the problems one observes in user interface design.

The System Usability Scale (SUS) is a simple, ten-item scale giving a global view of subjective assessments of usability [11]. The scale is a Likert scale. The statements are carefully selected so that there will be an intercorrelation between the answers (agreement between respondents) and the common response to half of them is strong agreement, and to the other half, strong disagreement. The scale is used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. The respondents read through the statements and mark their degree of agreement or disagreement with the statement on a 5 point scale. If they feel that they cannot respond to a particular item, they should be asked to mark the centre point of the scale.

SUS yields a single number representing a composite measure of the overall usability of the system being studied. The score is calculated by summing the score contributions from each item and multiplying the sum by 2.5. Each item's score contribution range from 0 to 4. For items 1,3,5,7,and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. The total score is a number between 0 and 100.

Both heuristic evaluation and empirical tests with users was used to evaluate the final prototype. A discussion of the tests and the results can be found in chapter 7.

Chapter 4

Interviews

As part of the research, semi-structured interviews was conducted with four representatives from cultural heritage institutions in Trondheim. The goal of the interviews was threefold:

- To identify if there was an interest in developing a mobile augmented reality application with historical images from Trondheim.
- To identify if the stakeholders would be able to commit to the project.
- To gather valuable feedback regarding any services or functionality the stakeholders felt would be important in such an application.

An interview guide was developed to identify relevant topics for discussion before the interviews. Only brief notes was recorded during the interviews.

4.1 About the Interviews

The interviews was conducted with a total of four representatives from cultural heritage institutions in Trondheim that have an interest in the web site Trondheimsbilder.no. The interviewees represented NTNU University Library, the owner of a large part of the images available through the Trondheimsbilder.no; the Regional State Archives in Trondheim, responsible for receiving and making accessible to the public archival materials from the area; and Trondhjems Historiske Forening, one of the city's historical societies and the organization behind a number of historical publications about the city.

The interviews took place in the offices of the people interviewed. After the introductions, the interviewees was given a short presentation about the main idea behind the project. The subsequent questions and discussions concerned the web site Trondheimsbilder.no, local history in Trondheim, and the interviewees interest in a mobile augmented reality application with historical images from Trondheim. The original interview guide (in Norwegian) is included in the appendices.

4.2 Local History in Trondheim

The interviews uncovered that there is a large interest in local history in Trondheim. There are several local history societies in the area, both in the city and the surrounding suburbs. In addition to this, there are several large cultural institutions that work with cultural heritage and manage large collections of historical pictures.

One of the local historical societies is Trondhjems Historiske Forening. That society alone has about 400 members. They arrange regular meetings with speakers, publish an annual book and arrange historical tours in the area. The tours are also popular among non-members, but they have trouble reaching out to the younger audiences. The typical member in the club is around 50 years old and have higher education.

NTNU University Library is one of several cultural institutions that manage collections of historical images in Trondheim. They are a part of the Archive Center at Dora and hosts regular events with tours, lectures and exhibitions. They also cooperate with schools in the district. Their experience is that images is an effective way to communicate with younger audiences.

4.3 Experiences from Trondheimsbilder.no

Trondheimsbilder.no is the result of the work of the historical institutions in Trondheim, not the work of the many members of local historical societies in the area. The site was developed as a joint project between the City Archive of Trondheim, Trondheim Public Library, NTNU University Library and Sverresborg Trøndelag Folk Museum. These institutions regularly add new images to the system but no work is done on the front-end as the initial grant only covered development, not maintenance or further work. As a result, the front page states that one can search among 50.000 pictures while a quick search reveals that there are more than 70.000 portraits alone. The site has not been updated since January 2005.

In both 2007 and 2008, students were working on location-based services and mobile applications for the site. Unfortunately, there have been no resources to follow up this work or maintain the servers.

4.4 Interest in and Requirements for a Mobile Augmented Reality Application

There is an interest in a mobile augmented reality application among the stakeholders. One of the historical societies in the city have already been talking of developing a mobile virtual tour guide and would like to see what can be done with Augmented Reality. Another of the historical societies are interested in an application that can be used in conjunction with the already existing tours.

Many of the people that already participate in historical tours and lectures, have limited technical experience. It is therefore important that an application is easy to learn and easy to use.

The University Library at the Norwegian University of Science and Technology is willing to contribute both with selection of images and with access to images without watermarks. Their willingness to do so is essential as they and the other collection owners have copyright to the images available through Trondheimsbilder.no. The images from the site could not be used in the application without their permission. Furthermore, selecting a subset of images from the vast collection at Trondheimsbilder.no is no small task. That the library contribute the time and resources to do so shows their interest in an AR application.

