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Indoor Navigation for the Visually Impaired - A Systematic Literature Review

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Abstract

It is difficult for the visually impaired to navigate complex buildings without the help of other humans. This study examines the needs that must be satisfied for them to navigate independently and what technological solutions exist today. In order to obtain this knowledge, we conducted a systematic literature review. Through this review, we found 40 papers related to the relevant domain. We observed that the visually impaired require both their own position and direction, in addition to the route to reach their destination. The main issue lies with providing an indoor position, as GPS becomes very inaccurate indoors. Other technological solutions, like the use of beacons, require investment in infrastructure for all buildings. The most realizable solution that can provide indoor position without the need of additional infrastructure is trilateration with Wi-Fi access points, however, this can be inaccurate at times. We therefore suggest further testing is performed with trilateration in order to verify whether the solution is robust enough for indoor navigation for the visually impaired.

Preface

This specialization project was performed during the fall of 2016, and was a part of our ninth semester of Computer Science at the Norwegian University of Science and technology (NTNU). The specialization project will be the groundwork for our Master's thesis, that will be written during spring of 2017.

We would like to thank Odd Erik Gundersen, Iván Sánchez Ortega, Małgorzata Grzyb and Dag Jomar Mersland from MazeMap for their cooperation during the project.

We would also like to thank our supervisor, professor John Krogstie at NTNU, for his valuable feedback and guidance this fall.

Eirik Zimmer Wold and Sondre Heggernes Padøy
Trondheim, 14th December 2016

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1 Introduction

Here we will present the motivation and background for doing this literature review and then describe how the rest of the project report is structured.

1.1 Background and Motivation

A problem for the visually impaired, is that they struggle when they are navigating in large and complex buildings [1]. This can become a problem when they for example need to find a specific room in the hospital for their doctors appointment or go to a lecture at a university. While it is possible to ask for directions, their ability to move independently is severely reduced. Indoor maps are often not available digitally, and the applications that have them are not necessarily accessible for people with visual impairments.

MazeMap [2], a company that specialises in indoor maps and navigation for many complex buildings, have received several request for indoor navigation and position finding, including requests from Blindeforbundet, an organization for the visually impaired in Norway. For MazeMap, it is important that a solution can be created that does not require new infrastructure to be added to buildings. It is also important to have a solution that can be adapted to every building, instead of requiring a lot of additional work for every building. The project has been conducted in connection to work in Wireless Trondheim Living Lab [3].

1.2 Report Structure

In the following sections, we will provide background information for the domain both in terms of indoor positioning and visual impairment. Then we are going to discuss our method for the literature review followed by the result of the research. Finally, we will be discussing the information obtained and present our current answer to the research questions and provide focus areas to adress the issues and limitations we have discussed.

2 Background Theory

In this chapter we will introduce several concepts that are useful for understanding indoor positioning and visual impairment. The concepts related to indoor positioning are technology that can provide a position, either in coordinates, or relative to other known locations, or natural phenomenons. For visual impairment, we will describe standards that are useful when building software targeting the demographic.

2.1 Global Positioning System

The Global Positioning System (GPS) is a system of 24 satellites that provides position and velocity to a receiver. Satellites will send a signal to a receiver, and the receiver can find it's position based on the transit time from several satellites, which have known positions. Inside buildings, walls and roofs will interfere with the signal, which significantly reduces the accuracy of the system [4].

2.2 Trilateration

Trilateration is a method of obtaining a location based on the received signal strength indication (RSSI), from three access points, for example Wi-Fi routers. The main advantage of using routers as access points is that they are already common in most buildings, removing the cost of adding infrastructure for indoor trilateration [5].

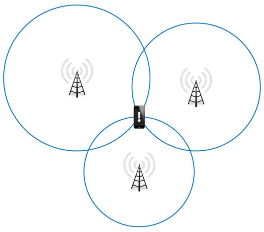

Figure 2.1: Trilateration with three access points
[6]

2.3 Magnetic field

The Earth is surrounded by a magnetic field. By monitoring its strength at a specific location, you can detect your geographical location. However, it is affected by electrical systems, which interferes with the accuracy indoors. The magnetic field can also be used to provide the direction a device is pointing [7].

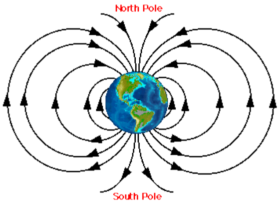

Figure 2.2: Earth's magnetic field
[8]

2.4 Visual impairment

Norway has five levels of visual impairment. These are moderate vision impairment, severe visual impairment, blindness category three and four and complete blindness. The level of visual impairment is decided by testing the person's best eye, and is measured by the distance an object is seen clearly. The sight is depicted with fractions, where the denominator is the farthest distance a perfect sighted person can see an object clearly, while the numerator is the farthest distance the person doing the test can clearly see the object from [9].

