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Evaluation of Indoor Navigation for the Visually Impaired

User Experience and Requirements

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Master of Science in Computer Science
Submission date: June 2017
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Master's Thesis in Computer Science, Spring 2017

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Abstract

There are many challenges regarding indoor navigation in unknown areas, and the difficulty is higher for the visually impaired. One significant question is the amount of information needed for visually impaired to independently and successfully navigate through complex buildings. In this study, a prototype application initially developed by MazeMap was further developed and maintained. This application was then used to test the amount of information needed and how this information should be presented to the user, and in what detail. An experiment, a survey and interviews were conducted with three participants. The experiment consisted of having the participants testing the prototype application while navigating through a building at Gløshaugen, a campus at the Norwegian University of Science and Technology (NTNU). In the survey and during the interviews, they provided feedback on the application and answered questions regarding their challenges for indoor navigation. The application was evaluated using the Technology Acceptance Model (TAM), focusing on Perceived Usefulness and Perceived Ease of Use.

Based on the TAM evaluation, this thesis concluded that the most important issue that need to be addressed is allowing the user to verify that the instructions are followed correctly. This can be executed by making use of electronic compass and precise indoor positioning systems in the application. Another possibility is using objects such as walls, doors, pillars or other structures as the endpoints in each instruction, since these are detectable with a white cane or guide dog. The research also stresses the importance of giving control to the users regarding the amount of information presented. This is important as different situations and users need different amounts of information.

Sammendrag

Innendørsnavigering er utfordrende i ukjente komplekse bygninger, spesielt for synshemmede. Et sentralt spørsmål er mengden informasjon som synshemmede krever for å kunne, uavhengig og vellykket, navigere gjennom komplekse bygninger og rom. I denne oppgaven ble en prototype-applikasjon, som initielt var utviklet av MazeMap, videreutviklet og vedlikeholdt. Denne applikasjonen ble brukt for å teste hvilken informasjon som er nødvendig og hvor detaljert denne informasjonen må være. I tillegg var presentasjonen av informasjonen til brukeren et fokusområde. I denne masteroppgaven ble et eksperiment, en spørreundersøkelse, samt intervjuer gjennomført med tre deltakere. Eksperimentet gikk ut på å ha deltakerne teste applikasjonen mens de navigerte gjennom en bygning på Gløshaugen, et universitetsområde ved Norges teknisk-naturvitenskapelige universitet (NTNU). Gjennom spørreundersøkelsen og intervjuene, ga de tilbakemeldinger om applikasjonen og de svarte på spørsmål om sine utfordringer ved navigering innendørs. Applikasjonen ble evaluert ved bruk av akseptansemodellen Technology Acceptance Model (TAM) med fokus på opplevd nytte (Perceived Usefulness) og opplevd brukervennlighet (Perceived Ease of Use).

Denne masteroppgaven konkluderte, basert på TAM-evalueringen, med at det viktigste problemet som må bli adressert er muligheten for brukeren å validere at de har utført instruksene korrekt. Dette kan oppnås ved å ta i bruk av elektronisk kompass og presise innendørs posisjoneringssystemer i applikasjonen. En annen mulighet er å bruke objekter som vegger, dører, søyler og andre strukturer som endepunkt for hver instruks, siden disse er lett gjenkjennelige med førerhund eller hvit stokk. Forskningen påpeker også viktigheten av å gi kontrol til brukeren når det gjelder mengde informasjon som blir gitt. Dette er viktig ettersom forskjellige situasjoner og brukere krever forskjellige mengder informasjon.

Preface

This Master's thesis was written in the spring of 2017. It was the only course, representing thirty course credits, in the tenth semester of Compute Science at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway.

We wish to thank our supervisor, Professor John Krogstie, for his valuable feedback throughout this semester.

We would also like to thank MazeMap, in particular Dag Jomar Mersland, Odd Erik Gundersen and Iván Sánchez Ortega for their cooperation in this thesis.

Finally, we would like to thank the members of Blindeforbundet who participated in our experiment.

Eirik Zimmer Wold and Sondre Heggernes Padøy
Trondheim, 8th June 2017

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1 Introduction

In this chapter, the domain is introduced. Information regarding why this Master's thesis problem is important is also presented to explain our motivation for this research. At the end of the chapter, the structure of this Master's thesis is briefly detailed.

1.1 Background and Motivation

A major problem for the visually impaired is navigating through complex buildings, for example hospitals and universities. It is therefore necessary to provide them with navigational tools that can provide them with the information they need. There is a significant difference between providing indoor and outdoor navigation, and outdoor navigation has largely been solved. There can be issues with providing an accurate indoor location to the user and rooms are close together, meaning more precision can be required to navigate.

To address this issue, we will further develop a prototype mobile application, originally made by MazeMap, a company that provide indoor maps and provide indoor navigation instructions. MazeMap had developed this prototype due to a number of requests regarding the need to solve this issue. The application will be documented in this thesis, both in terms of what functionality it provides, and how the code is structured.

The work done in this thesis will be done in parallel with MazeMap themselves creating another prototype to address the same issue. The reason behind this is to create two different applications that can be compared and bring forth new ideas.

While research has been conducted on how to provide a precise indoor position and direction, there has been a lack of focus on what specific information the visually impaired require. There is also a lack of focus on what the application should do when the system is unable to provide a precise location. This was an observation done by us in a specialization project which was completed in the fall of 2016. In this specialization project, a litterature review of indoor navigation for the visually impaired was performed.

In this thesis, the mobile application we develop will be tested and evaluated. The testing will be done in a partnership with Blindeforbudet, an association for the visually impaired in Norway. In addition to the testing, interviews will be conducted in order to provide shared domain knowledge, and thereby improve indoor navigation for the visually impaired.

The work has been done in connection to Wireless Trondheim Living Lab [1], in particular related to the NFR BIA project "Tilgjengelige bygg for alle" (Accessible buildings for everyone).

1.2 Thesis Structure

This chapter is followed by the following chapters:

Chapter 2: Background Theory *In the second chapter, background theory that is useful for the reader to understand the domain and our thesis is provided. This means information regarding visual impairment and how one should develop products that inclusive, and research theory.*

Chapter 3: Method *In the third chapter, the research method is presented. Here, the goal of the thesis is presented, as well as how we intend to achieve these goals. Relevant stakeholders will also be introduced.*

Chapter 4: Related Work *The fourth chapter contains research previously conducted that is related to this thesis. Focus areas for related research is universal design and indoor positioning.*

Chapter 5: Development *Based on the related work and goals previously presented, the fifth chapter will detail a system for indoor navigation for the visually impaired. Requirements, architecture and user stories will be presented, as well as the actual prototype used in the testing.*

Chapter 6: Experiments and Results *The experiment conducted, as well as the results of this experiment will be presented in the sixth chapter.*

Chapter 7: Discussion *Answers to the research questions will be discussed in chapter seven, along with the limitation of this study.*

Chapter 8: Conclusion *In the eighth chapter, a conclusion based on the discussion from chapter seven will be drawn. Also, suggestion for future work will be presented.*

2 Background Theory

In this chapter, information that is either necessary or useful to understand this thesis and its domain is presented. As technology acceptance testing is vital to this thesis, the Technology Acceptance Model is introduced. This is followed by a short introduction to indoor positioning and visual impairment, before the concept of universal design is described. Finally, VoiceOver, a system created by Apple Inc. for iPhones and iPads that makes applications more accessible for the visually impaired is presented.

2.1 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) was proposed in Davis Jr [2] with the goal of detailing what makes a user use an information system. As technology advances it is necessary to know how to make people take advantage of the opportunity the new technology presents. Testing the users' willingness to use a system will also provide information related to how successful the system will be on release.

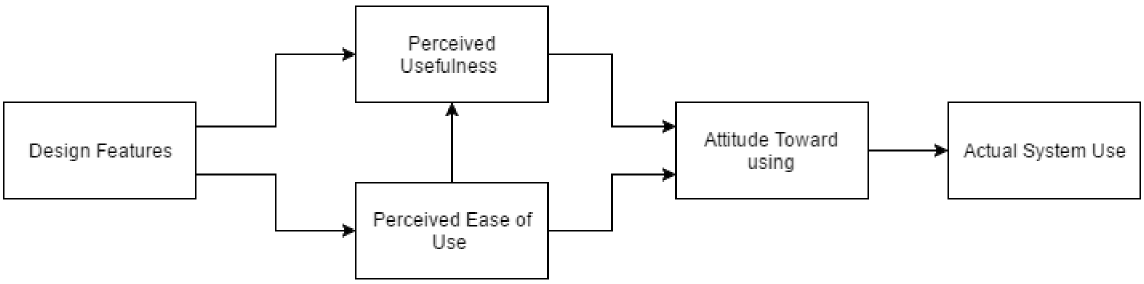


Figure 2.1: Technology Acceptance Model.

2.1.1 Variables in TAM

TAM proposes that there are multiple variables about a users thoughts and feelings toward the technology that affect their acceptance towards use of technology. TAM looks at the significance of these variables and their effect on each other. Figure 2.1 shows these relations with the arrows, for example "Perceived Ease of Use have a positive relationship with Perceived Usefulness" meaning if the technology seem easy to use, then it might seem more useful as well. The variables are detailed below:

Design Features *The model starts at the design features, functionality and graphical user interface for example. Decisions made at this stage influences the perceived usefulness and perceived ease of use.*

Perceived Usefulness *Perceived Usefulness refers to the information system's ability to help the user reach their goal. For example, will the information system allow me to check my bank account balance.*

Perceived Ease of Use *Perceived Ease of Use refers to how easy it is to use the application. A vital aspect of TAM is that the Perceived Ease of Use increases the perceived usefulness of the application.*

Attitude Toward Using *The users intention to use the system, which is influenced by perceived usefulness and perceived ease of use.*

Actual System Use *Actual System Use refers to whether the user ends up using the system. It is affected by the Attitude Towards Using.*

2.1.2 Extensions

There are multiple variances and additions to TAM that have been suggested and researched since TAM was introduced. These extensions add new variables that is believed to significantly affect the users willingness and attitude towards using the technology in question or even affect other variables such as Perceived Usefulness and Perceived Ease of Use.

An example of extending TAM is the mobile services acceptance model (MSAM). Gao et al. [3] developed and proposed this model focusing on acceptance of advanced mobile services that is connected to other information systems instead of being an independent system. This model proposes more factors that have a significant effect on people's intention to use the system. As shown in Figure 2.2, MSAM include factors such as Trust, Perceived Enjoyment, Context and Personal Initiatives and Characteristics in addition to Perceived Usefulness and Perceived Ease of Use. They proposed seven hypotheses on the relationships between the factors and through testing found support for these.

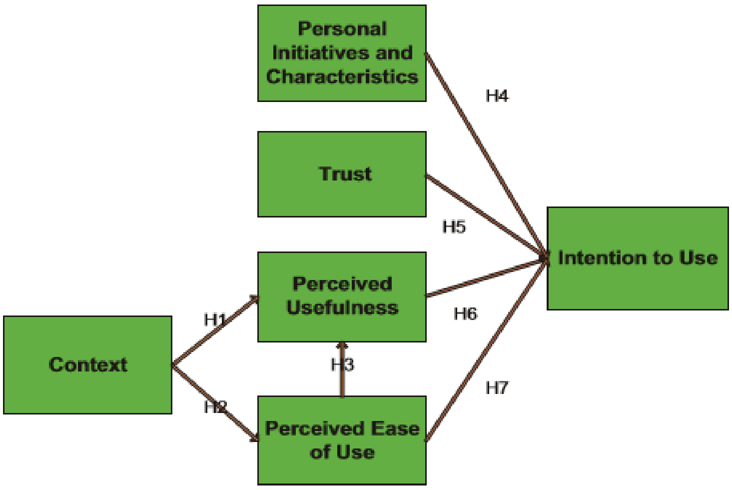


Figure 2.2: Mobile Services Acceptance Model [3].