It was agreed that the utility of the app is not so much determined by the number of photographs it contains as it is on the quality of the photographs and the amount of information and quality of information about each one. The major concern was that while they might get funding for development, they would definitely not get any funding for maintenance. For this reason, it would be better to have an app with embedded pictures, than one that required a web service and thus a server that would have to be maintained. It was also mentioned that it would be good if it was possible to integrate advertisements, as this would be a way to fund the development.

A final concern from the University Library was that it should be easy to identify them as the owners of the images. The source and photographer for each image should be included in the application.

4.5 Summary of the Results

Below are the main conclusions based on the findings from the interviews.

- There is a large interest in local history in Trondheim, but the institutions and historical societies have problems reaching out to the younger audiences. Historical photographs might make it easier to reach out to this group.
- The University Library and the rest of the Archive Center at Dora have an interest in developing a mobile augmented reality application with historical images from Trondheim. They will be able to help with access to and selection of images.
- The application developed should be maintenance free. More specifically, it should not be dependent on a server that would have to be maintained and updated after the end of the development period.
- The application will be used by people with limited technical experience. It should be easy to learn and easy to use.
- It is essential that it is easy to identify the University Library as the owners of the images and that the source and photographer for each image is included in the application.

Chapter 5

Selecting and Preparing Materials

A mobile augmented reality application with historical images from Trondheim is dependent upon having images associated with a particular location. The assets must at the least be assigned latitude and longitude. Since none of the images from Trondheimsbilder.no are geocoded, this have to be done manually when adding images to the application.

The four institutions behind Trondheimsbilder.no manages collections that together holds more than one million images. However, many of these are portraits, and thus not connected to a location. Others do not contain enough information to determine the location or are not suitable to use as overlays because they were not taken at street level or contain borders. Finding a suitable subset of the images to show in a mobile augmented reality application is an extensive job and requires some knowledge of the collections.

The head librarian at NTNU University Library chose a subset of 200 images that might be suitable for use in the application. These images was in turn evaluated according to certain criteria, to be able to determine which would be most suitable to include in the application. Finally, the images were located on a map and geocoded.

5.1 Selecting Images

The 200 selected images were first evaluated to find pictures that could be represented as overlays. The following list of criteria was used:

- Located in Nordre gate in downtown Trondheim
- Possible to locate/geocode
- Taken at street level

The first criteria was chosen to allow for a safe and pleasant user-experience and easier usability testing. It was decided to include images from only one street to ensure that when using the application in that street, the users would get plenty of results. Nordre gate was chosen because it is the major pedestrian street in Trondheim. This means that there is a good selection of pictures from the street and that users can use the application in the street without having to fear being run over by a car. The Museum of London has chosen a different approach where they include images from almost all of London's boroughs to engage with as many Londoners as possible [19].

However, that approach would make the application less suitable for use during historical tours or as a virtual tour guide on its own. It would also make reliable usability testing difficult.

The second and last criteria was included to make sure that it would be possible to geocode the images and show them as overlays.

5.2 Locating and Geocoding Images

The original plan was to use Google Street View to locate the images as they did when developing the Augmented Reality by PhillyHistory.org application [9]. However, Google Street view does not cover Nordre gate in Trondheim. As a result, all images had to be located manually.

Google Maps Latitude, Longitude Popup [24] was used to get the longitude and latitude of the locations after the images had been pinpointed on a map. This application lets the user zoom in to the required level and click on the map to get the latitude and longitude of the exact point. The satellite view makes it easier to recognize the location.

It would have been possible to link each image to an area of interest instead of a single point. After all, an image does not depict a single point in space. However, this approach would have made it difficult to show the images as points of interests in the augmented reality view. Another approach would have been to add a direction to the images so that they would only be visible when viewed from the front. However, this could harm the usability of the system as the users would have had to turn around to make sure they did not miss a picture. A more likely improvement in later versions will be to only display the four or five closest points to avoid cluttering on the screen. Another solution to the cluttering problem would be to group the points as suggested by Choi et al. [15].

Chapter 6

Prototype

A prototype for a mobile augmented reality application was designed and implemented as part of the project. This chapter begins with a presentation of the scenarios and use cases that were used to develop the functional and non-functional requirements for the system. The requirements are presented in section 6.2. The chapter ends with a presentation of the final system.