Name	Up to	Less than	Comment
Moderate visual impairment	6/60	6/18	
Severe visual impairment	3/60	6/60	
Blindness category three	1/60	3/60	Also when a person has a visual field of between 10% and 20%
Blindness category four		1/60	Also when a person has a visual field of less than 10%
Complete blindness			No light sensitivity

Table 2.1: Levels of visual function

There are roughly 180,000 visually impaired citizens in Norway, but only about 1,000 of these are completely blind [10].

2.5 Universal design

Universal design is the principle that products and environments are accessible for all demographics, regardless of age and abilities to the extent that it is possible. These products and environments should be accessible without the need for adaptation, meaning the user should not be affected by the accessibility [11].

There are seven principles that form the foundation for universal design:

- Equitable Use: The product is useful for people with different abilities.
- Flexibility in Use: Can be adjusted according to preferences for the user.
- Simple and Intuitive Use: Easy to use regardless of previous experience or abilities.
- Perceptible Information: The product presents the necessary information effectively to the user regardless of the user's abilities.
- Tolerance for Error: The product minimizes the consequences of unintentional actions.
- Low Physical Effort: The product can be used with minimal impact on the user's fatigue
- Size and Space for Approach and Use: The product can be used regardless of the user's size, posture and mobility.

An example of universal design that affects the visually impaired is having an audio speaker announce what floor the elevator is currently at, or having braille text on signs. This does not impact other users, yet significantly increases the visually impaired's ability to travel independently.

2.6 Machine learning

Machine Learning is a type of artificial intelligence that gives computers the ability to learn without being explicitly programmed. Looking at large amounts of data, machine learning try to find patterns and use these patterns to make predictions on future data. This can be used for multiple areas such as recognizing images, giving recommendations based on peoples previous actions or determining what the next step a player should perform in a game [12].

3 Method

In this section, we will present our goal and research questions. We will then describe how we worked to obtain the necessary information to answer the research questions, and how we ensured that the results were relevant to reach our goal. Our method is based on the paper Linkman et al. [13].

3.1 Goals and Research Questions

As we intend to work with indoor navigation for the visually impaired in our Master's thesis, it was necessary to obtain knowledge regarding the domain. An understanding of the needs of the visually impaired, as well as previous proposed solution is necessary if we are to contribute to this field and is therefore the goal of this report.

Goal *Gain an understanding of what the visually impaired need for indoor navigation, and how we can meet those needs at a low cost.*

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

Research question 1 *Which challenges are the visually impaired facing for indoor navigation?*

Research question 2 *What solutions have been proposed to solve the indoor navigation problem and what are their limitations?*

3.2 Search process

In order to find relevant papers, we used a search engine for scientific papers called Google Scholar, first looking at the most cited papers, then limit the search to recent years to find newer research. We used combinations of the following search phrases during this process:

- Indoor positioning

- Indoor navigation
- Visually impaired
- Universal design
- Universal design visually impaired
- Magnetism
- Trilateration
- Light
- RFID
- Accuracy
- Ultra-Wideband

In addition to the use of Google scholar, we also had discussions with other stakeholders in this project about related research. MazeMap had previously conducted research and testing within the domain, and gave us access to the report Remmen and Toft [14]. We also received papers from our supervisor, John Krogstie, which were relevant for our research questions.

3.3 Inclusion and exclusion criteria

For a scientific paper to be included in our results, it had to relate to one of three domains:

- Indoor positioning
- Indoor navigation for visually impaired
- Needs of the visually impaired for navigation

When looking at scientific papers related to indoor positioning, we looked for technology that can provide an accurate position indoors. If possible, we wanted papers that also included how accurate a solution was with specific results. It was also necessary that they described the setup process, both in terms of hardware changes and implementation. When looking for indoor navigation for visually impaired we looked for ways to guide the user without relying on sight. We also looked at possible ways to help the user to detect and navigate through obstacles. For the domain, needs of the visually impaired for indoor navigation, our focus was on the issues that prevent the visually impaired to navigate through complex buildings without the help of others. Another key focus was issues the visually impaired face when they are using technology.

For papers that passed the inclusion criteria, we also checked against an exclusion criteria to make sure the paper gave new insight:

- It discussed technology already has been covered

3.4 Data collection

For papers related to indoor positioning technology and indoor navigation for visually impaired, the relevant details are the accuracy it can provide as well as the cost of setting up and using the technology. In the challenges and needs of visually impaired domain, we specifically look at experiences visually impaired had when navigating indoors. We also examined experiences the visually impaired had from using technology to help them.