2.1.3 Limitations of TAM

While TAM is widely used in research and determining success with information systems, it is not without its flaws. There are no situations or systems that are exactly alike and there are other variables that can affect acceptance in different situations. These are some reasons multiple extensions have been proposed and used over the years. Legris et al. [4] mentions that while TAM is useful it needs to be integrated into a bigger model to be able to cover all significant factors. Expanding the model to be of general use however makes it more complex and less understandable and therefore smaller more specific extensions for a given situation are used.

2.2 Indoor Positioning

Technical solutions for indoor positioning are significantly different than solutions for outdoor positioning. While outdoor positioning can easily be achieved through for example the Global Positioning System (GPS), as satellites are easily able to receive accurate signals when there is nothing blocking their path, indoor positioning suffers due to interference. This interference is caused by the signal needing to penetrate walls and roofs. Therefore, in order to achieve an accurate indoor position, infrastructure inside buildings, like Wi-Fi access points and beacons, are used. Research related to indoor positioning will be presented in Chapter 4.

2.3 Visual Impairment

In Norway, visual impairment is divided into five levels. These are called Moderate Visual Impairment, Severe Visual Impairment, Blindness Category Three, Blindness Category Four and Complete Blindness. A person's level of visual impairment is based on the sight of their best eye. A fraction is used to describe their eyesight, with the denominator being the distance a perfectly sighted person can view an object, while the distance the visually impaired person can view the object is the numerator [5]. The differences between the levels are described here:

Moderate Visual Impairment Moderate Visual Impairment is the lowest degree of visual impairment. A person with Moderate Visual Impairment has an eyesight between 6/60 and 6/18.

Severe Visual Impairment Severe Visual Impairment is the second lowest degree of visual impairment. It is the level for people with an eyesight between 3/60 and 6/60.

Blindness Category Three Blindness Category Three is a level of visual impairment where the person has an eyesight between 1/60 and 3/60. A person can also be in this category if their visual field is between ten and twenty percent.

Blindness Category Four Blindness Category Four describes people with an eyesight below 1/60. This level is also used when a person has visual field below ten percent.

Complete Blindness If a person does not have any light sensitivity, they are placed in the Complete Blindness category.

2.4 Universal Design

A way to make environments and artifacts accessible for everyone, regardless of age and abilities, is to use the concept of universal design. In addition to this, it is important that the environments and artifacts are accessible without the need for adaptation. This means that other users should not be negatively affected by the accessibility [6].

Universal design consist of seven principles, which are described here:

Equitable Use *Equitable Use means that the artifact is useful for people regardless of abilities. For example an application that supports text-to-speech to present information can be used by both the visually impaired and those with no visual impairment.*

Flexibility in Use *Flexibility in Use is that the user can modify the artifact based on their preferences. An example is allowing a near sighted user to modify the size of the text on an application to make it more easily readable.*

Simple and Intuitive Use *Simple and Intuitive Use refers to making an artifact easy to use regardless of the user's previous experience or abilities. This could for example be having a high usability on an application.*

Perceptible Information *Perceptible Information means that the artifact makes the necessary information easily available to the user regardless of their abilities.*

Tolerance for Error *Tolerance for Error refers to the artifact's ability to minimize the consequences of unintentional actions. If an application has a button that allows the user to regret their previous action, the tolerance for error increases.*

Low Physical Effort *Low Physical Effort means that using the artifact causes minimal physical fatigue. An example of this is having a button that opens a door so that the user does not need to exert energy opening it themselves.*

Size and Space for Approach and Use *Size and Space for Approach and Use is that the artifact can be used by anyone regardless of their size, posture and mobility. For example, having a large handle on a door that people of all heights are able to easily reach would make the door more accessible for people of all sizes.*

2.5 VoiceOver

VoiceOver is a service provided by Apple Inc. that enables iOS, the operating system for iPhones and iPads, applications to become more accessible for the visually impaired. Some of its functionality is listed here:

Gestures *VoiceOver allows the user to explore an application using their finger. The application will then tell the user what they are touching.*

Text Input *The keyboard on the iPhone becomes more accessible with VoiceOver allowing you to click on a character to hear what button the user pressed, while a double tap allows the user to enter this character.*

Rotor *Users can scroll through all images, text and buttons by rotating two fingers on the screen. This means that the user does not have to search for the location of buttons and text they wish to access.*

Font Adjustments *Allows the user to change the size of text in applications to make it more easily readable.*

Zoom *The user can zoom in on certain parts of the screen to make it more easily readable.*

Speak Screen *VoiceOver provides text-to-speech functionality.*

3 Method

In this chapter, the goal of the research is presented. This goal is achieved by answering three research questions. The methodology for an experiment is detailed as well, since the experiment is necessary to reach the goal. The presentation of the methodology is based on the paper by Preece and Rombach [7].

3.1 Goals and Research Questions

A key challenge when developing a system for a specific group of users is knowing exactly what they need to accomplish their goals. Through interviews with visually impaired people, and the evaluation of an application for indoor navigation for the visually impaired, we hope to achieve an understanding of their needs. It is possible to provide a large amount of information, however, it is also necessary to consider the usability of the application. Therefore, we wish to find the sweet spot for providing useful information to the user, while also not flooding them with information they fin unnecessary.

Goal *Gain an understanding of what the visually impaired need for indoor navigation.*

Based on this goal, we have created the following research questions:

Research question 1 *What information is always needed to properly navigate indoors?*

Research question 2 *How much of the information should be presented at once?*

Research question 3 *What functionality do the visually impaired require in order to navigate independently indoors?*

3.2 Experiment

In order to reach our goals, we believe it is necessary to conduct an experiment. An evaluation of a mobile application will be performed.

3.2.1 Study Goal

Purpose

The purpose of the experiment is to gain an understanding of how much information is necessary for the visually impaired to navigate through complex buildings. While we are evaluating an application, the goal is not to verify if the application can be released, or to learn what improvements is necessary for it to be released. The user interface is also not relevant for this experiment as long as the usability is not so poor that it hinder the test of the functionality.

Focus of Study

Reliability is the main focus of this study. We wish to understand what is necessary to provide a reliable solution for the visually impaired in order to navigate complex buildings. In this context, reliable means that the solution can for example handle an inaccurate indoor position, by providing the necessary information to navigate the building.

Viewpoint

We are interested in the viewpoint of the end-user in this experiment. Here, this means visually impaired people who need support in order to navigate complex indoor environments. In order to answer the research questions, it is necessary to focus on the end-user, as they will be aware of the information they need during the experiment.

3.2.2 Study Plan

Learning Approach

The learning approach for this study is usability engineering. In the experiment, the focus will be on human-computer interaction with the test participants performing tasks. The researchers will collect quantifiable data during the experiment, and will also discuss the results with the participants in order to gain a shared understanding of issues and possible solutions.

Study Design

The experiment has a replicated project layout. Multiple test subjects will be given the same task with the same amount of resources in the same environment. Every participant in the test will be provided the same origin and destination, and use the same version of the mobile application to navigate through the building. This is done to increase the detection of faults and necessities for indoor navigation for the visually impaired. See Section 6.1 for details on the experiment.

Study Control

During the experiment, the researchers will only observe the participants in order to have a minimum amount of influence on the results. After a short introduction of how to use the mobile application, the researchers will remain silent while taking notes until either all tasks have been completed, the participant asks help or the participant wishes to end the testing. After the test has been completed, the researchers will have a significantly higher influence, as they will conduct a survey on the participants, and discuss the results with the participants. While it is not the researchers goal to influence the answers from the participants, it can be difficult for some to be critical of the researchers' mobile application and ideas in a face-to-face conversation. On the other hand, if the participants are unclear about any of the questions, they can be explained and clarified.

Study Location

As we intend to gain an understanding of real life scenarios, the experiment will be conducted in a natural setting. The location will be the campus Gløshaugen, at the Norwegian University of Science and Technology (NTNU). This university has complex and large buildings, that will provide the same difficulty as hospitals and other universities. We will not seal off the area where the experiment is conducted, meaning that both students and employees at NTNU can be an obstacle during the experiment.

3.2.3 Study Methods

Here, the study method will be detailed. The different participants and their activities will be described. Finally the timing of the activities will be presented.

Participants

In this study, there are two researchers: Eirik Zimmer Wold and Sondre Heggernes Padøy. Both Padøy and Wold are students at NTNU, and are currently writing their Master's thesis. There are also three members of Blindeforbundet partaking in the study, with the role of end-user.

Activities

The responsibility of the researchers is mainly to collect data during the experiment. This is done through observation, surveys and interviews. In addition to this, a tutorial for the participants must be conducted by the researchers. The end-users will perform tasks while being observed. They will also answer a survey regarding the experiment through. In addition to this an interview with each participant will be performed. During the interview, one researcher will take notes, while the other researcher asks questions and discuss with the interviewee. Once all data is collected, the researchers will analyze it, and discuss their findings, and write a conclusion to answer the research questions.

Timing of Activities

Once the mobile application has been developed and tested by the researchers, the experiment will start. After the experiment has been completed, surveys and interviews will be conducted. Finally, when all data has been collected, discussions and documentations of the findings will be performed.

3.2.4 Study Technique

Nature of Data

The data collected will be quantifiable. During the experiment, the researchers will write comments of their observations, the surveys will be answered with a number and the interviews will presented as comments. Comments from different interviews can then be compared to observe trends. Interviews will also be recorded to ensure validity of the data. The results and discussions will be presented in this report in Chapter 6.

Data Handling Mechanisms

Data is collected through observations, surveys and interviews. In order to validate the data, discussions between test participants and researchers will be performed. The researchers will also discuss their observations between themselves. In addition to this, the researchers will read related research and see if these papers draw similar conclusions as the researchers and test participants. This ensures that the conclusions drawn are based on multiple sources.

3.3 Interview

3.3.1 Research Model

The prototype used for testing is not a finished product and has been set up to be able to test specific scenarios and aspects of using a indoor navigation application. To see to what degree these aspects are being accepted and understood is the primary goal of the experiment. To understand this, the survey and interview questions are targeting the Perceived Usefulness and Perceived Ease of Use of the participants.

In order to determine the Perceived Usefulness of the application, the participants will respond to questions related to:

- Whether and to what degree the application enables them to achieve their goal
- Whether and to what degree the application enables them to achieve their goal more efficiently
- Whether and to what degree the application enables them to achieve their goal more easily
- Whether and to what degree the application overall is useful to achieve their goal

To understand the application's Perceived Ease of Use, questions were asked to determine:

- Whether and to what the degree learning to use the application was easy

- Whether and to what the degree getting the application to do what the user wishes was easy
- Whether and to what degree the application is rigid and inflexible
- Whether and to what degree the application overall is easy to use

Finally, to determine the users' Attitude Towards Use, questions detailing the following was asked:

- Whether and to what degree the user would be willing to use the application in their daily life

The precise interview questions are written in Norwegian, as our test participants are all from Norway. These are detailed in appendix 1.

3.4 Deviations from protocol

Due to MazeMap's limited access to possible participants for the experiment, it was decided that MazeMap would conduct testing of their own application right after our test was completed. This meant that interviews and surveys were conducted after a person had tested two applications and it was possible that this influenced their answers during the survey and interview. For example, a participant in the experiment could claim to give a score based on our application, when they instead were thinking of MazeMap's application.

A representative from MazeMap also asked questions to the participants during the interview, and we decided to include information from their question in our results if it was deemed relevant to the research questions. This also provided us with the opportunity to compare two solutions to make it easier for the participant to evaluate the application developed for this thesis.

4 Related Work

In this chapter, key research related to our thesis is presented. It includes research found by us, by MazeMap, and papers found on Google Scholar, a search-engine for scientific papers. The research is divided into three domains: indoor positioning, requirements for the visually impaired and indoor navigation. A short description of a popular commercial navigation applications for the visually impaired is also presented.