6.1 Scenarios and Use Cases

This section explains the system in more detail by proposing two scenarios that show the application in use. The scenarios are chosen to highlight how the system can be used on its own or integrated into existing activities arranged by the historical institutions and societies in Trondheim. The personas in the scenarios are developed to reflect both the typical user of existing historical resources (male, 30+, starting to settle down) and the user groups museums have had a harder time to reach but might reach with an AR application (younger, no higher education) [35, 19]. The scenarios in themselves are developed to fit with the use suggested during the interviews.

6.1.1 Scenarios

Scenario 1: using the application as an integrated part of a historical tour

Mio is a 30 year old doctor from Trondheim with a growing interest in cultural heritage. He has just bought his first apartment together with his fiancée and wants to learn more about the historical background of the city he lives in. To do so, he signs up for a historical tour in downtown Trondheim. At the time of the sign-up, Mio is informed of the Historical Tour guide application. He thinks it sounds like an exciting idea and downloads the application to his tablet.

On the day of the tour, Mio brings along his tablet. He follows the normal tour, but in addition, he uses the Historical Tour Guide to look at photographs from the past. Not everyone on the tour has their own tablet, but those who have share theirs so all the participants get the opportunity to look at the old photographs. Mio is satisfied when he comes home from the tour that day. Looking at the picture overlays made it easier to imagine how the places must have looked at the past and added an extra dimension to the tour.

Scenario 2: using the application as a virtual tour guide on its own

Maud is a 18 year old high school student enrolled at one of the high schools in downtown Trondheim. She likes to use new technology, but have never been particularly enthusiastic about history. However, after reading about the Historical Tour Guide in the newspaper, she decides to try the app. She downloads the program to her tablet, launches the tour guide and goes to the map view to see if there are any photographs nearby. She discovers that there are a lot of photographs from Nordre Gate and walks there to try the application.

Maud's grandfather grew up in Trondheim in the 1930s so she is curious to see how the city looked back then. She selects to view pictures taken between 1930 and 1939 and goes to the list view to get an overview of the photos. The closest one is not far away. She selects to view the picture and reads more about the motive before looking at the image as an overlay over the current scene. Afterwards, she continues down the street and look at other images from the same time period.

6.1.2 Use Cases

A use case describes the course of action in a more formal way than user scenarios. The use case diagram gives a graphical overview of the functionality provided by the system in terms of actors, their goals (represented as use cases), and any dependencies between those use cases. The textual use cases provides more detail and explains the basic and alternative flows of events. The use case diagram and textual use cases presented below follow the notation specified in the Unified Modeling Language (UML) standard [23].

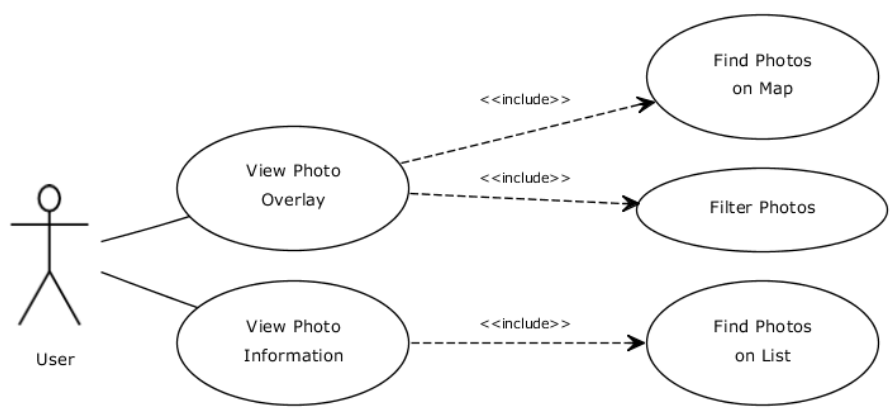

Figure 6.1: Use case diagram

	View photo overlay
Description	User locates an area with photographs and views an old photo as an overlay over the current scene.
Precondition	The user has previously given the application permission to access location information
Basic Flow	1. User launches the application 2. System updates map with the location of the photos and the user 3. User looks at map to find nearby photos 4. User goes to location with photos 5. User holds up the tablet to see points of interest (POIs) 6. System calculates the location of POIs and presents them to the user 7. User selects one of the points of interest to view photo overlay 8. User moves to align the image with reality 9. User closes photo overlay
Alternate Flows	1. The user has used the application before and knows where to find photos. Skips looking at the map in step 3. 2. The user wants to view photos from a specific decade. Selects to do so after launching the application in step 1. The scenario continues at step 2, but only photos from the selected decade are shown. 3. The user wants to know more about the picture after viewing the photo overlay in step 8. Selects to read more about the picture before either returning to the overlay in step 8 or closing the view in step 9.