3.5 Deviations from protocol

Initially, we planned to test and set up an application created by MazeMap, but due to some problems in access to this system we ended up writing a literature review instead, following the format of Linkman et al. [13] and removed the topic of architecture and discussion of the application itself. The related work of the applications turned into part of the result of the literature review instead, since we no longer compared work to an application.

4 Results

Here we will summarize the articles we found during our literature review and used to answer our research questions. the first section will give a summary of what the systematic search revealed, The second section will present some of the key issues that face the visually impaired when navigating complex buildings. Then, the third section will introduce technology that can provide the position of the user indoors. Finally, the fourth section will discuss some solutions to the issue of moving between two indoor locations. In all sections, we will summarize the information in a table.

4.1 Search results

Through the systematic search we found 40 papers that we looked at further. We used 7 papers to research the needs and challenges for the visually impaired, 20 papers for technology that try to improve indoor positioning and 13 papers for technology that focuses on navigation of visually impaired. Using the inclusion and exclusion criteria we chose to omit some papers. As an example, there were multiple papers using vibrations on different wearables as a basis for communicating direction to visually impaired, but only two papers were examined further.

4.2 Needs for the visually impaired

The main issue the visually impaired face for indoor navigation is the lack of knowledge regarding their own position and direction. In addition to this, information regarding the building they will be traversing, like number of floors, size of rooms, whether they have revolving doors are also important [1].

In Remmen and Toft [14], they conducted interviews with four people from Blindeforbundet about their needs to be able to navigate through complex buildings independently. The interviewees said they wished to be informed of more than just the path, they also wanted to be notified of stairs, doors and elevators. One of the participants also wanted to know the entire route at the beginning, before being presented a step by step navigation route as they walked.

Another issue the visually impaired face are obstacles in their path. In a dynamically changing environment where crowds can appear and block a path, the visually impaired will need a way through the crowd or an alternative route. Therefore, it is necessary to continuously present the information regarding obstacles to the traveller [15].

An application that support visually impaired in navigation indoors need to make the visually impaired want to use it, without being forced or feel that it is cumbersome. Avila et al. [16] conducted a survey of an application that connected sighted people with visually impaired with video and audio to help the visually impaired. The survey asked, among other situations, if the application was useful for navigation, which the responses were neutral and that the application was not very useful when their hands were busy which they usually were when navigating somewhere. Williams et al. [17] conducted another survey that mention usefulness of applications. While the focus of the survey was on training with the navigation tools, white cane and guide dog, there was a part of the survey about the use of technology. There were some participants that said they had tried but stopped using technology for navigation. This was due to the fact that it was distracting because they needed to constantly interact with the application(s) to obtain the information they wanted.

Williams et al. [17] also discusses navigation indoors for the visually impaired, where there are not typically available navigation technology. They use sighted people to navigate unfamiliar places, and memorize the building to navigate independently. Wide-open spaces and crowded spaces pose the biggest challenge since it is difficult to explore with a cane.

A third survey was presented in Abdolrahmani et al. [18], where the authors examined how the visually impaired responded when technology failed them. Participants were first a part of an experiment for indoor navigation where a system gave them information of signs. In the experiment, the technology gave them false positives, false negatives and object misidentification. There were 41 participants in the survey. The results were as follows:

- 34 % accepted errors

- 18 % were neutral
- 27 % did not accept the errors

Accepting the error in this context, means if they would still use a system making these errors. The remaining responses considered the errors irrelevant in the experiment. The responses which accepted the errors emphasized that false negatives were far more acceptable than false positives or object misidentification. Participants were also more accepting in difficult environments. For responses that did not accept the errors, the problem was primarily object misidentification. In the experiment, the user were going to a restroom, and intended to use the restroom with their gender. When they were sent into the wrong restroom, they were annoyed.

Kulkarni et al. [19] presents ways to make a robotic assistant cane more comfortable to use. The system they describe is not meant to be owned by the users, instead it belongs to a building, and the users borrow it. The report focuses on minor details, like having a wooden handle instead a metallic one, due to the metallic one leading cold to the user, can improve the user's experience. Also allowing the user to select the voice of the text-to-voice functionality can lead to enjoyment for the user. When the users interact with the robot, they can press a button to get an explanation of what it does, while double clicking activates the action. Finally, the system saves previous users, so that they easily can activate their personal preferences if they return.