4.1 Research

In the fall of 2016, we conducted a literature review in order to gain an understanding of the domain. We were provided information by MazeMap regarding their previous work in a collaboration with an NTNU bachelor's thesis [8]. They performed some early testing in addition to interviewing four visually impaired people. Due to limited resources for the students writing their bachelor's thesis, MazeMap wanted us continue to explore the domain.

4.1.1 Indoor Positioning

To provide a precise indoor position, several technologies have been researched. Rajamäki et al. [9] presented a system called LaureaPOP, which used unmodified existing Wi-Fi access points in a building to provide indoor position to the user. These Wi-Fi access points were used for trilateration, which means that a position is detected based on the signal strength from multiple transmitters. In order to allow the visually impaired user to communicate with the system, LaureaPOP used a speech user interface with the Voice over Internet Protocol. The indoor position provided by trilateration has also improved significantly over time. In 2009, the average error was slightly below four meters when Mazuelas et al. [10] conducted their research, while in 2015 improvements had decreased the error to one meter in Yang and Shao [11]. The main disadvantage is that Wi-Fi access points are not available in every room, so the signal is affected by walls, ceiling and floor.

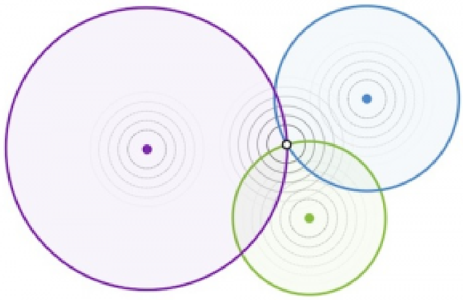


Figure 4.1: Trilateration [12].

Another method to provide indoor positioning is adding new infrastructure to buildings, for example beacons. If beacons are added to every room, they can avoid the issue of interference from walls. Willis and Helal [13] used Radio Frequency ID tags in their system, while Gualda et al. [14] used Bluetooth beacons and Rainer [15] used beacons that communicate with infrared light. Beacons however, cost money to produce and require resources to place and maintain in a system.

Magnetic fields can be used to provide indoor position by mapping the magnetic signal detected at indoor locations. However, they suffer from interference from electronic equipment, which then can cause the system to present the user with an incorrect position. Montoliu et al. [16] concluded that it requires a significant amount of work-hours in order to document the magnetic signal at indoor locations and provide an accurate positioning system.

In Tilch and Mautz [17], a solution using optical lights was discussed and tested. Rooms were equipped with lasers pointing at ceiling, while the user used a system with a camera. Based on the angle the camera viewed the lasers, and what wavelength the lasers had, the system is able to to detect which room it is in, and its location within this room. The infrastructure needed for this solution is only the lasers and a system mapping the location with the lasers. Smartphones are widely used by people, and the users will therefore already have access to cameras.

Another way of using a camera for indoor positioning is with machine learning. This was tested in Golding and Lesh [18], where a system using multiple sensors was able to discern the users position with a 98 percent accuracy. The use of machine learning however, requires the system to be trained to detect every location within a building. This means that it requires significant manpower in order to obtain enough training data for this solution to be useful in large and complex buildings.

Since the issue with using the Global Positioning System (GPS) is the interference due to the walls and roofs, a solution is to have a stronger signal. This can be created with pseudolites, which can provide strong signals and cover larger areas. In Gioia and

Borio [19], they found that pseudolites can provide indoor positioning with meter-level accuracy, meaning a significantly better solution than using a GPS-only solution. They presented that in a partially obstructed scenario, the maximum positioning error was reduced by a factor of ten.

Figure 4.2: Pseudolite [20].

If a system has access to a users initial position, it is possible to provide a position while the user is navigating through a building with the use of dead reckoning. Dead reckoning uses an initial position, while collecting the users current speed and direction to continually provide a position to the user [21]. This system therefore requires no infrastructure, however, since there is no way for the system to correct an error, either in the initial position or errors in the collection of information regarding the user's movement, errors will increase over time.

4.1.2 Requirements for the Visually Impaired

Surveys regarding how visually impaired respond to errors from digital equipment were performed in Abdolrahmani et al. [22]. They focused on false positives, which caused the testers to enter wrong rooms, and false negatives, where the system believed they were in the wrong location when the user was at the correct location. Testers were significantly more forgiving of false negatives. The study also found that users were more forgiving of errors when they used the system in a challenging environment.

Avila et al. [23] also conducted a survey. It focused on the issues of using an application while navigating for the visually impaired. One of the struggles they detected was that users found applications distracting as they had to occupy one of their hands with a smartphone at all times. This became a great annoyance when they were using a cane while also for example carrying bags from a grocery store. Williams et al. [24] came to similar conclusions, and also pointed out that users disliked having to interact with the application all the time in order to obtain the information they needed.

Kulkarni et al. [25] focused on how to make useful technology more enjoyable to use for the visually impaired. For example, they claim that allowing the user to change the voice of the text-to-speech functionality can increase satisfaction with the system. Another minor detail they present is that if a robotic cane is used, users will find it more comfortable if it has a wooden handle instead of a metallic one. They also focused on usability in this paper, presenting that users clicking on a button to get an explanation of the button's purpose, while double clicking activates its functionality would make the system easier to use.

Hub et al. [26] presented some key information the visually impaired find helpful when navigating through complex buildings. These key pieces of information include type of doors and stairs the user will find in their path, size of rooms and the number of floors in the building. This information can either be obtained through sensors, like in Diepstraten et al. [27], or by knowing the users specific location in a building. Both solutions require a digital model to contain the information.

4.1.3 Indoor Navigation

In recent year, building information modelling (BIM) has been created for complex buildings. These contain information regarding buildings that applications can easily access [28]. This information can for example be description of rooms, landmarks or stationary obstacles. However, BIM are not always available, and applications require digital information when images of maps are the only information that exist. If so, the images must be analyzed, for example with a rule-based approach or through machine learning.

If BIM are available and contain information regarding landmarks, it opens the possibility for landmark-based navigation. Landmark-based navigation means that someone uses landmarks instead precise distance and direction to describe the route between two locations. One of the main advantages with landmark-based navigation is that it allows the user to verify that they have followed the instructions correctly. If someone is asked to walk past a cafeteria, it is easy for this person to know if they have arrived at a cafeteria. This makes landmark-based navigation especially useful when someone is navigating on unknown environment [29]. While the visually impaired are unable to see landmarks, they can still detect them due to scent or sound, for example the scent of food from a cafeteria [30].

4.1.4 Supplementary Technology for Indoor Navigation

Even if the visually impaired know the precise route they need to take to reach their destination, indoor navigation can still provide issues. For example, obstacles that are not detailed on the maps that the application is using can provide challenges or annoyances. In Ulrich and Borenstein [31], they created a white cane that is able to detect obstacles through ultrasound sensors, and was able to steer the user around them. During tests, the users were able to walk one meter per second while avoiding obstacles. The advantage of using an enhanced white cane is that the user will not be required to use both their hands to navigate, as the user usually already requires a white cane. This enables the users to for example carry groceries while navigating.

Smartphones can also be used to detect obstacles, due to their camera. The main issue with using the camera, is that the camera lens will struggle with providing clear images while the user is moving. In Chan et al. [32], they used an algorithm to increase contrast in the images, which allows the software to more easily detect edges. Edges are vital, as they separate objects from each other, like walls and tables. The application can then provide the information to the user. This solution provided useful assistance without adding any cost to the user, as most people already have a smartphone. However, it requires the user to use one of their hands to hold the smartphone in front of them, while they may have to use the other to hold a white cane or a guide dog, which can cause annoyances for the user [24].

Wearables are another possible supplementary technology for the visually impaired. In Schirmer et al. [33], they presented a shoe that vibrated in the direction the user should walk, while Henze et al. [34] had previously proposed a system of multiple vibration devices that would be placed on the users arms and back to provide the user with feedback on correct direction. The users direction was detected with an electronic compass.

4.2 Commercial Applications

BlindSquare is an application for outdoor navigation for the visually impaired. It uses GPS for positioning, and retrieves data regarding points of interest in order to be helpful for the user. For example, it notifies the user of intersections. It can also present the user with their location when the user shakes their smartphone, allowing them more easily recognize locations they have been before. All information is presented with text-to-speech, to make sure the user can obtain the information they need. It can also notify the user if they are near or have reached user generated points [35].

5 Development

In this chapter, the prototype application developed for this thesis is described. First, scenarios and use cases for the prototype is presented. Second, the software requirements are listed followed by the architecture of the prototype application, shown through the 4+1 architectural view model. Thirdly, some implementation choices are presented as well as the application as a whole. An additional application will also be introduced. This application was developed entirely by MazeMap, and due to this, the architecture for this application will not be presented.

5.1 Scenarios and Use Cases

This section presents a detailed description of how the application will be used. Two visually impaired personas will be used to create realistic scenarios for the evaluation that will be performed. These personas are based on information obtained in a literature review conducted in the fall of 2016. In addition to the scenarios, use case diagrams will be produced to detail how the flow of the application will be.

5.1.1 Personas

Riley is a 22 year old student who is moderately visually impaired. While she is able to avoid obstacles and detect the dimensions of rooms, navigating through complex buildings, which are plentiful at the Norwegian University of Science and technology (NTNU), can still provide issues. In order to save time, she often relies on asking strangers about directions, however, she prefers to be independent during her daily life. Therefore, she decides to download the application.

Ian is a 24 year old blind student at NTNU. Recently, he broke his leg, and therefore he uses crutches. The university consists of many buildings, all with multiple floors. While he has learned the route to all of his lectures, group assignments require him to navigate to new rooms every week, as many of the rooms dedicated to group work are often occupied by other students. By downloading the application, he hopes to simplify his navigation process.

5.1.2 Scenarios

Riley had a lecture in TDT4175 Information Systems, and once it was completed she joined some friends at a cafeteria where they could talk. After an hour she has to leave in order to go to a lecture in TDT4136 Introduction to Artificial intelligence. As she is the only one among her friends at the cafeteria to have that course, they are unable to give her the route to the lecture from the cafeteria. She therefore requests the route from the application in order to avoid needing to ask strangers. The application gives her the instructions she require through text-to-speech. During navigation, she has to walk down one set of stairs, and is notified of this to ensure that she does not encounter any surprises. When she finally arrives outside the lecture hall, the location of the entrance is presented, and she is able to enter the room.

Ian is taking the course TDT4140 Software Engineering at NTNU, a course where the grade is decided by a group project. His group try to use the same room, F203 at Elbygget at Gløshaugen, every week, however, one time this room was reserved by other students. The group leader has reserved the room Zoo-4 at Realfagsbygget instead. Ian has never been to this room before, however he knows the location of Realfagsbygget, a building at Gløshaugen. Therefore, he asks the application to provide him the route from the entrance to room Zoo-4. Due to his leg injury, he prefers to avoid stairs if possible. The application describes then presents the route. During navigation, he is presented with the location of the elevator and the floor he needs to take it to. As he can easily access the information, he is able arrive to the meeting on time.

5.1.3 Use Cases

In order to formalize the scenarios, we created use cases. These present the actions the user can perform, either with a graphical or textual representation. In this thesis, the unified modeling language (UML) was used to create the graphical diagram, while two tables present the textual use case.

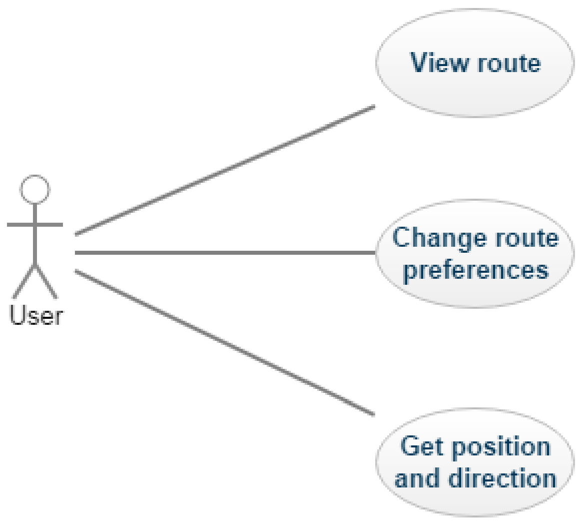


Figure 5.1: Use Case Diagram.