Table 6.1: Textual use case 1

	View photo information
Description	User views information about a specific photograph.
Precondition	The user has given the application permission to access location information
Basic Flow	1. User launches the application 2. System updates list with titles of photos and distance to user 3. User looks at list and selects to view information about one of the photos 4. System presents photo with information 5. User closes the information view
Alternate Flows	1. The user wants to view photos from a specific decade. Selects to do so after launching the application in step 1. The scenario continues at step 2, but only photos from the selected decade are shown. 2. The user recognizes the motive in step 4 and wants to view the photo overlay. Selects to do so before either returning to the information view in step 4 or closing the view in step 5.

Table 6.2: Textual use case 2

6.2 Requirements

This section describes the functional and non-functional requirements for the system. The requirements have been elicited based on information gathered during the interviews, experiences from similar projects at other cultural institutions, and the scenarios and use cases.

6.2.1 Functional Requirements

FR1 The users should be able to view points of interests in augmented reality in order to find photos in their near vicinity

FR2 The users should be able to view historical images as overlays over the camera feed in order to imagine what the current scene looked like in the past

FR3 The users should be able to view their own location and the locations of the photographs on a map in order to locate where they are in relation to the photos

FR4 The users should be able to view a list of photographs with distance in order to get an overview of the available photos and easily access information about each photo

FR5 The user should be able to filter the images according to decade in order to reduce the amount of information presented and make it easier to find photos of interest

FR6 The user should be able to view more info about the images, including the title, a description of the motive, the year the photo was taken, the source of the photograph and the name of the photographer. The three first items are included to give users the context and help them understand what the picture is trying to convey. The latter two items must be included to be allowed to use the photos in the app

6.2.2 Non-Functional Requirements

The non-functional requirements are global constraints on the software system. They may specify properties the system must possess or constraints on the environment in which the system must exists. Specific attention have been given to task of making these requirements measurable.

NFR1 The application should start up efficiently. Specifically, it should start in less than 5 seconds.

NFR2 The application should be so small that it can be downloaded over Wi-Fi. Specifically, it should be less than 20MB, Apple's limit for Over the Air downloads [3].

NFR3 The application should be easy to begin using. Specifically, users should not be required to fill in user preferences or similar information in order to start using the application.

NFR4 The application should run efficiently. Specifically, each operation, e.g. show a photo overlay or open the map view, should take a maximum of 1 second.

NFR5 The application should be maintenance free.

NFR6 The system should be easy to use. Specifically, at least 80% of users shall say that they agree or strongly agree with the statement: "I thought the system was easy to use" and disagree or strongly disagree with the statement "I think that I would need the support of a technical person to be able to use this system'".

NFR7 The system should be easy to learn. Specifically, at least 80% of users shall say that they agree or strongly agree with the statement: "I would imagine that most people would learn to use this system very quickly" and disagree or strongly disagree with the statement "I needed to learn a lot of things before I could get going with this system".

NFR8 The application should run on iPad 2 devices with Wi-Fi and 3G.

6.3 Presentation of the Final Prototype

The final prototype is called the Historical Tour Guide Trondheim. It is a location-aware mobile information system that uses mobile augmented reality to present local historical photographs in Trondheim.

The system is built atop CroMAR [2], a system that uses mobile augmented reality to support reflection on crowd management. For further details on that system, see section 2.5.3 in the preliminary study. This section presents features in the Historical Tour Guide.

6.3.1 Augmented Reality View

Figure 6.2 shows the augmented reality view. This is the the main view. Points of interest (POIs) are shown as floating icons overlaying the camera feed. The name of the application is shown in the toolbar at the top.

6.3.2 Photo Overlays

Figure 6.3 shows one the application's photo overlays. The transparent overlays over the camera feed let the user see historical images over the present day scene. The buttons in the toolbar at the top of the screen are used to close the overlay or go to the detailed information view belonging to the picture.

6.3.3 Detailed Information Views

Figure 6.4 shows one the application's information views. Each photo has an associated detailed information view that contains a description of the motive and lets the user know when the picture was taken, the source of the photograph and the name of the photographer.

6.3.4 Map

Figure 6.5 shows the application's map. The map shows the user's current position and the position of nearby POIs. Each POI is tagged with the name of the photo and the distance from the user.

The difference between this map and the map in the CroMAR application described in chapter 2 is that this map uses standard iOS controls, and can thus be closed by tapping outside the frame. The image on the button and the size of the map is also changed.