Priority	Description
Must have	Know their location
Must have	Know their direction
Must have	Know the route to their goal
Nice to have	Navigate obstacles
Nice to have	Know their entire route before they start walking
Nice to have	Know information regarding the building
Must have	Application must be easy to use
Must have	Application must not be distracting
Nice to have	Avoid object misidentification
Nice to have	Changeable settings in application

Table 4.1: User requirements for indoor navigation

4.3 Indoor positioning

The report "RFID Information Grid for Blind Navigation and Wayfinding" presented an alternative solution to indoor GPS, choosing instead to use radio frequency ID (RFID) tags that were placed in all rooms of buildings. This avoids the issues with inaccurate indoor positioning, since the RFID tags will not be affected by walls and roofs assuming they are available in all rooms. In order for the visually impaired to navigate complex buildings, it is necessary that the information they are provided is accurate. Otherwise, the application can send them in the wrong direction, which would require the user to ask for directions from someone else. The issue however, is that while RFID tags are cheap to produce, they still need to be organized all over buildings and be maintained. The signal from RFID tags can also suffer from interference from other electronic devices, which can affect accuracy [20].

Extensive testing of RFID was done in Gikas et al. [21]. In unobstructed environments, where the RFID beacon has a line of sight to the user, the error can be of the order of 0.7 meters. Another important point made in the paper, was that while use of RSSI required calibrations during setup of the beacons, the same configurations could be used in similar environments, making it easier to use the same solution in several buildings.

An attempt to avoid the interference RFID tags can suffer from, was using light for communication. This was tested in Nakajima and Haruyama [22], where LED was used to convey the location and direction of the user. According to the report, this provided a stable signal, however, when they conducted user tests with visually impaired people, they detected inaccuracies. These were caused by the test participants having a sensor suspended by their neck, which meant it would swing during movement. This solution also requires new infrastructure in every building, since the LED lamps needs to be able to send a unique signal. There also has to be a mapping between light and location. In Kuo et al. [23], the accuracy of a system using LED for communication was tested. They were able to achieve an accuracy of 30 centimeters.

In order to provide indoor positioning using existing infrastructure instead of RFID tags, the use of trilateration has been researched. Using Wi-Fi access points' signal strength, the indoor position can be calculated with a mean error of 3.97 meters. Wi-Fi access points also have a long range, meaning it is not necessary to have them available in every room like with other solutions. This research was conducted with unaltered

Wi-Fi access points, which means that the solution can easily be transferred to other buildings. By being easily transferable to other buildings, it will be easier for governments to impose rules that forces building owners to support indoor navigation for the visually impaired [24].

LaureaPOP is a system for the visually impaired that uses Wi-Fi access points for indoor positioning, presented in Rajamäki et al. [25]. This system combines both indoor and outdoor navigation for the visually impaired, by switching between WiFI location and GPS depending on the user's location. In order to convey information to the user, the system will read out instructions, while accepting voice commands. The paper also presents the issue with the lack of standardization of indoor maps, which affects systems's ability to provide indoor navigation. Another issue is that the solution's accuracy can vary.

Improvements to the Wi-Fi indoor positioning was proposed in Yang and Shao [26]. Their solution sends multiple predefined messages which reduces the number of antennas needed, as well as the bandwith required. In simulation, their solution gave Wi-Fi positioning an accuracy of 1 meter without the need to modify the Wi-Fi access points.

The Drishti system uses machine learning to do image sequence matching for indoor positioning. This is done by training the system to detect its position in specific locations based on what the camera can see. Training the system will require a lot of resources since it will require training data for every single room, otherwise the system will not be able to help the user detect their location [27].

Machine learning was also used with wearables in Golding and Lesh [28]. Here, users of the system wear several sensors and based on the input provided from these and the paper's 'data cooking' module, the system can detect the user's location with an 98 percent accuracy. However, this obviously require training data from the locations the system will support. Another issue is, as said in Hesch and Roumeliotis [29], is the inconvenience the user can experience by requiring them to wear hardware.

WebBeep, an indoor location service using audio, was developed and discussed in Lopes et al. [30]. By using audio to send signals to other devices, it is possible to triangulate the position of the user. However, this solution can become inaccurate due to noise, and can cause annoyances for other people in the room.

In Li et al. [7] and Gozick et al. [31], the potential use of the Earth's magnetic field to detect the user's location indoors is discussed. The most compelling advantage with this solution is that no infrastructure is necessary and that the user can obtain a position with their smartphone's magnetometer. It does require, however, a mapping between the magnetic field and the positioning inside a specific building. Another issue is that the magnetic field can be affected by very small distances indoors due to interference from electronic devices. For example, if a user holds their mobile phone at a different height than the people who did the mapping, it can cause them to receive a wrong position from the system.