This diagram displays that the user should be able to receive instructions regarding a route, from origin to the destination. How the user gains access to this information is presented in the first textual use case (Table 5.1). Another case the diagram presents is that the user can change route preferences, meaning deciding whether they prefer using an elevator or using the stairs to move between floors. How this is done is described in the second textual use case (Table 5.2). Finally, the user should be able to obtain their position. This is used in both textual use cases as one of the actions.

Goal	Get route from current position to destination
Description	The user gets the route from their current position to their destination with a step by step description.
Pre-condition	Internet access on mobile phone
Basic Flow	1. User selects “Get Route”. 2. User selects “Start position”. 3. User selects “Use current position”. 4. User selects “Destination”. 5. User enters destination. 6. User selects “Start”. 7. Application calculates the shortest path. 8. User selects “Full path”. 9. Application uses text-to-speech to describe the route.
Extensions	

Table 5.1: Textual Use Case 1.

Goal	Change preferences and get new route
Description	The user changes preferences to avoid having to walk up stairs on their route to their destination.
Pre-condition	Internet access on mobile phone
Basic Flow	1. User selects “Set preferences”. 2. User selects “No stairs”. 3. User selects “Get Route”. 4. User selects “Start position”. 5. User selects “Use current position”. 6. User selects “Destination”. 7. User enters destination. 8. User selects “Start”. 9. Application calculates the shortest path without stairs. 10. User selects “Full path”. 11. Application uses text-to-speech to describe the route.
Extension	9b. No available path without stairs. 9b1. Application notifies the user of this.

Table 5.2: Textual Use Case 2.

5.2 Software Requirements

Based on the scenarios and use cases, a list of software requirements were created. These were split into functional and non-functional requirements. Functional requirements describe what the system should do, while non-functional requirements impose restrictions on the system.

5.2.1 Functional Requirements

FR1 *The application shall find the route between the origin and destination.*

FR2 *The application shall provide a step by step description of the route.*

FR3 *The application shall provide the user with the option to avoid stairs.*

FR4 *The application shall present the route on a map.*

FR5 *The application shall be able to obtain the user's current position through GPS.*

FR6 *The application shall support text-to-speech.*

FR7 *The application shall be able to update the user's current position while the user walks to their destination and provide up-to-date directions.*

Figure 5.2: List of functional requirements.

5.2.2 Non-Functional Requirements

NFR1 *The application shall be accessible for blind users.*

NFR2 *The application shall run on smartphones.*

NFR3 *The text shall be of a large size to support visually impaired users.*

Figure 5.3: List of non-functional requirements.

5.3 Architecture

To describe the architecture of the application, the 4+1 architectural view model was used. It describes the application from multiple point of views. The physical view depicts the physical artifacts the software runs on, and the relationship between them. To depict the functionality of the system, the logical view is used. The development view showcases the relationship between components from a developers point of view. Meanwhile, the process view describes the system at runtime. Scenarios are also a part of the 4+1 architectural view model, yet were presented in the previous section, therefore it will be skipped here.

5.3.1 Physical View

The application relies on two servers, the MazeMap server, which provides an application programming interface (API) for the second server, where the developed software runs. MazeMap's API provides the shortest path between two locations. Our server have door locations on the NTNU Gløshaugen campus, and runs the developed application. This application is then accessed by a mobile phone through Google Chrome, an Internet browser.

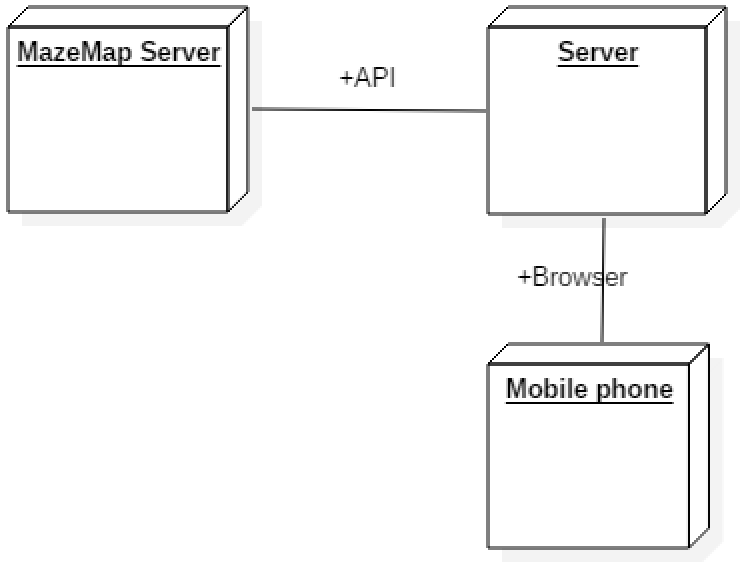


Figure 5.4: Physical View.

5.3.2 Logical View

The implementation of the application consists of JavaScript and HyperText Markup Language (HTML) files. A list of the files and their main purpose is provided here:

Debug *Allows the user to input origin and destination to obtain their path. Can then send this information to Demo with a URLPath. Also gives additional information on the data retrieved and created for easier debugging*

Demo *The website users will interact with during use. It retrieves the map and path through the MazeMap API. Demo will also access the JavaScript files through PathDivider.js in order to provide the user with information regarding their path.*

Main *Imports all JavaScript files.*

Pathdivider *Transforms all the files Main.js has imported to one large file, in order for Debug and Demo to have easy access to all the JavaScript files and easier putting the application on a temporary server.*

Control *The controller that holds the different classes that handle and transform data, and gives Demo and Debug access to it*

Path.js *This class takes the information retrieved from MazeMap for the route and creates the steps that the whole path consists of*

Segment *Holds the information of one part/step of the route. Calculates the distance between steps into meters from coordinates as well as distance from the end of the step and the users position.*

Doors *This class that holds the information of doors on the map. This is used to detect doors in the path so the user can be aware of doors as obstacles*

Rooms *Rooms.js holds rooms and information regarding these rooms.*

DirectionButtons *This class creates buttons that allows the user to interact with the application and obtain the step-by-step directions.*

Describer *Describer creates the textual description of the path based on information such as distance, elevation, if there is a door in the way or if the step involves stairs, elevators, walking out of or into a building.*

The following diagram depicts the organization of the classes. It provides the name of the classes, as well as all the functions each contain. The relationship between the classes is also presented.

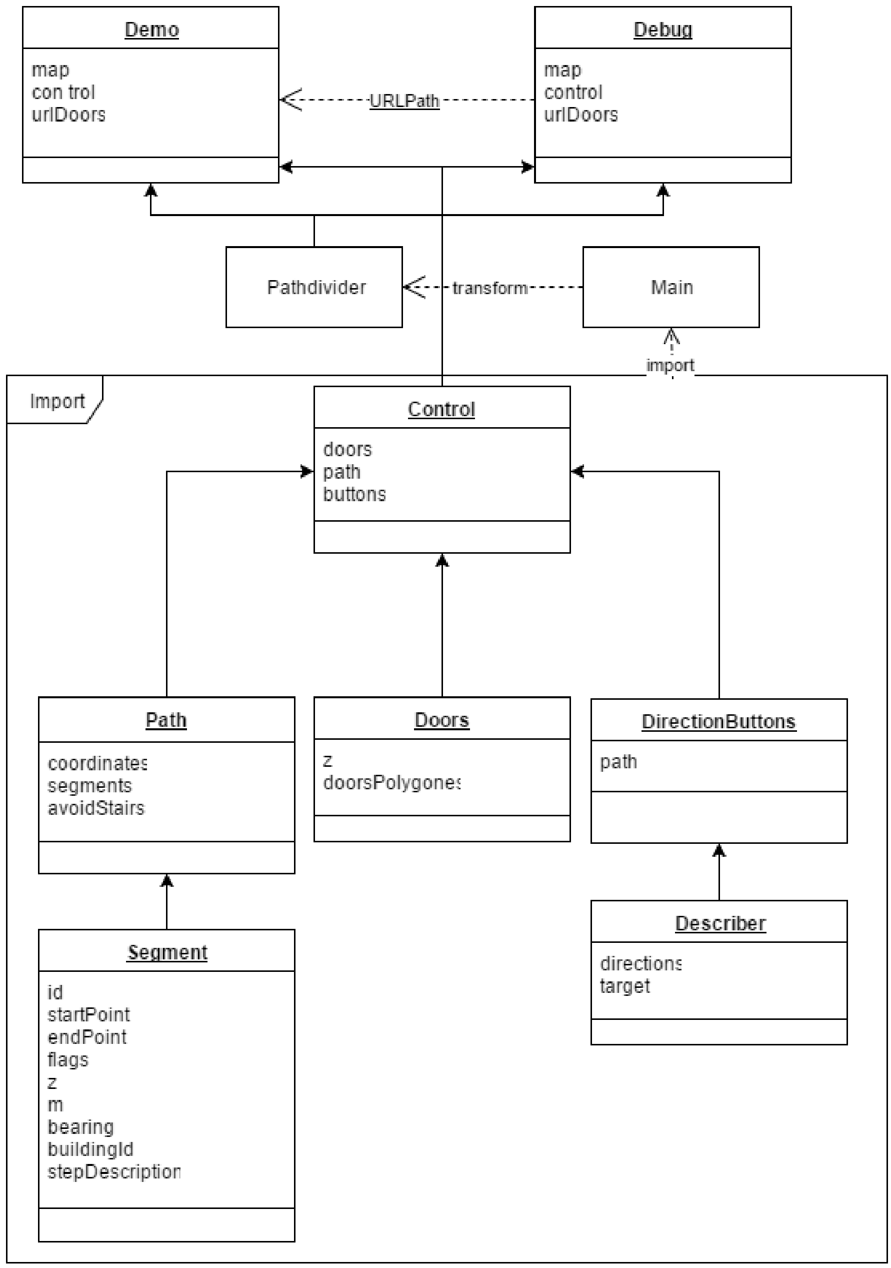


Figure 5.5: Logical View.

5.3.3 Development View

The server runs scripts that provide the logic for the application. Accessing the MazeMap API is also the responsibility of the script, as the application will need this API in order to provide the path to the user. The server will also host the website pages that the user can access. These pages are written in HTML, which makes them readable for Internet browsers. The user will therefore be able to access the application on their smartphone if they have access to the Internet.

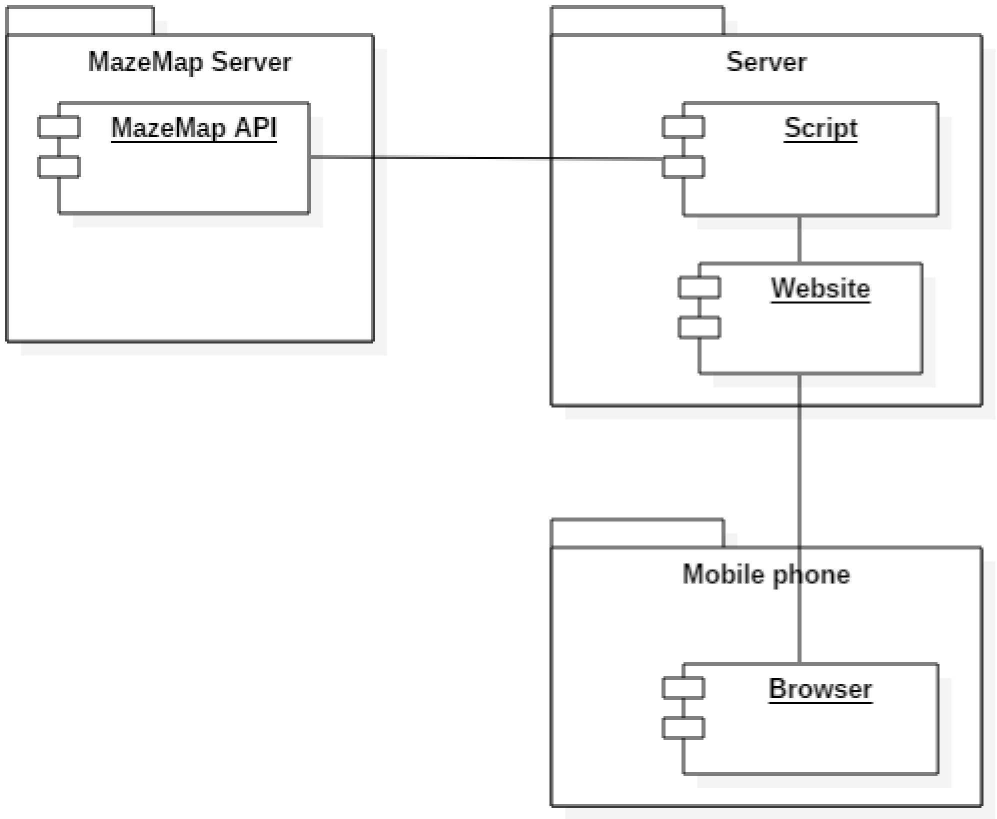


Figure 5.6: Development View.