Figure 6.2: Screenshot of the AR view in the Historical Tour Guide

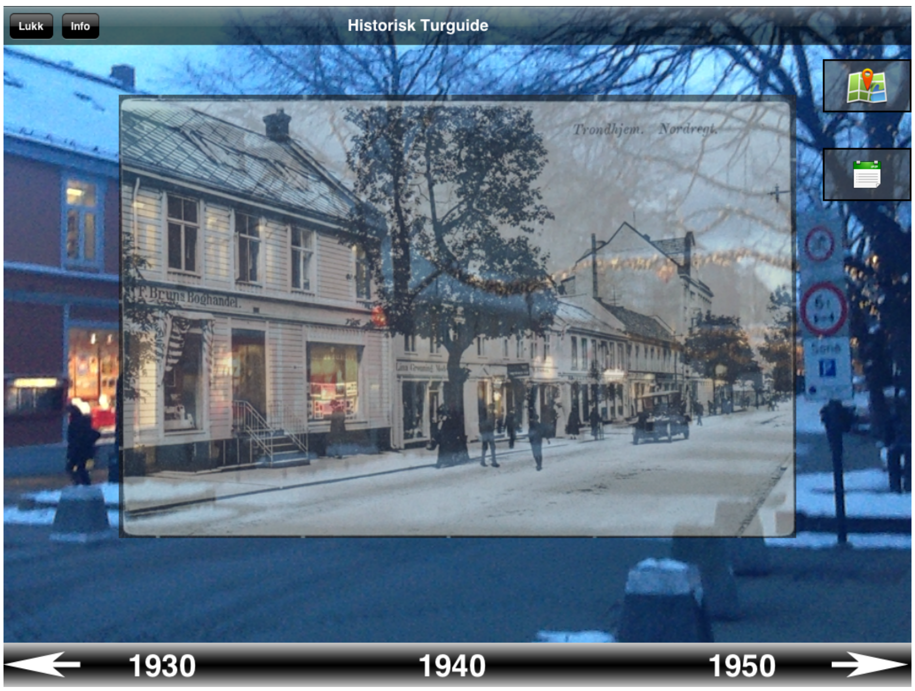

Figure 6.3: Screenshot of the overlay in the Historical Tour Guide

Figure 6.4: Screenshot of the info view in the Historical Tour Guide

Figure 6.5: Screenshot of the map in the Historical Tour Guide

6.3.5 List View and Timeline

Figure 6.6 shows the application's list view. It gives the user a list of all nearby photographs with their distance from the user. The timeline at the bottom of the screen lets the user filter the amount of incoming information so they only see POIs from a specific decade. The selected decade is marked in green and written in the upper-left corner.

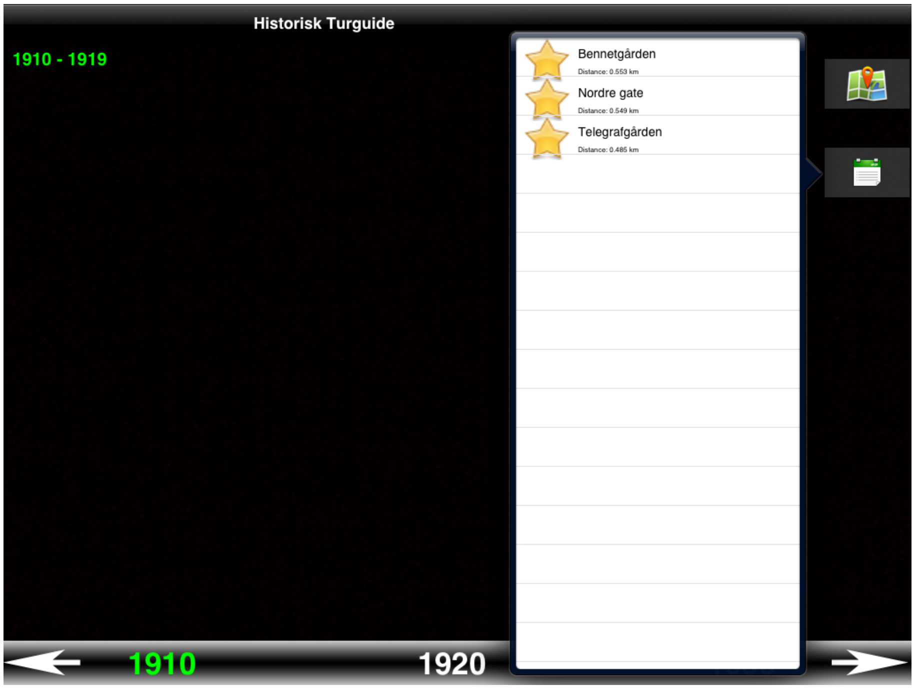

Figure 6.6: Screenshot of the list in the Historical Tour Guide

Chapter 7

Evaluation

The functional prototype was evaluated in order to validate the realism and value of the suggested solution and to see how easy it would be to use for people with limited technical experience.