Another issue with using Earth's magnetic field for indoor positioning is how the user's movement affects the observed magnetic values. In Montoliu et al. [32] they try to handle this issue, by using a method based on Bag of Words. Bag of Words is usually used in text classification, by ignoring the order of words, and creating a histogram of the occurences of each word as a vector to feed a classifier. In this setting, the positioning problem is used as a pattern recognition problem and each position becomes a vector. Through this solution, the researchers were able to achieve an accuracy of three to four metres.

The use of an ultrasonic position system was described in Gualda et al. [33]. Here, they present a system with ultrasonic beacons, and then use time of flight techniques to detect someones location. Unfortunately, like RFID tags, this solution requires significant infrastructure and work hours. Each beacon must be calibrated before the system can be used, and their location must be manually added to the system. Another disadvantage is the limited range of the beacons, which means it is necessary to have many in order to provide an accurate position indoors.

Pseudolites offer similar functionality to satellites in the GPS-system, but instead of orbiting the Earth, the are placed on the ground. They can offer position in places where the reception from satellites are poor, like indoors. Each pseudolite also has a very long range, meaning it is not necessary to place these on every building. The obvious problem here is that the infrastructure costs [34].

The paper Martinez-Sala et al. [35] discusses the advantages of using Ultra-Wideband for indoor positioning, and uses it in their system, called SUGAR. Ultra-Wideband uses narrower radio frequency pulses than other radio frequency solutions, like RFID. This leads to distinguishing direct path signal, which provides the position from reflectors. The main advantage of using this system, is that the consequences of having to send signals through obstacles are small. Therefore, this solution is quite robust. In the paper, the authors also note that they have performed tests, both with a visually impaired person testing the SUGAR and accuracy testing. The error in terms of accuracy was less than a meter. The use of ultra-wideband, however, is expensive.

Dead reckoning is a method for positioning where an object has an initial position and a velocity. Based on this information, a system can calculate the objects current position. Unfortunately, this means that an error in either position, velocity or both will continue to affect the object's position in the system for as long as it is tracked. The errors will also propagate, meaning the system will get less and less accurate for this particular object as time goes on. In Beauregard and Haas [36], they were able to lower the inaccuracy to two percent with a neural network.

Zigbee is a network of nodes consisting of micro controllers and a multichannel two-way radio. These nodes are designed to use little power, and have little computational power, and little data throughput. Through RSSI levels, the nodes can detect the distances between them, and a position can therefore be provided by communicating with this network. The nodes have a very short range in order to keep power consumption low, and therefore it is neccessary to have many of them in a system that shall provide accurate positioning [37].

In Tilch and Mautz [38], the authors presents CLIPS (Camera and Laser Indoor Positioning System) which provides optical indoor positioning. The system consists of lasers that points towards the ceiling, and a camera that is used by the person who will be tracked. The camera will then use the laser points in the ceiling to discern its own position. In order for this system to be used in complex buildings, it will be necessary to provide lasers in all rooms, however, due to the prevalence of smartphones, users will have access to cameras. Also, assuming the user does not always need to know their precise location, it will only be necessary to point the camera towards the ceiling if they are uncertain of their location.

It is possible to use infrared beacons to provide indoor positioning. Unlike lasers, infrared beams are invisible to the human eye, making it less intrusive. The infrared beacons are placed in known locations, and it is then possible to determine someone's location by sending out infrared light. There are two possibilities for communicating with infrared technology, direct and diffused infrared. Direct is only effective at a short range, and uses little power. Diffuse has a longer range, around nine to twelve meters, but also requires more power [39].

Technology	Accuracy	Cost	Comment
RFID tags	High	Medium	RFID tags are cheap to produce, but the manually placing them and adding their location to the system is costly.
Light sensor	High	Medium	Requires specific light for specific locations, and a mapping between light and location
Trilateration	Medium	Low	Uses existing infrastructure, however accuracy is affected by walls and roofs.
Machine learning for image recognition	Medium	High	Requires a system to be trained to recognize all rooms in every building
Machine learning using sensors	Medium	High	Requires a system to be trained to recognize all rooms in every building
Audible sound	Medium	Medium	Sound can suffer from interference and the system can be an inconvenience for other people.
Magnetic field	Medium	High	Requires monitoring of magnetic field in all rooms in all building. Accuracy is affected by where in the room the measurements where done.
Ultrasonic	High	Medium	Short range on beacons, requires many for high precision.
Pseudolites	High	High	High infrastructure cost.
Ultra-Wideband	High	High	Very precise, but also very expensive
Dead Reckoning	Medium	Low	Errors increase over time.
Zigbee	High	Medium	Requires many nodes to be effective.
Camera and laster	High	High	Requires lasers in every room. Lasers can cause annoyance as it is visble light.