5.3.4 Process View

The process starts with the user entering the origin and destination to the application, and selects whether they prefer stairs or elevators. Then, the user presses the getPath-Button, which finds the path between these two locations, before the user presses the DemoButton. This presents the user with a map containing the path which will either use stairs or elevators depending on the users choice. The user will then press the FullPathButton, which will present all instructions to the user through text-to-speech functionality. In order to hear their next instruction, the user can press the NextButton and to hear a previous step, the user press the PrevButton. There is also the option to press the DistanceButton which calculates the distance to the next step and present it. Once the user has reached their destination, the application will no longer provide further instructions.

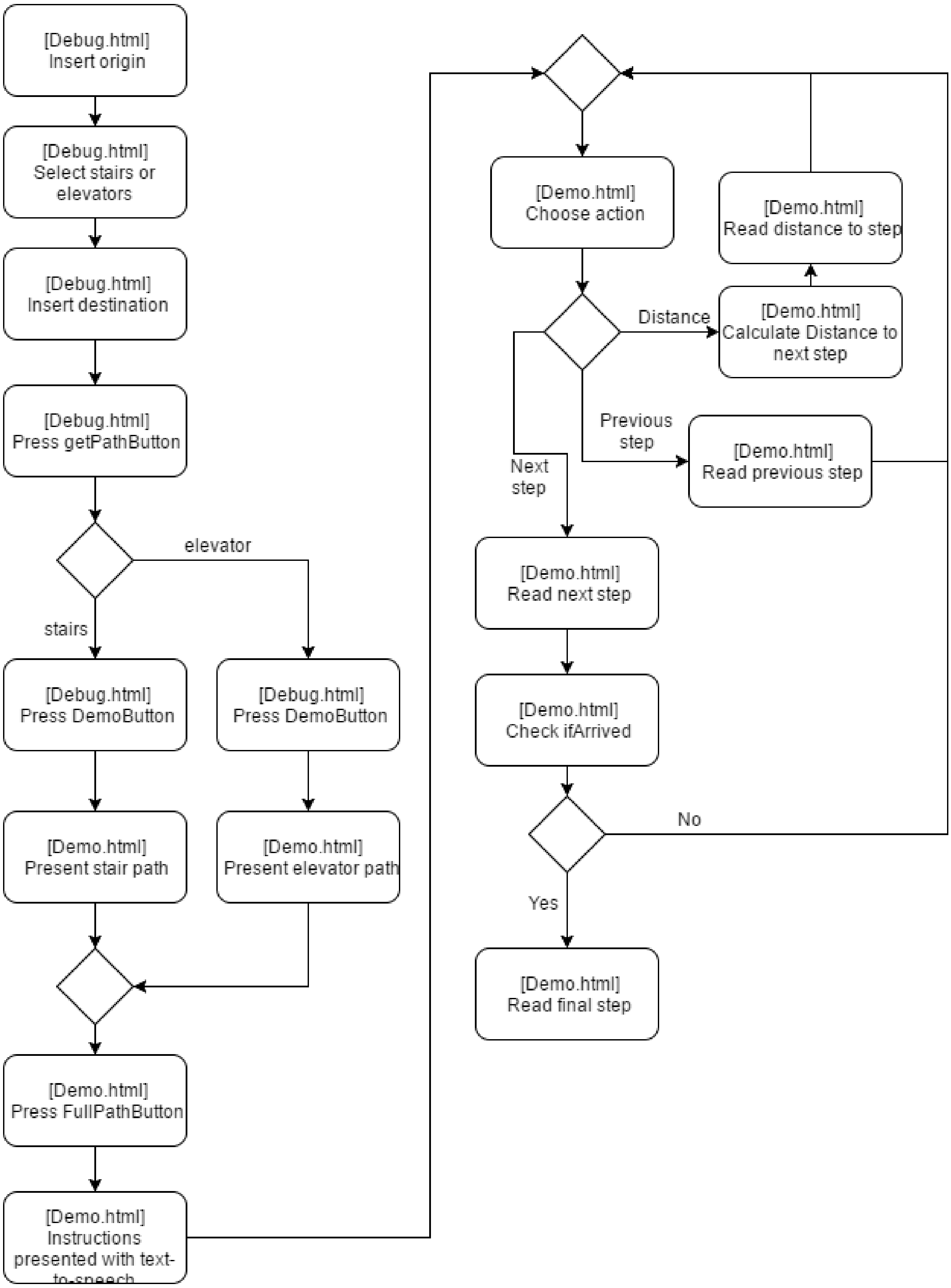


Figure 5.7: Process View.

5.4 Implementation

In this section, implementation details will be presented. This section is divided into two subsections, one focusing on the door collision detection in order for instructions to notify the user of doors in their route. The second subsection will describe the algorithm used to create the instructions.

5.4.1 Door Collision

Through the MazeMap API, information on stairs and elevators that the route navigated through were available, but there was no information regarding the doors that may block the path. In parts of the route, as shown in Figure 5.8, being aware of the door was required. To implement this functionality, MazeMap provided lists of doors on all floors and buildings at Gløshaugen. These were in the form of objects with information on the location of the doors. This information was then used to determine when the route passed a door by going through each door object and checking if the current instruction of the route collide with the object.

Figure 5.8: A part of the route where the algorithm should notice the door.

Computing whether the instruction intersected with the object was done by first splitting the object of the door into multiple small lines as seen in Figure 5.9. Then, for each line check for intersection with the instruction line. This allowed the application to mark that the instructions should include passing a door. There were however an issue of sensitivity. In smaller corridors where the doors open outward, multiple doors that only were passed by instead of through were detected, making the application notify users of more doors than necessary. As an alternative, an algorithm simplifying the doors was made. Each door was made into a single line segment from point A to C shown in Figure 5.10 by the grey line. This method made the detection of collision only react when the route passed through a door.

Figure 5.9: Left shows the form of a door object. Right shows an example of how the object was turned into line segments.

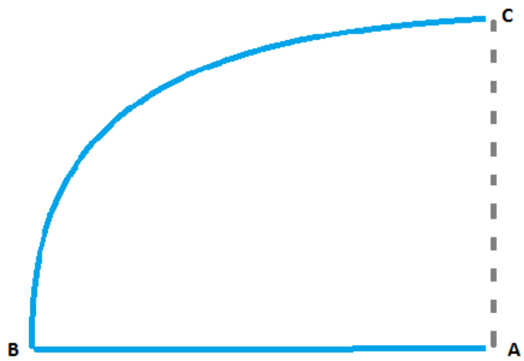


Figure 5.10: Shows the alternative algorithms line. the blue object is converted into the grey line.

5.4.2 Description algorithm

An important part of the prototype was to automatically create descriptive instructions for routes created using the Mazemap API. By sending start point and endpoint coordinates and elevation, an array was returned with information such as coordinates for each step's start and endpoints, elevation and if a step interact with a stair or an elevator. In addition to this, it provided the buildingId. To make this information into descriptive instructions, each step was split up and variables were calculated (shown in Figure 5.11).

```
this.stepDescription = {
    step: isStep,
    stepNo: stepNo,
    direction: direction,
    elevation: elevation,
    elevationType: elevationType,
    door: isDoor,
    last: isLast,
}
```

Figure 5.11: Calculated variables used to create the route description.

Variables "step" and "stepNo" *Used to determine if two steps could be merged. If no turning was needed and there were no doors, stairs or elevators between two steps then they could be merged.*

Variable "direction" *Could be either "RIGHT," "LEFT" or "STRAIGHT" determined by the change of direction at the end of a step. Used to ask the user to turn left or right.*

Variable "elevation" *Calculated difference in elevation between the start and end of a step. Positive if the step goes up to a higher floor, negative if the step goes down to a floor and zero if the there is no floor change.*

Variable "elevationType" *Tells what type of tool is used to change floors. "NONE" if elevation is zero and "STAIR" or "ELEVATOR" based on the user preference. Is "OUTSIDE" if the step goes from inside to outside or outside to inside.*

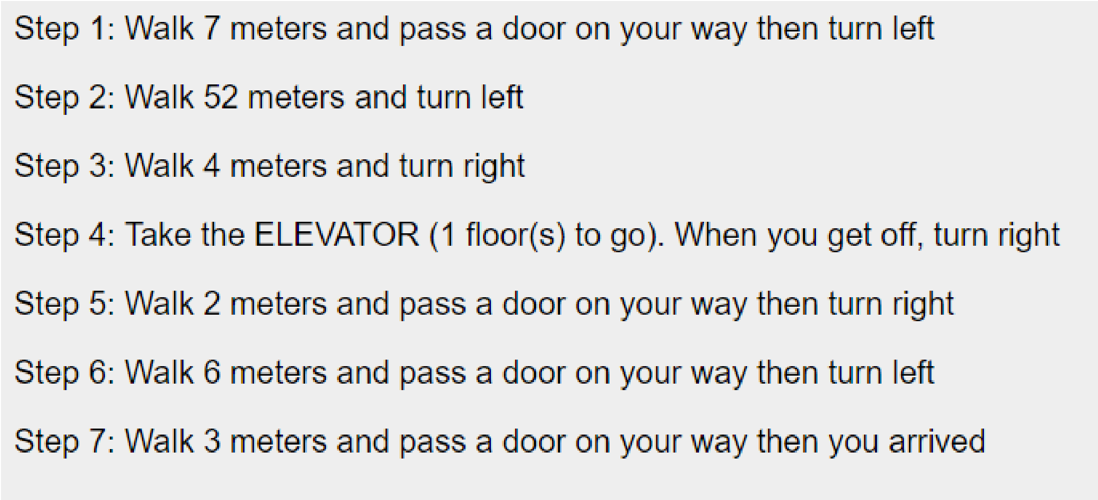
Variable "door" *Tells if the step collides with a door.*

Variable "last" *Tells if the step is the final step.*

The algorithm used these variable to determine whether certain sentences should be added to a step. Figure 5.12 shows an example of a created path description. Algorithm 1 shows pseudocode of the algorithm. Here, "currentStep" represent the step currently being described, "previousStep" represents the previous step and "text" is the description. The structure of the description is based on certain conditions as presented in this pseudocode:

Algorithm 1 Pseudocode of the description algorithm.

```
if currentStep.start != elevator then
    text ← ”Walk Currentstep.distance meters and”
end if
if previousStep.end == stairs then
    text ← ”Walk up/down the stairs then”
end if
if currentStep.doors == true then
    text ← ”pass a door on your way then”
end if
if previousStep.end == outside and previousStep.start == inside then
    text ← ”go outside and”
end if
if previousStep.start == outside and previousStep.end == inside then
    text ← ”go inside and”
end if
if currentStep == lastStep then
    text ← ”you arrived”
else if currentStep.direction == left or right then text ← ”turn left/right”
elsetext ← ”go straight”
end if
if currentStep.elevation !== 0 then
    if currentStep.elevationType == stairs then
        text ← ”then take the stairs up/down currentStep.elevation floor(s)”
    else if currentStep.elevationType == elevator then
        text ← ”Take the elevator up/down currentStep.elevation floor(s)”
        if currentStep.direction == straight then
            text ← ”go straight ahead”
        else
            text ← ”turn left/right”
        end if
    end if
end if
```



Step 1: Walk 7 meters and pass a door on your way then turn left

Step 2: Walk 52 meters and turn left

Step 3: Walk 4 meters and turn right

Step 4: Take the ELEVATOR (1 floor(s) to go). When you get off, turn right

Step 5: Walk 2 meters and pass a door on your way then turn right

Step 6: Walk 6 meters and pass a door on your way then turn left

Step 7: Walk 3 meters and pass a door on your way then you arrived

Figure 5.12: An example of a route created with the description algorithm.