The evaluation was conducted in three steps: First, a group of computer science students conducted a heuristic evaluation; secondly, the application was tested with prospective users; and finally, it was evaluated to what extent the application fulfilled the functional and non-functional requirements.

7.1 Heuristic Evaluation

Nielsen [45] recommends that the heuristic evaluation is done with between three to five evaluators and that any additional resources are spent on alternative methods of evaluation. In accordance with this, three master students in computer science received a list of Nielsen's ten heuristics and asked to give comments on the user interface of the Historical Tour Guide. An aggregated list of the issues they found is presented below.

- Issue: The map and list view closes when the user clicks outside the window while overlays and info buttons are closed with a click on the close button.

  Suggested solution: All windows should be closed the same way.

- Issue: There are a mixture of red and green markers on the map.

  Suggested solution: All markers should be in the same color unless they depict different types of items.

- Issue: The buttons and map annotations are in English while the rest of the application is in Norwegian.

  Suggested solution: Change all text to Norwegian.

- Issue: The user interface rotates when the iPad is turned upside down but the icons are not shown correctly.

  Suggested solution: Disable rotation.

- Issue: A user that uses the map view to localize a picture will have to go to the list view to open up the image.

Suggested solution: Make it possible to open images directly from the map view.

- Issue: When a year is selected and the user clicks the arrows to look at another part of the timeline, it is not clear enough that the year is still selected. There is a label in the corner but it is easily overlooked.

  Suggested solution: Always show the selected year in the middle of the timeline. Use the arrows to move to the next or previous decade.

- Issue: It is possible to zoom in on the camera feed but the icons do not move or change size.

  Suggested solution: Either make it possible to zoom in on the icons or disable zooming.

- Issue: There is no help or documentation.

  Suggested solution: Make a short user guide.

7.2 Testing with Users

A total of five users participated in the usability tests. Although Nielsen argues that the best results of usability testing come from testing with no more than 5 users and running many small tests [44], this is not enough to draw any final conclusions as to the usability of the system. Nielsen himself states that his formula only holds for comparable users. When there are two groups of users with sufficiently different behavior, as is the case with the Historical Tour Guide, it is necessary to test with people from both groups. Nielsen recommends 3-4 users from each category if testing two groups of users, and 3 users from each category if testing three or more groups of users.

Faulkner [20] argues that it is advisable to run usability tests with the maximum number of participants that schedules, budgets, and availability allow. She has shown while that while some sets of 5 participants may find 99% of the problems in a system; other sets will only find 55%. With 15 users, the lowest percentage of problems revealed by any one set was increased to 90%.

However, the principal outcome of a usability evaluation is not a collection of quantitative measurement data but a list of usability problems and suggestions for interface improvements [42]. It would have been better to test with more users, but the five tests that were run was enough to identify a number of issues and to get some suggestions for interface improvements. A more formal evaluation would have been useful to evaluate the value and realism of the solution, but this was not within the scope of this project.

The evaluations was conducted as part of an iterative design process, where the prototype was updated based on the feedback from each evaluation. Most of the updates happened between the first and second test. Two of the participants in the tests had computer science background and were familiar with tablets. The three others were working at NTNU University Library and the Regional State Archives in Trondheim. They had never used a tablet before.

All the tests was conducted in the same way. The users was given a short presentation of the system, before being asked to conduct a set of three tasks. The original introduction and tasks (in Norwegian) are included in the appendices.

7.2.1 Task 1

The first task consisted of two parts: First, the participant was asked to start up the application, find a nearby picture and view this as an overlay. Secondly, the participant was asked to find the name of the photographer.

All but the first user were able to identify and start up the application. This is probably because of the custom icon and application name that was implemented just after the first user test. The results might not have been so good if the users had to open up an external AR browser and search for the channel with historical pictures.

The users did not understand how to use the augmented reality view to find a nearby picture. This can probably be explained by the fact that none of the participants had any experience with an augmented reality viewer but it does indicate that it might be a good idea to include some sort of introduction or information for first-time users. Furthermore, it was mentioned the star icons that indicate the position of photographs should be replaced by more descriptive icons. Some of the users had trouble selecting a photograph because of the number of icons on the screen. An improvement in later versions would be to only display the four or five closest points to avoid cluttering on the screen.