Infrared	High	Medium	Invisible to the human eye, short range.

Table 4.2: Accuracy and cost of indoor positioning solutions

4.4 Indoor navigation

Ultrasound sensors has been used in a special cane, presented in Ulrich and Borenstein [40]. Here, the cane detects obstacles for the user, and steers them around it. The report also had an experiment where the system was tested by ten people, including three blind people who are used to using a cane, while the seven other test participants were blindfolded. The participants required only a few minutes of instruction to operate the system. Once they knew how to use it, they were able to navigate through obstacles at a walking speed of one meter per second. Ultrasound was also used in the Drishti system [27], in order to allow users to avoid obstacles by providing feedback to the user.

Jaffer and Sathishkumar [41] makes use of ultrasonic sensors to both plan routes and guide users along. By recording the distance between the user and permanent objects, the system maps out buildings and rooms. Then, using this data it creates a route. When guiding a user the system use the ultrasonic sensors to detect obstacles for the user to avoid and landmarks to determine how far along the path the user is.

A way to guide users through a building is by providing them information regarding landmarks they will pass on their way. This gives the user reference points during their navigation, and makes it easier for them when they have to navigate somewhere else in the building at a later time. Examples of indoor landmarks are elevators, stairs and cafeterias. Landmark-based navigation has been documented as particularly helpful when someone is travelling through an unknown environment [42]. For the visually impaired, landmarks will often be noises, tactiles or scents relating to certain locations. For example can they detect a cafeteria when they notice the scent of food [43].

If there exists 3D models of a building, it is possible to use a sensor to detect obstacles, like stairs. This possibility was tested in Diepstraten et al. [44]. In this report, they used a system that could provide very specific information, for example how many steps the stairs has, if you are required to change direction while climbing and so on. This can simplify the navigation process for the visually impaired significantly, however, 3D maps are not always available. There are however in later years used building information modeling (BIM) models for big and complex buildings that include a lot of different data. Isikdag et al. [45] talks about how this data can be used for indoor navigation by creating specific models to support indoor navigation. The model provide with information on landmarks and static obstacles such as beams and doors. There are possibilities of using these models in applications for navigation indoors.

Avila et al. [46] proposed another way to help navigate visually impaired indoors. They presented a proof of concept using drones. The concept is a wearable bracelet with a small drone mounted to it. This drone can be voice activated to detach and follow a predetermined path to a destination, using camera and distance sensors to no crash into anything. The drone stays about one meter ahead of the user at all times, and the user follows the drone by hearing for the distinct sound it makes.

Henze et al. [47] Did not want to occupy the most important sense of someone visually impaired in order to guide them, and therefore presented an non-intrusive approach using the somatosensory system. The solution is composed of an electronic compass to discern direction, three vibration outputs, one on each back arm and one on the back and a PDA and GPS receiver. The user is given the direction to go using the feedback from the vibration outputs. Similarly Schirmer et al. [48] presented a wearable for vibrations in shoes, giving directions by lightly vibrating on either side of the feet or both for turning around.

In J.Xiao et al. [49], a system is discussed that make use of simultaneous localization and mapping technology to assist visually impaired with independent navigation. The system use a variety of sensors to collect data and communicate with the user. One interesting aspect of this solution is exploring unfamiliar buildings where the system gradually maps the building as the user moves along as well as detecting obstacles, recognize landmarks and recognize/read signage. This is a infrastructure-free solution but it have its drawbacks. There are limits when it comes to the current research. Allocating computational resources when a lot of data is being collected can prove difficult and the image recognition is dependent on head mounted camera images which easily get blurry while walking.

Since almost everyone has access to smartphones today, solutions that can be realized by the technology you find in these would be cost-effiecent. Therefore, in Chan et al. [50], a solution using the smartphone camera to detect obstacles was created. In order to detect obstacles, the application must detect edges in the image, that differentiates objects from floors and walls. This can be troublesome, as the camera will be moving as the user walks, which causes blur. To solve this, the authors created and tested an algorithm, which among other things, increased contrasts in images. This simplified the process of detecting edges. The application was tested with a user with a white cane, and one with a guide dog. The participant with the white cane had less movement, which caused less blur compared to the participant with the guide dog. When there was significant blur, the algorithm showed better performance in terms of complexity and edge detection than earlier solutions.

Another use of smartphone technology is presented in Jafri and Khan [51]. Here, they use Google Tango Tablet Developement Kit with additional sensors to detect obstacles. With the use of an infrared sensor, detection of obstacles becomes affordable and non-invasive, as infrared light cannot be seen by the human eye. In addition to these advantages, it also functions when there is little or no light. The main issue with the use of this technology, is the range of the sensors and inteference from other infrared sources, like sunlight. Google Tango also uses other sensors that is synchronized with the infrared sensor, which allows the system to detect erroneous data.