5.4.3 Web server

To have the application running, a server needed to be hosted locally. This initially was done using gobble file [36], but was changed to a separate web server. This was done due the use of the smartphone's GPS in the application. Since the Chrome web browser does not allow access to the phone's GPS without a secure origin, a Hypertext Transfer Protocol Secure (HTTPS) server was required.

5.5 Presentation of Prototype

Figure 5.13 depicts the final version of the prototype. There are five main components of the prototype. At the top is a map showing the campus, with the route drawn. Then there is the “Full Path” Button which will read all the steps of the route. The “next” button reads the next step in the route while the “previous” button reads the previous step, making it possible to navigate back and forth through the route as one sees fit, giving a better tolerance for error. The final button, the “distance” button, makes use of the smartphone's GPS, giving an estimate of how far away from the next step the user is.

Figure 5.13: How the final version of the application prototype looked.

Since the prototype was aimed at visually impaired, it was decided to focus on the buttons over the map as a prominent feature, making sure that the buttons were big to be easily identified and pushed. The map was kept to see if it had any use at all for the test participants.

MazeMap worked in parallel with their own prototype making use of VoiceOver and swiping to navigate through the user interface. The application as shown in Figure 5.14 had a menu where the user could swipe to navigate between buttons and the label would be presented through text-to-speech and double tap to activate the selected button. After searching for the correct room, the user is sent to the directions page (Figure 5.15) and by swiping left and right the different steps was presented. Having this functionality added to the equitable use of the application.

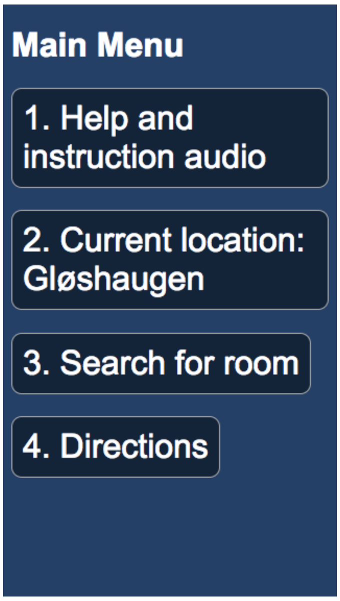


Figure 5.14: Main menu of MazeMap's prototype application.

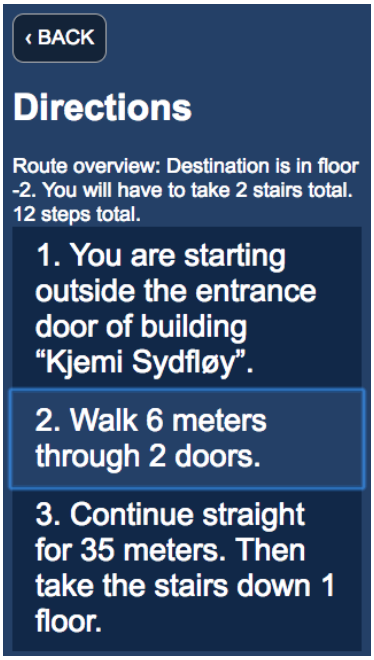


Figure 5.15: Directions page of MazeMap's prototype application.

6 Experiments and Results

In this chapter, the experiment plan are presented followed by the results. First the plan of the experiment and the setup, where the test route and different steps are explained. Second, the observations made of the test participants during the experiment are shown. This is followed by the results from the survey questions and the results from the interviews, which were performed with the test participants after the experiment. These results are divided into Perceived Usefulness and Perceived Ease of Use.

6.1 Experimental Plan and Setup

As this thesis worked parallel to a project at MazeMap, testing of the prototype application happened in tandem with testing of their application. The experiment was to have participants that were visually impaired take control of the prototype application and use it to navigate through the inside of a building at Gløshaugen campus. To prepare for this, the researchers created a route that included multiple situations that can commonly occur when navigating indoor, further explained below. The same route was used on both the applications. The participants were acquired through the collaboration between Blindeforbundet and MazeMap. Four visually impaired people were scheduled to participate in the test, but one had to cancel, leaving three participants. Two of these had severely limited vision, only being able to see contours and shapes, only differentiating between light and dark. The last participant was completely blind. All the participants used white canes to navigate. This experiment was executed to see how well the users of the application would perform, and challenges they faced while using it. The participants were also, while being interviewed, asked questions related to the Technology Acceptance Model (TAM) to determine the acceptance of the application.

For the experiment, a route was set up to be able to test multiple small scenarios and situations that can often occur while navigating indoors. As seen in Figure 6.1, the route consists of eleven steps. Most of these steps creates a new situation to be tested and observed. The route starts at the entrance of “Kjemi Sydfløy” and ends two floors down at room “R20”. Figure 6.3 depicts where each step started.

Origin of route: Entrance of Kjemi Sydfløy.

- **Latitude:** 63.41591295778831
- **Longitude:** 10.404764860868456

- **z:** 1

Destination of route: Room R20.

- **Latitude:** 63.415463435426304
- **Longitude:** 10.405342206358911
- **z:** -2

Step 1: This step is set at an entrance to a building, with doors that open automatically once a person stands in front of it. There are also separate entrance and exit doors.

Step 2: This is the longest step, going 36 meters before reaching stairs. There were also pillars to the right of the path.

Step 3: The first set of stairs. These stairs are large and wide.

Step 4: A straight line in a open room, with no indication other than the distance to when the step is completed.

Step 5: A short step with a turn to the second set of stairs. This is the prototypes way of making the user take a u-turn.

Step 6: The second set of stairs. These are smaller stairs, where traffic in the other direction might create a challenge for the user.

Step 7 Another small walk followed by a turn. This step is used to align the user with the door in the next step.

Step 8 A straight walk through a door then a turn. This door is always open, and is used to see if the user can recognize that they walked through it, or if they believe they have simply walked through a hallway.

Step 9: Another door. This door is however closed and need to be opened by the user.

Step 10: Adjusting and turning to face the door. The prototype does not ask the user to enter a door on the right or left, instead use a step to have them face the door.

Step 11 Entering the final door and arriving at the end of the route.

MazeMap used this route as the basis for their own application, either adding details to the steps or reuse them. Their test had the participants navigate a menu and initialize the navigation on their own through VoiceOver, see chapter 2.5 for further details. Figure 6.2 shows the route as MazeMap presented it. This route consist of an additional step, the initial step, due to their test starting outside the building.

Your route consists of 11 steps.

Step 1: Walk 3 meters and pass a door on your way then go straight

Step 2: Walk 36 meters and go straight then take the STAIR down 1 floor(s)

Step 3: Walk down the stairs then turn right

Step 4: Walk 11 meters and turn left

Step 5: Walk 2 meters and turn left then take the STAIR down 1 floor(s)

Step 6: Walk down the stairs then turn left

Step 7: Walk 2 meters and turn right

Step 8: Walk 11 meters and pass a door on your way then turn right

Step 9: Walk 6 meters and pass a door on your way then go straight

Step 10: Walk 1 meters and turn right

Step 11: Walk 2 meters and pass a door on your way then you arrived

Figure 6.1: The route taken for the test. How the researchers presented the route.

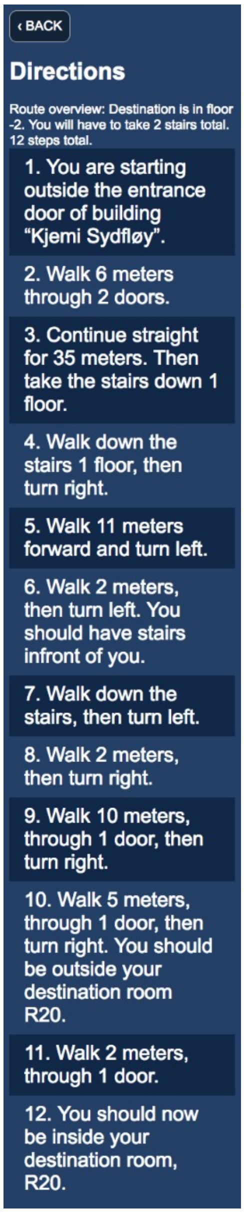


Figure 6.2: The route taken for the test. How MazeMap presented the route.

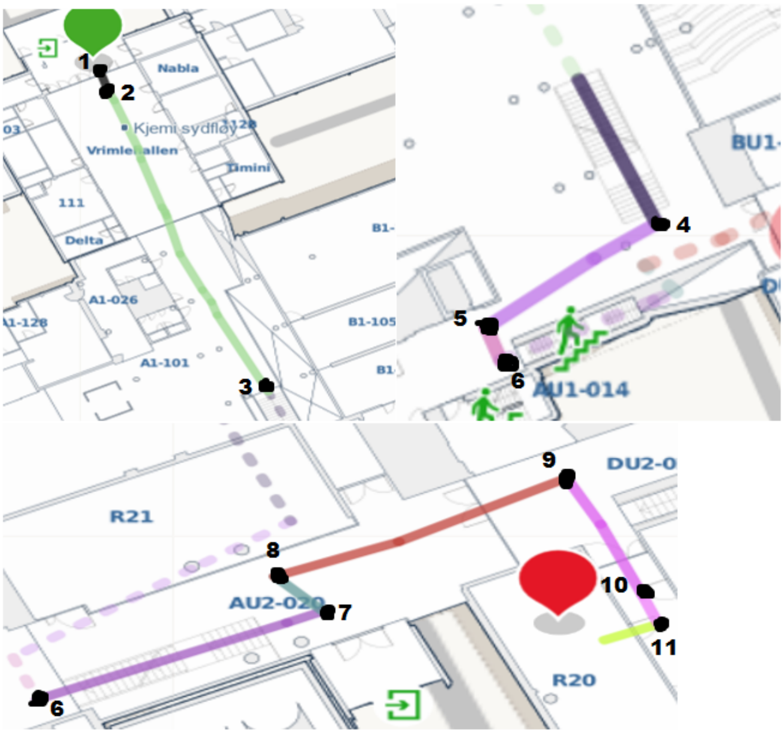


Figure 6.3: A map of the route. Black dots show where each step (in Figure 6.1) refers to.

6.2 Experimental Results

6.2.1 Observations

During the experiments, the researchers observed the participants closely and took notes of their actions and behavior. Here these observations are noted.

Before the testing

When entering the building, we passed a revolving door, which two of the participants asked to avoid. Instead, we used an alternative door that could be opened with a button, which was preferable. The participants said they would prefer to be notified of this alternative route in an application. When the application was explained and taught to the participants, a couple of things were noted. For one, the two participants with some vision made an effort to try and see and read the buttons on the application, with some success, but found it straining to do so. All participants tried out every button a couple of times to familiarize. Only one participant decided to listen to the whole route before beginning the test.

Step 1: ***Walk 3 meters and pass a door on your way then go straight.***

The first step had an automatic door, opening on its own. The participants were hesitant and made sure that the door was open before going through. Two of the participants stopped right after the door to go to the next step while one continued walking about five meters before hearing the next step.

Step 2: ***Walk 36 meters and go straight then take the STAIR down 1 floor(s).***

The participants all detected one of the pillars shown in Figure 6.4 with their cane. A couple of the participants were unsure of when the step ended, until they found the stairs. They did not process that the stairs was the endpoint until they reached it.