Finding the photographer turned out to be harder than expected. In order to do so, the user had to push a button placed in a horizontal menu bar anchored to the top of the screen. This is the approach used in the Machintosh operating system, but it was clearly not intuitive for this type of application as none of the participants even registered the navigation bar before they started to search the interface. A more suitable position for the button must be found.

7.2.2 Task 2

The second task was to find the number of pictures from the 1920s included in the application and identify their location. All the participants correctly started out by using timeline. The first user tried to use the map, but was having trouble because of the size of the map view. The size of the map was adjusted and all the other participants successfully completed the task.

7.2.3 Task 3

The third and final task was to find the picture named "Bennetgården". This task was affected by the task above. Three out of five participants did not realize that they were still only viewing pictures from the 1920s. It remains an open question whether the last two consciously unselected the time period or just happened to be lucky. The label showing the time period in the upper-left was clearly not enough of an indication and something must be done to make the use of the timeline easier. All users successfully found the picture after being made aware of the fact that they were only looking at pictures from one time period.

7.2.4 Results from Evaluation Using the System Usability Scale (SUS)

The participants in the usability tests were asked to score the system on the System Usability Scale after they had used the application. Table 7.1 summarize the results. The average system usability score was 76.5.

Non-functional requirement six and seven deals directly with results from the System Usability Scale.

NFR6 The system should be easy to use. Specifically, at least 80% of users shall say that they agree or strongly agree with the statement: "I thought the system was easy to use" (statement

Statement	1 (strongly disagree)	2	3	4	5 (strongly agree)
1. I think that I would like to use this system frequently			2	3	
2. I found the system unnecessarily complex	3	2			
3. I thought the system was easy to use			1	3	1
4. I think that I would need the support of a technical person to be able to use this system	3	1	1		
5. I found the various functions in this system were well integrated			1	4	
6. I thought there was too much inconsistency in this system	1	2		2	
7. I would imagine that most people would learn to use this system very quickly			1	3	1
8. I found the system very cumbersome to use	4	1			
9. I felt very confident using the system				5	
10. I needed to learn a lot of things before I could get going with this system	1	3		1	

Table 7.1: Results from Evaluation Using the System Usability Scale

3 in SUS) and disagree or strongly disagree with the statement "I think that I would need the support of a technical person to be able to use this system" (statement 4 in SUS).

NFR7 The system should be easy to learn. Specifically, at least 80% of users shall say that they agree or strongly agree with the statement: "I would imagine that most people would learn to use this system very quickly" (statement 7 in SUS) and disagree or strongly disagree with the statement "I needed to learn a lot of things before I could get going with this system" (statement 10 in SUS).

As can be seen from table 7.1, both requirements are met. Four out of five respondents agreed or strongly agreed with statement number 3 and 7, and disagreed or strongly disagreed with statements number 4 and 10. However, a total system usability score of 76.5 out of 100 show that there is room for improvement.

7.3 Overall Evaluation

7.3.1 Fulfillment of Functional Requirements

As can be seen from table 7.2, all functional requirements are implemented. The list of requirements is not long. However, during the discussions with end-users after the testing, the wish was for more data, not more functionality.

Requirement	Status
FR1	Fully implemented
FR2	Fully implemented
FR3	Fully implemented
FR4	Fully implemented
FR5	Fully implemented
FR6	Fully implemented

Table 7.2: Status functional requirements

7.3.2 Fulfillment of Non-Functional Requirements

As can be seen from table 7.3, all non-functional requirements are met. Non-functional requirements number six and seven concerns how easy it is to use and learn to use the application and are covered in section 7.2.4.

Requirement	Status	Details
NFR1	Met	Starts up in less than 2 seconds (takes longer the first time)
NFR2	Met	Size less than 4.5MB
NFR3	Met	
NFR4	Met	
NFR5	Met	
NFR6	Met	
NFR7	Met	
NFR8	Met	

Table 7.3: Status non-functional requirements

7.4 Suggested Improvements

During the evaluation phase, a few shortcomings with the initial design were identified. This section lists the enhancements that should be implemented in the next version of the Historical Tour Guide.

- Develop a short and easy-to-read user guide for the application.
- Disable zoom and rotation and make sure all markers of the same type are in the same color.
- Change the timeline so the selected year is always shown in the middle.
- Make it possible to open photo views from the map.
- Implement navigation without buttons in the toolbar.
- Only show the four closest points of interest in the augmented reality view.