The use of bluetooth has also been proposed as a solution to detect obstacles with a smartphone, for example in Kim et al. [52]. In this paper, the StaNavi system is presented, which gives directions and uses bluetooth for obstacle detection. The system was tested in Tokyo Station with eigth visually impaired people, all of whom where able to reach their destination. Each participant were asked to perform four navigation tasks, with the length of each task requiring at least 600 meters of movement. Based on this, the researchers concluded that the system was usable in a real-life environment.

Name	Description
Ultrasound	Detect obstacles.
Landmark-based navigation	Provide easy to recognize locations that the user can navigate between.
3D Maps and sensor	Provide information regarding obstacles.
Drone	Guides the user in order to avoid obstacles
Vibration	Non-intrusive way on guiding user.
Computer Vision	Maps the building including obstacles.
Edge detection in images	Detects edges in images to determine whether an obstacle is ahead of the person with the camera.
Infrared	Use infrared light and depth sensors to detect obstacles and the distance to them.
Bluetooth	Use bluetooth to detect obstacles in front of the user.

Table 4.3: Solutions for indoor navigation

5 Discussion

In this section we will discuss the research questions, looking at what challenges and needs we found for indoor navigation of visually impaired and proposed solution and their limitations.

5.1 Which challenges are the visually impaired facing for indoor navigation?

Through the review we found 7 challenges and/or needs in regards to visually impaired navigating indoors with applications.

- Direction: Determining if the direction you walk in is correct.
- Position: Knowing where in a building you currently are.
- Getting information of route: Learning the next step to get to the destination.
- Building information: Having information on buildings such as number of floors and type of doors communicated in a proper matter and accessible.
- Maneuvering obstacles: Being aware of obstacles in the path that are difficult to detect, or that are in motion.
- Using application: Using an application without finding it cumbersome and distracting.
- Identifying objects: Finding specific objects or reading signs and symbols correctly

5.2 What solutions have been proposed to solve the indoor navigation problem and what are their limitations?

We discovered many different approaches to solve the different challenges through the review, with different costs and benefits.

- RFID tags and other beacons: Using beacons to give precise positioning inside a building. While this can be used to improve the navigation indoors, you have to set up the beacons for every room in every building you want to maneuver, and registering their locations in a system or in the beacon. This makes it quite expensive. The beacons is not necessarily compatible with any program, so applications need to adapt to the beacons software to work. The use of narrower radio frequencies is another approach, using Ultra-Wideband, being more precise than RFID and able to send signals through obstacles with little consequence. This does, however similar to RFID, need a setup of multiple sensors, which is costly.

- Wi-Fi Trilateration: Using Wi-Fi access-points and signal strength to determine position. Since Wi-Fi is so integrated in today's society, there are more availability with this approach. The trilateration is not as precise and accurate as might be needed for a good application and user experience, but can still be a large improvement over GPS indoors.

- Image recognition: Teaching a system to recognize rooms in a building, being able to know where you are and where to go. This approach means a lot of images of each room in a building is necessary to teach the system and can not be used in untrained areas.

- Ultrasound: Focusing on maneuvering obstacles, using ultrasound to detect and warn about obstacles in the path. This requires extra hardware for the user, making it less available.

- Pseudolites: Setting up infrastructure on the ground with the same purpose as a satellite in the GPS-system. A pseudolite can cover a large area, but is costly. Pseudolites can also interfere with each others signals if they are too close to each other.

- Laserpointers and camera: Using a camera, pointing at laserpoints in the ceiling, one can determine the position in a room. This solution needs some infrastructure to add laser pointers to every room, but the cost would be smaller than other solutions presented. The solution is limited in that it needs to be in view to be used, as lasers can not penetrate walls.

- Magnetic fields: Measuring the earth's magnetic field to detect location and direction. Since it requires monitoring across all rooms and the measurements are so easily affected by electronic equipment, it becomes difficult to properly use it in such a dynamic setting as indoor navigation.

- Landmark-based navigation: Method that focuses on using landmarks as waypoints in navigation. Requires landmarks to be used, and the system needs to know about the landmark of wherever you navigate. In buildings with multiple of similar landmarks one might mistake the one the system refers to for another.

- Audio triangulation: Sending audio signals to other devices to find the users position. The audio can be distracting to the user and the surrounding people. Sound from other people and systems can interfere with this approach making it unreliable.

- Drone: Navigating by following a drone to the location: This concept is in a early stage and there are limitations. Such technology would be expensive and since the user rely on hearing the drone, noisy surroundings can interfere and make it difficult to determine the drone location.