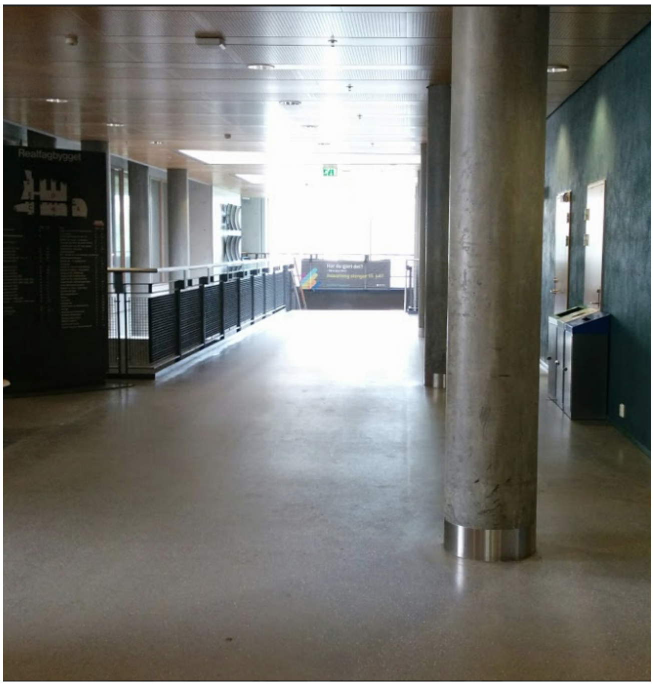


Figure 6.4: The hallway the participants walk through in step 2.

Step 3: ***Walk down the stairs then turn right.***

One participant used the railing, while the other two did not. There were no problems with the staircase being wide as the participants only kept to one side. Here was the first turn, where all three turned in the right direction, but one started walking before hearing the next step and another one turned too many degrees.

Step 4: ***Walk 11 meters and turn left.***

One participant walked too much to the right, reaching a wall in the middle of the open room. The other two participants managed to avoid this wall, but walked too far past the turning point, becoming confused and unsure of their surroundings. The participant that went off path, was led back on track before continuing.

Step 5: ***Walk 2 meters and turn left then take the STAIR down 1 floor(s).***

All the participants detected the wall as they walked forward. Two of the participants used this as an indicator of when to turn and the third participants became confused thinking she would find a staircase, because they forgotten they had to turn before finding the stairs. The two participants that remembered the turn had walked further than the path intended. This caused them not to find the stairs at their immediate left as the step said and they became unsure if they had followed the instructions correctly. After hearing the steps four and five again and searching with the cane, they managed to find the staircase, and the third participant understood they had to turn.

Step 6: ***Walk down the stairs then turn left.***

No problems walking down these stairs either. One participant started walking after turning, before hearing the next step.

Step 7: ***Walk 2 meters and turn right.***

The participants walked up to the wall then turned. The participant that had started walking early in the previous step believed that they had made a mistake since they believed they were meant to go further where the wall was.

Step 8: ***Walk 11 meters and pass a door on your way then turn right.***

The participants found the door easily. All the participants managed to recognize that they went through a door even though it was open to begin with. One participant ended up turning a little much in the previous step and walked a little to the right of the door. They managed to find the opening by searching with their cane.

Step 9: ***Walk 6 meters and pass a door on your way then go straight.***

Participants had no problems finding this door and no issues with opening the doors at all with a smartphone and cane in their hands. One of the participants followed the wall with their cane to find the door.

Step 10-11: ***Walk 1 meters and turn right - Walk 2 meters and pass a door on your way then you arrived.***

Unfortunately the room R20 was in use during the testing, leaving the last steps not fully explored. We asked the participants to listen through the steps and try to determine where the door they were supposed to find was located. All the participants seemed to understand that the steps directed them to a door on the right and correctly determined the door that they were supposed to find.

In general

None of the participant seemed to remember the distance functionality of the application during the test. During the test, none of the participants made use of the "full path" functionality. All of the participants at one point wanted to hear the same step over again, and achieved this by clicking the "previous" button then the "next" button. One of the participants had the habit of not only turning, but also starting to walk in the direction they turned to before going to the next step. Step four was especially difficult, with the open room. The participants expressed that it was difficult to ascertain the end of the step compared to other similar steps like five and seven since there was no clear indicator of how far they had gone. In the other steps, there were either a set of stairs, a door or even a wall helping the participants know that they needed to continue to the next step.

Observations made during the test of MazeMap's application

The participants seemed more comfortable using their own phone. One participant noted that knowing what floor to travel to in the beginning of the navigation was useful to them. In one instance, the participant managed to go through the path much faster the second time through. The two other participants became a little lost at the open space at step four, having to retrace their steps again to manage to find the stairs in step five. The last two steps became a little confusing for some of the participants since they believed they were at the goal after step ten.

6.2.2 Survey Results

All test participants were willing to participate in the survey to answer questions regarding the application detailed in Chapter 5. The survey was divided into three parts. These are: Perceived Usefulness, Perceived Ease of Use and Attitude Towards Using. For a description of what each part refers to, see Chapter 2.1.1. In total, the survey consisted of fourteen questions, were the participant would provide a score between one and six. Since there was an even number possible answers, the participant was forced to provide either a positive or a negative answer to each question.

Perceived Usefulness

In the survey, five questions were used to detail the Perceived Usefulness of the application. These are translated and presented in the table below, along with the answers from the test participants. In this part of the survey, a six means very useful, while a score of one means not useful. In the table, each possible score is given a column, then the number of participants who gave that particular score is presented for each question. For example, in question one, two participants gave the score six, while one participant gave it the score five.

Question	1	2	3	4	5	6
How useful was the presentation of each step	0	0	0	0	1	2
How useful was the the button that presented the entire route at once	0	1	1	0	1	0
How useful was the the button that presented the distance to the next step	3	0	0	0	0	0
How useful was the description of doors and stairs in the application	0	0	0	1	1	1
How useful was the application overall	0	0	0	1	2	0

Table 6.1: Perceived Usefulness Results.

Perceived Ease of Use

Seven statements were presented in the survey in order to determine the Perceived Ease of Use of the application. The participants were asked if they agreed or disagreed with the statements. A six meant that they completely agreed with the statement, while a one meant they completely disagreed with it. The statements are translated and presented with the results in the table below.

Statement	1	2	3	4	5	6
Learning to use the application was easy	0	0	0	0	0	3
Starting and stopping the presentation of the entire route was easy	0	0	1	1	1	0
Getting the application to present the next or previous step was easy	0	0	0	0	0	3
It was easy to obtain the information I wanted at the right time	0	0	1	0	1	1
The application required a lot of concentration to use	0	0	1	0	1	1
The application was distracting	1	2	0	0	0	0
Overall the application was easy to use	0	0	1	1	1	0

Table 6.2: Perceived Ease of Use Results.

Attitude Towards Using

Participants were asked to decide if they agreed with two statements in order for to describe their Attitude Towards Using an application with similar functionality as the prototype used in this thesis. As in the previous part of the survey, a six meant that they completely agreed with the statement, and a one meant that they completely disagreed with the statement. It was made clear to the participants that the statements were not about the application they tested specifically, as it is not intended for a public release. The statements were translated in the table below along with the results.

Statement	1	2	3	4	5	6
I want to use this type of application when I am navigating in an unfamiliar building	0	0	0	0	0	3
I want to use this type of application when I am navigating in a familiar building	0	0	0	0	2	1

Table 6.3: Attitude Towards Using Results.

6.2.3 Interview Results

Once the survey was completed, the test participants were asked more open questions to provide possible improvements both in functionality and presentation. Unlike the the survey, the interviews also discussed the application MazeMap had developed in parallel with the one developed for this thesis. The information obtained in these interviews will be divided into the following parts: Perceived Usefulness and Perceived Ease of Use.

Perceived Usefulness

All participants in the test expressed an interest in using the electronic compass in a smartphone to detect if the user is walking in the right direction during the navigation. This would be particularly useful in open areas, which are often found at universities and hospitals, since walking slightly in the wrong direction can lead you to walk past doors, stairs and elevators. Participants wished for the application to notify them, either through sound or vibration, when they were walking in the wrong direction.

The participants who were not completely blind were asked how useful a large map which presented their route on their smartphone would be. The map would use a lot of contrast to make the route and rooms more easily discernible, however the response was that it was not very useful, especially on smartphones, since the screen is small. One of the participants expressed an interest being able to view a map on a tablet before they start navigating, since the screen is much larger, yet can still be carried in a bag.

Another functionality that was requested was a precise indoor positioning functionality. Participants found it difficult to know if they had walked the correct number of steps, since they were asked to walk a specific number of meters in a direction. If they knew they were supposed to stop once they reached for example a door or the stairs, it was not a problem, but when they were asked to turn in a different direction in an open space, confusion was created. Therefore, the possibility to be notified when they walked the correct distance would be useful.

One of the participants had access to a guide dog, which was not used during the experiment, and said that landmarks can be particularly useful then, since the guide dog can find doors, stairs and elevators on command. This avoids the issue of having the user go a specific amount of meters in a given direction, which can lead to user error since it is difficult to know the specific number of meters they have walked.

Multiple test participants requested additional information in order to make the application more useful. For example, participants would find it useful if they were directed to walk on a given side while walking through a hallway or a large open room. This helps the user to not miss the door, stairs or exit they are navigating towards. Participants also expressed an interest in being notified of tactile paving as shown in Figure 6.5 on the floor in order to know that they are on the correct path when they detect them.

Figure 6.5: Tactile paving on top of the stairs used in the route.

During the experiment the participants always changed direction by turning ninety degrees either to the left or right. In order to align themselves with a door, they were asked to do multiple small steps with ninety degree turns instead of only one step with for example thirty degree turn. Two of the participants believed using clock position was a great alternative, however believed that this should optional. The final participant had difficulty with using clock position.

Being able to customize the amount of information the user would obtain from the application was also seen as important. Landmarks were for example not always interesting to the user, as too much information at once could lead to confusion during navigation. Participants also claimed that it could be more useful to receive more information while navigating through unfamiliar buildings compared to familiar buildings.

During the interview, we received feedback regarding how the steps were written. See Figure 6.1 in Chapter 6.1 to see the steps used during the test.

Pass a door *When the application used the phrase "Pass the door", users were confused. They were unsure if it meant that they were supposed to walk through a door, or if there was a door near their path. "Walk through the door" should be used instead.*

Turning at the beginning or end of a step *Users were asked to to turn at the end of a step, so that they could walk straight in the next step. However, participants preferred to walk the way they turn in the same step. Example: "Walk through the door, then walk 7 meters to the right" instead of "Walk through the door and turn right", then "Walk 7 meters".*

Information regarding the end point of the step *In step 2, users are asked to walk thirty-six meters, then take the stairs down one floor. Participants responded positively to being notified of the stairs in this step, as it allowed them to know when they had walked thirty-six meters.*

Perceived Ease of Use

One participant complained about the difficulty of finding the correct button at times. While the buttons were of large size, not knowing precisely where the buttons were placed caused minor issues. For example, the application would read the previous step when the user wanted it to read the next step.

In the application MazeMap tested, the user interacted with the application through VoiceOver. All three participants were already familiar with VoiceOver and used it regularly in their daily life. During the interview, participants claimed that using VoiceOver to scroll through the different steps was easier than using the buttons. A disadvantage with the user interface however, was that going from the selecting and reading steps to interacting with buttons or going back to the previous menu, required the user to scroll through a lot of information. This was due to the steps simply being in a list instead of a next, current or previous step button.

During the interviews, multiple interviewees highlighted a mobile application they were already using for outdoor navigation, called BlindSquare. They found it very accessible, and was therefore added to Chapter 4.2, where it is described in detail.

7 Discussion

In this chapter, the results are discussed in relation to the three research questions, presenting what has been learned through the experiment described in the previous chapter. This chapter also contains limitations of the experiment that can be addressed in future research.