Chapter 8

Conclusion and Further Work

8.1 Conclusion

Trondheim Historical Tour Guide is a stand-alone mobile augmented reality system for cultural heritage that is developed specifically to suit the needs of smaller organizations that lack the necessary technical staff and support to maintain a server and do not have the resources to hire someone to do so within their operational budget. The application has gone through a heuristic evaluation and been tested with a small set of users, and it is shown that this is a suitable solution for the cultural institutions in Trondheim.

Three research questions guided the work during the project:

1. Is there an interest in developing a mobile augmented reality application with historical images from Trondheim?
2. What requirements do smaller cultural heritage institutions have for a mobile augmented reality application?
3. Is a tablet a suitable device for an augmented reality application where historical images are presented as overlays?

The first research question concerns whether there is an interest for a mobile augmented reality application with historical images from Trondheim. Interviews confirmed that the cultural heritage institutions in Trondheim have such an interest. Technology acceptance models and theories should be used to determine if the general public have an interest in this type of application. The second research question concerns what requirements smaller cultural heritage institutions have for a mobile augmented reality application. It was uncovered that the institutions in Trondheim are looking for an application that is easy to use for people with limited technical experience. They want an application that requires no maintenance. The last research question concerns whether the tablet is a suitable device for such an application. Initial testing with users indicates that this is the case, but further testing and development is required to verify this.

8.2 Further Work

Trondheim Historical Tour Guide should at the present time be considered as a proof of concept. Further usability testing with resulting improvements is needed to determine if the tablet is a suitable device and to build a user interface that is easy to use for people with limited technical experience. Technology acceptance models and theories should be used to do a more formal evaluation of the system.

In addition, the application should be expanded to include data from other sources such as the censuses and the Street Directory of Trondheim. Both of these contain information on the name, address and occupation on the inhabitants of Trondheim, making it possible to develop an application where the user can select a time period, hold up the tablet in front of a house and see the name and occupation of the people who was living in the house at that time.

Appendix A

Heuristics

Nielsen [43] have developed the following ten heuristics for user interface design:

Visibility of system status

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

Match between system and the real world

The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

User control and freedom

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

Consistency and standards

Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

Error prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.

Recognition rather than recall

Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

Flexibility and efficiency of use

Accelerators – unseen by the novice user – may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

Aesthetic and minimalist design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

Help users recognize, diagnose, and recover from errors

Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

Help and documentation

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Appendix B

Interview Guide (in Norwegian)

- Presenter prosjektet.
- Hvilken rolle har personen i forhold til Trondheimsbilder.no?
  - bruker han/hun siden?
- Hvilken rolle har personen i det historiske miljøet i Trondheim?
- formidling:
  - Hva gjøres?
  - Er det populært?
  - Hvilken aldersgruppe benytter seg av dette?
  - Gjøres det noe spesielt for å henvende seg til barn og unge?
- Interesse for en AR-app
  - Kunne de tenke seg å bruke noe sånt?
  - Holdninger til teknologi i det historiske miljøet
  - Har personen smart phone?
- Ideer til hva som bør være med i appen?
- Er det noe denne personen kan/vil bidra med?

Appendix C

Usability Tasks (in Norwegian)

Den historiske turguiden er en iPad applikasjon som viser deg historiske bilder fra Trondheim. Programmet finner din ut hvor du er og viser deg historiske bilder i din nærhet. Du har muligheten til å se bildene som et ekstra lag over videoen fra iPaden. Du kan også lese mer om hvert bilde, se plasseringen av bildene på et kart eller velge et bilde fra en liste for å få opp informasjon om det bildet direkte.

Applikasjonen inneholder bilder fra Nordre gate i Trondheim og må derfor testes der. Første steg er derfor å gå til Nordre gate. Utfør deretter følgende oppgaver:

Oppgave 1 Start applikasjonen Historical Tour Guide. Finn et bilde i nærheten og se bildet som et ekstra lag over videoen fra ipad-en. Prøv å flytte deg slik at bildet og videoen stemmer overens. Finn ut hvem som har tatt bildet.

Oppgave 2 Finn ut hvor mange bilder fra 1920-tallet som er i nærheten og hvor de er plassert.

Oppgave 3 Finn ut mer om et bilde fra Bennettgården.

Fyll ut SUS-skjema. Spesifikke spørsmål:

- hvordan var det å få bildet og videoen til å stemme overens?
- savnet du noe funksjonalitet?
- er det noe som kunne vært gjort annerledes for å gjøre det enklere å bruke programmet?

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