- Wearables: There have been a few examples of using wearables.
  - Using equipped sensors together with machine learning to determine position of the user, which would need training data of where it is used, limiting the availability or adding cost to produce the training data.
  - Use of a camera on the users head and pictures it takes to map unfamiliar areas. This would require computational power, meaning wearing more hardware, and since it is dependent on the camera images to not be blurry it either requires the user to periodically stop or move restrictively to ensure high quality pictures.
  - Being equipped with vibrator outputs to guide the user in the right direction without use of sound. This solution requires very precise location, otherwise it will send the user in the wrong direction. As mentioned in 4, object misidentification can cause significant annoyance for the user.

- 3D modeling: Taking 3D models of buildings such as BIM and making use of the data these models possess to support navigation. Limited to where such models exists and there is a challenge in creating models which include valuable information for visually impaired.

- Infrared: Sending and detecting infrared signals to determine position and detect obstacles. Infrared signals can be used to effectively navigate small places, and work well in dimly lit rooms. It is also not visible to humans making it non-intrusive. Infrared is however limited to small places since it can not penetrate walls and it is also easily interfered by other infrared signals such as sunlight.
- Bluetooth: Communicating with bluetooth beacons to discern where you are and where to go. Easily available since most smartphones includes bluetooth functionality. Does not require line of sight between beacon and phone. Limited by cost, needing many beacons to be effective. Can also be limited by scale where if many are communicating at once, there might be interference
- Dead reckoning: Calculating position based on initial position and velocity. An approach not needing sensors or infrastructure, only data from your phone. while cheap, the accuracy can become low over time since an initial errors will propagate.

5.3 Limitation of research

Due to using a manual search on Google scholar to find research papers useful to our research questions, it is possible that relevant reports and solutions were not found. While we also discussed the domain with employees of MazeMap, and our supervisor to find additional research, this still only provides us with topics and technology they knew of. The researchers lack of knowledge regarding systematic search caused them initially to only look at the most cited papers, missing several relevant newer papers in earlier drafts of the report. The papers were also manually judged by the researchers if they were relevant enough to include in the review. It was also the researchers gauge of similarity that decided if two papers on similar topics should both be included or not and this might have caused certain research to be omitted.

6 Conclusion and further work

In this chapter, we will present our conclusions to our research questions. It is divided into two sections, one for each research question. There will also be presented further work for each research question, and what we intend to do during our Master's thesis next spring.

6.1 Which challenges are the visually impaired facing for indoor navigation?

The key challenge for the visually impaired for indoor navigation today is knowing their own position, the direction they are facing and knowing the specific route to their destination. Without the knowledge of this, the visually impaired has to request help from other people or risk getting lost.

To help the visually impaired navigate indoors, there should also be a focus on how to handle errors in the system. As mentioned in 4.4, the use of landmarks can be helpful to provide a specific location even if the system does not know the user's location. If there is no nearby landmark, and the system can not offer an accurate position of the user, the system must notify the user of this. An example of how the system can detect errors with its accuracy is if it believes the user is outside the building, while being at a high altitude, like the top floor of the building.

While the research that has been discussed in 4.2 focuses on what the visually impaired needs and wants to know, it is important that the system does not overload the user with information. This could lead to annoyance from the user, and therefore the user should be able to dictate how much information they want and when they want it.

Another key focus of a solution needs to be universal design, see 2.5. If the visually impaired find a solution cumbersome to use, they will avoid it, and instead use nontechnological solutions like cane and guide dogs. Key issues that should be avoided are making it difficult for the user to obtain the information they need, and not allowing the user to multitask by requiring them to use their hands to operate the system at all times.

6.2 What solutions have been proposed to solve the indoor navigation problem and what are their limitations?

Today there exists many technological solutions that can provide the position of a user indoors. However, there is a trade-off between cost and accuracy, as a precise indoor locations requires additional infrastructure. Unfortunately, adding this infrastructure to every complex buildings is unlikely to happen. Therefore, the focus should be on testing how accurate a solution must be in order to support the visually impaired in indoor navigation. If the users are able to handle some inaccuracy, a low-cost solution, for both the building and the user, could be realized. As mentioned in the previous section, the solution also needs to be able to handle inaccuracy and still be helpful to the user.

The solution that had the lowest cost was using Wi-Fi access points for trilateriation. We therefore propose that significant amount of testing is done using trilateriation in the context of indoor navigation for the visually impaired. In the spring of 2017 we intend to test a prototype for MazeMap, that will use the Wi-Fi access points at NTNU. Through a partnership with Blindeforbundet, our target is ten visually impaired to participate in the testing and interviews.

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