7.1 Research Questions

Here we discuss the different findings of the experiment in regards to the research questions in 3.1.

7.1.1 What information is always needed to properly navigate indoors?

The visually impaired require precise information regarding the route they need to take in order to reach their destination. Imprecise information lead to confusion for the user, as it can lead them to look for artifacts, such as doors, where there are none. Ambiguity must therefore be avoided, and the application must be consistent in how it presents information. During the experiment, the use of "pass a door" lead to participant being unsure of whether they were going to walk through a door or whether a door simply was present near their route. This was clear in the survey results as well (Table 6.1 for full results), since the description of doors and stairs only received one perfect rating, while the two other ratings were a slightly lower score. Another ambiguity that the participants reacted to was when they were asked to turn right or left. They were not certain if this meant turn ninety degrees, or if they were supposed to only slightly turn. A possible way to convey this information is with the use of clock positioning, where the clock is used as a compass, and each number represent a direction.

Participants in the test made it clear that they also wished for more precise information regarding how they should move through hallways and rooms. For example, at one point during the test the users were walking through a large, open room, and the participants expressed an interest in walking near a wall and follow that wall until they reached the next step. Large and open rooms are common in hospitals and universities, making this a common issue that will often affect the visually impaired. Therefore, the application should present information to help them obtain this knowledge. An example of this would be "Go to the wall on your left side, then turn right and follow the wall for thirty-six meters".

Information to help users verify if they have reached the end of a step in a step-by-step description of a route also reduces confusion for the user. If they know that they should reach a door, stairs, or a wall at the end of the step, they can confirm that they are following the instructions correctly. Also, if they have a guide dog, they can give it a command to find this object, which enables them to more easily complete the step. In step four of the route for the application developed for this thesis, the step ended without any way of users knowing if they had completed the step, and this was also a place the participants struggled.

In the first step of the route, the participants had to walk through a door. They started in front of the door, however there was another door to the same room. The door they started near was an entrance door, while the other was an exit door. These are used to ensure that people always are able to enter a building if many people are exiting and vice versa. The users should be notified of this information to ensure that they do not try to enter through a door dedicated to people who are exiting. This is also relevant for doors that are restricted to some people, for example employee-only doors.

7.1.2 How much of the information should be presented at once?

In the interviews, it became clear that landmarks could be useful to the visually impaired. Examples were the location of elevators and the location of the cafeteria, both of which were near the route used in the experiment. However, the interviewees were concerned that the amount of information could become overwhelming. Therefore, it is vital that the users are able to adjust the amount of information they receive from the application.

There were however, information that was useful to present at the start of the experiment. Participants liked, for example, to be presented with what floor their destination was located at and the amount of stairs they were going go up or down before they started navigating. This was due to them wanting to be able to verify if they were on the right floor, and if they somehow got lost, yet were able to find stairs, they could more easily find their destination.

The experiment took the test participants through multiple different doors. As shown in Figure 7.1 there was a automatic door, a door that was constantly open, a closed door they had to open themselves and the last door being to the right of where the participants were facing. All these doors were presented with the same instruction, “Then pass a door” with no information to tell them apart. The participants had no problem with any of the doors, outside wanting to know if a door was exit or entrance only and the brief uncertainty because of the ambiguity of "pass a door". This indicates that when it comes to going through doors, there does not need to be specific information regarding each door, like direction it opens or whether or not it is open on its own.

There are a couple of exceptions to information about doors that would need further testing. The first case are the automatic doors, since the participants started by them and was told the door opened on its own. No data on unknowingly passing through automatic doors were collected and therefore drawing a conclusion on whether this information is useful would be premature. The other case are revolving doors. The little information gathered on these types of doors were that they were uncomfortable to use, so revolving doors should be avoided entirely if possible and need to be tested separately.

Figure 7.1: The different doors that the route passed through. Top right: Automatic doors, top left: door to the right of the path, bottom right: Open door, bottom left: Closed door.

7.1.3 What functionality do the visually impaired require in order to navigate independently indoors?

The information the application intends to convey should be presented through text-to-speech functionality to ensure that the visually impaired are able to obtain the information. Participants responded positively to its use during the experiment, and is a way to make the application equitable in use, one of the principles of universal design.

Reading the full path was a feature that was not useful for all participants. The question related to the full path (table 6.1) shows that some found it on the lower end of useful while another found it useful to have. The function was used by only one of the participants in full before starting the navigation, while the others tried the function and stopped it before it had completed its presentation of the entire route. This indicates that there can be a use of reading the full path, but should only happen on request by the user and the user should easily be able to stop or pause it.

There were some difficulties in terms of how much one should turn given the instruction to “turn left” or “turn right”. There were suggested solutions to this by giving clearer instructions with use of clock direction or turning with degrees. Another suggestion was to add verification functionality helping the users assure that they had turned correctly. Using the electronic compass in the phone to ascertain what direction the user is currently facing and interacting with the user to make them turn. These interactions could be vibrations, becoming weaker as the user turns correctly, or a voice that warns the user if they are going the wrong direction. When asked, the participants said they preferred to be notified when they were facing the wrong way and not be constantly told that they were facing the right way. The last interview question presented in table 6.1 shows that there are improvements to be made for the application.

The functionality that saw the least use was the “distance” button that used GPS to calculate how far from the next step the user was at the moment. The button was presented and used before the test like the other buttons, but during the test, none of the participants used this functionality at all. Because of this, the perceived usefulness score was set to 1 (Table 6.1). When asked about why they found the functionality to be not at all useful, the answer was that they had forgotten that the button existed. The participants did say that knowing the distance to the next step could be useful had they actually remembered that it was an option. It seems that the interface or the explanation of the functionality at the beginning of the test was insufficient and needs to be improved. This was further supported by one participant mentioning that she likely would have remembered the button if the system had VoiceOver functionality that she was familiar with.

It became clear during the experiment that the visually impaired needed to hear certain steps multiple times during navigation. Therefore, it is important that the user easily can control when the next step is presented. For example, the application should not automatically present the next step when it believes the user has completed the current step. Participants appreciated the control during the experiment, which can be seen in the survey, where the participants were very positive (see table 6.2) when asked about getting the next and previous step presented. They also said that an automatic repeat of the current step at regular intervals would likely be more distracting than helpful.

In the final section of the survey, participants were asked about their intention to use an application similar to the application used in the experiment. With the functionality provided in the prototype, the participants responded positively to using the application for indoor navigation (see Table 6.3) for both familiar and unfamiliar buildings. The prototype used in the experiment with the additional functionalities that participants requested in the interviews should provide functionality for the visually impaired to successfully navigate through complex buildings. However, as these participants are people that has said themselves willing to participate in these experiments, they might have a bias to wanting this technology and might be more positive than a general population would be.

7.2 Limitations

There are some limitations of this study. First of all, there were only three test participants in total. This is a small number making it difficult gain a sense of the general consensus among the visually impaired. This was due to the difficulty in finding willing participants, fitting the criteria of being visually impaired in the immediate vicinity of Trondheim. Another limitation is the nature of the participants. All the participants were young adult women resulting in a lack of diversity of gender and age, which limits the range of answers we receive. The main goal however was not to give a general opinion of the application, but rather to gather information regarding the use of a similar application, what functionality is important and what is difficult to convey to the user.

The application made by MazeMap had to be run on one of the researchers phones during the test, since neither of the researchers was in possession of an iPhone. The application developed for this thesis was not compatible with an iPhone, forcing the participants to use a mobile device they were unfamiliar with and without functionality they were comfortable with. Because of this, the whole experiment was not necessarily in the most accurate setting to mimic a real situation which might have affected the collected data.

8 Conclusion

In this chapter, a conclusion to the research is drawn based on the discussion provided in the previous chapter. Also, based on the limitations of the study, research areas that should be further investigated and evaluated will be presented.

8.1 Conclusion

In this study, we have found that it is vital that the visually impaired have a way of verifying that they are following instructions correctly during navigation. Even if the information presented is precise and correct, user errors are bound to happen, and in order for the visually impaired to navigate independently, there must be a way for them to correct themselves. Possible ways for an application to offer this functionality is using an electronic compass to verify direction, and using an indoor positioning system to verify position. It is also possible to allow users to verify that they are following instructions correctly by giving instructions that contain objects that the visually impaired can verify with either a white cane or a guide dog. Examples of this include walls, stairs, elevators and pillars. Examples of instructions are presented here:

Step 1 Turn left and walk four meters until you reach a wall.

Step 2 Turn right and walk fifteen meters until you reach a set of stairs.

Step 3 Walk down the stairs.

Another important aspect when presenting instructions is to allow the users to decide the amount of information the instructions should contain. Since different users have different goals at different times, presenting information that can enable them not only to reach their destination, but also additional goals is important. For example, in an unfamiliar building it can be useful to notify the user when they pass by a cafeteria, restrooms and elevators to enable them to find these more easily at a later point.

8.2 Future Work

The prototype lacked any accurate indoor positioning technology such as trilateration or beacons. Therefore, the evaluation of the Perceived Usefulness of this functionality were based on hypothetical interview questions. The results also highlighted the usefulness of notifying the user if they went in the wrong direction. It should therefore be researched in future studies how indoor positioning technology and electronic compass allows the visually impaired to correct their errors during navigation.

Ensuring that the user can obtain information regarding automatic and revolving doors as well as its effect on the user, are aspects that should be researched. Future studies should also examine how offering alternative paths to avoid revolving doors can improve the user experience for the visually impaired. Another possible research area is what information would be needed to have users easily use these doors.

Participants requested information regarding landmarks, such as pillars, cafeterias and other distinguishable features mentioned in the instructions. However, providing too much information to the users to focus on can cause user errors. Therefore the use of different levels of detailed instructions should be examined. Future studies should perform an evaluation where the users test an application with instructions that have a adjustable detail level.

Another possible area for research is examining user interfaces for the visually impaired. In the application developed for this thesis, buttons were used, and MazeMap's application used VoiceOver. However, other possibilities should also be expored to make applications accessible.

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Appendices

1 Appendix A Interview questions (in Norwegian)

Perceived Usefulness

På en skala fra en til seks, hvor nyttig var

- PU1: Opplesning av hvert steg for å navigere frem?
- PU2: Å få hele ruten lest opp for å navigere frem?
- PU3: Opplesning av lengde til neste steg?
- PU4: Instruksene for dører, trapper og/eller heis?
- PU5: Applikasjonen som helhet?

Perceived Ease of Use

På en skala fra en til seks, hvor enig er du i påstanden?

- PEOU1: Å lære å bruke applikasjonen var enkelt
- PEOU2: Å starte og stoppe opplesningen av hele ruten var enkelt
- PEOU3: Å få applikasjonen til å lese opp neste instruks var enkelt
- PEOU4: Å få informasjonen du har bruk for akkurat nå var enkelt
- PEOU5: Applikasjonen trengte mye konsentrasjon å bruke
- PEOU6: Applikasjonen var distraherende
- PEOU7: Å bruke applikasjonen til å navigere var enkelt

Attitude Towards Using

På en skala fra en til seks, hvor enig er du i påstanden?

- BI1: Jeg har lyst til å bruke en slik app i ukjente bygg
- BI2: Jeg har lyst til å bruke en slik app i kjente bygg

Åpne spørsmål

- Ville du foretrukket automatisk opplesning i intervaller fremfor opplesning ved trykk på mobilen?
- Applikasjonen leste opp retningen du skulle snu deg på slutten av hvert steg, den leste også opp dette før neste steg startet. Hva syntes du om dette?
- Et steg ba deg snu til venstre, gå to meter og så snu deg til høyre for å være mer i linje med døren. Har du noen tanker rundt dette steget. Var det nødvendig? Kunne det forklares på en bedre måte?
- Var det noen av instruksene du fant uforståelig eller manglende?
- Er det noe annen informasjon du kunne tenkt ville vært nyttig å få gjennom applikasjonen?
- Andre kommentarer?