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# Bluetooth Low-Energy Beacons Guidance System for Visually Impaired

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# Abstract

Visually impaired people need to get more independent in fulfilling their daily tasks. Smartphones are helping them to orientate in unknown environments and to get information about it. Indoor Navigation on a smartphone is a difficult task for developers, because absolute positioning indoors is challenging. Smart environments give the opportunity to interact with the environment. Small Bluetooth low energy devices that need little maintenance and have long battery time can be used to emit light, vibrate or play sounds. Visually impaired people are more used to relative positioning. In account with that a concept was designed in which they can explore their environment using these interactive devices.

In this thesis, a platform called Blidget is used which can advertise information using Bluetooth. The modular design of the Blidgets also gives the opportunity to use it as a sensor or an actor by attaching modules. The use of interactive audio feedback from the Smart Environment for indoor navigation for the visually impaired was therfore evaluated. For this purpose a navigation application was implemented using Blidgets to give audio output in different frequencies and durations. The user gets turn-by-turn instructions through the building and can interact with the Blidgets on his path. The usability of this navigational aid was evaluated by comparing it to a simulated ideal verbal guidance system and a tactile map. The results indicate that using the environment for indoor navigation is promising but the use of a touchscreen for input while moving and carrying a white cane needs further improvement.

# Kurzfassung

Es ist notwendig, dass blinde und sehbehinderte Personen unabhängiger im Alltag und bei der Erfüllung alltäglicher Aufgaben werden. Smartphones helfen ihnen bereits sich in unbekannten Umgebungen zu Orientieren und Informationen darüber zu bekommen. Innenraumnavigation mit einem Smartphone ist dabei eine schwierige Aufgabe für die Entwickler, hauptsächlich da absolute Positionsbestimmung im Innenraum kompliziert ist. Smart Environments geben die Möglichkeit mit der Umgebung zu interagieren. Kleine Bluetooth Low Energy Geräte, die wenig Wartung benötigen und eine lange Batterielaufzeit haben, können hierbei benutzt werden um zu leuchten, zu vibrieren oder Geräusche abzuspielen. Blinde und Sehbehinderte sind eher an relative Positionsbestimmung gewöhnt. In Übereinstimmung damit wurde ein Konzept entworfen, mit dem sie ihre Umgebung durch diese interaktiven Geräte erfassen können.

Für diese Diplomarbeit wurde eine Plattform namens Blidget verwendet, die via Bluetooth frei Informationen sendet. Das modulare Design der Blidgets gibt zudem die Möglichkeit es als Sensor oder Aktuator zu verwenden, indem zusätzliche Module aufgesteckt werden. Der Nutzen von auditivem Feedback aus dem Smart Environment zur Innenraumnavigation für Blinde und Sehbehinderte wurde hiermit untersucht. Zu diesem Zweck wurde auch eine Navigationsanwendung implementiert, die mit den Blidgets verwendet um einen Ton in unterschiedlichen Frequenzen und für unterschiedliche Dauern zu generieren. Der Nutzer bekommt eine Wegbeschreibung durch das Gebäude und kann mit den Blidgets auf seinem Weg interagieren. Die Usability dieser Navigationshilfe wurde evaluiert indem sie mit einem simulierten idealen Sprachführungssystem und einer taktilen Karte verglichen wurde. Die Ergebnisse zeigen, dass das Nutzen der Umgebung für Innenraumnavigation vielversprechend ist, aber die Nutzung eines Touchscreens für Eingaben während des Laufens mit einem Blindenstock weiter verbessert werden muss.

# List of Abbreviations

| | |
|---|---|
| BLE | Bluetooth Low Energy |
| RF | Radio Frequency |
| RSSI | Received Signal Strength Indicator |
| SBSOD | Santa Barbara Sense of Direction |
| VGS | Verbal Guidance System |
| VI | Visually Impaired |

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# 1 Introduction

## 1.1 Motivation

Human navigation is a very complex process that mainly relies on vision. As such, for the majority of visually impaired (VI) people, walking in unknown places can be a very difficult task to perform. It is generally known that the inability to move freely and independently can hinder the full integration of an individual into society. Visually impaired navigation is a problem which has been considered from several points of view. For blind people the orientation process is mainly based on subjective factors. It is usual to think that blinds use an imaginary grid to orientate, but they prefer to navigate using perimetral exploration. Thus to orientate in an unknown place blind people require to perform a previous exploration process. To navigate autonomously and efficiently a visually impaired person requires two fundamental operations:

Mobilization or Micronavigation: consists of avoiding obstacles in the immediate environment. Micronavigation involves the concrete perception of the immediate environment and surrounding objects. Fixed objects can be detected by touch scanning either manually or with the use of a guide cane. thus these objects can be added to the repertoire of points of reference benchmarks once learned its location. Moving objects require their perception on the spot.

Orientation or Macronavigation: This is the ability to establish and maintain awareness of the own position in relation to both markers in the area surrounding and a wanted destination. The orientation or macronavigation makes extensive use of cognitive abstractions with which a visually impaired person is able to perceive the spaces before reaching it, moving in it and then leaving it.

Orientation and mobility are essential skills to the success of a navigation task. For visually impaired as well as sighted people, landmarks play an important role in decision-making when traveling. With reference elements and notions such as proprioceptive stimuli, environmental information relevant as placeholders in the spaces and other points of confirmation or redirection, visually impaired people can generate a mental representation of space. So, providing the visually impaired with these environmental features during the guidance process is critical for successful navigation tasks.

The scientific work done in the recent years on the topics of “smart environment”, “ubiquitous computing” and “Internet of Things” has moved interactive devices in the scope of our daily lives[KPD+13] [CD07]. These interactive devices can enrich our environment with information, let us interact with it and even react to our behavior to make life easier and more comfortable. New small devices with long battery life time and little maintenance effort make it possible to reach easily into areas that otherwise would be hard to make accessible.

For the VI the interactivity with the environment has the potential to help them to master tasks in their common surroundings and especially in unknown environment. The utilization of this interactivity is believed to have the greatest potential to navigation, micronavigation as well as macronavigation. This thesis target on increasing personal autonomy for the VI by introducing a solution for indoor navigation that uses an interactive environment accessed with their smartphones.

## 1.2 Goals

The goal of this thesis project is the design, development and evaluation of a mobile App that allows perceiving near Bluetooth low energy devices and feedback this information in appropriate ways (e.g. Text-To-Speech, vibration patterns, etc.). The non-visual landmarks should be realized through BLE beacons, which are tiny battery-powered self-contained devices that can be deployed permanently indoors and outdoors. Further, these beacons can be used to identify moving objects such as buses and trains. The system was evaluated in a indoor deployment with visually impaired persons.

In addition to the original task an interactive audio feedback from the BLE beacons has been implemented. This audio feedback is meant to give the VI the possibility to orientate by hearing the beacon and localizing it using their auditive perception. With this feature the VI would not have to rely only on the feedback from their smartphone, but do also get direct feedback from their environment.

## 1.3 Structure

This document is structured in the following way:

**Chapter 2 – Related work:** describes the principles of accessibility and the theoretical approaches of smart environments, ubiquitous computing, Internet of Things, indoor navigation and ubiquitous positioning.

**Chapter 3 – Concept:** describes the idea behind this thesis. It shows how interactive Bluetooth devices can be used as indoor navigational aid.

**Chapter 4 – Technology:** gives a quick overview over the technology used for the app and the BLE beacons that are used for the implementation.

**Chapter 5 – Implementation:** shows the implementation of the app.

**Chapter 6 – Evaluation:** shows how the evaluation was done and presents the results.

**Chapter 7 – Conclusion and future work** outlines the results of the thesis and shows what new topics result from it.

# 2 Related work

This chapter shows the principles of indoor navigation for VI. It discusses the relevant approaches and gives an overview over the principles, which were used for the solution presented in this thesis.

## 2.1 Indoor localization systems

Indoor navigation is a current research topic and there are many technologies which try to solve this problem. These technologies include RFID, Bluetooth Beacons, WiFi, Ultrasound and Object Identification. Which will be described in the following sections.

### 2.1.1 RFID

D'Atri et al. created a system called RadioVirgilio/SesamoNet reusing RFID identity tags from cattle slaughtering [DMS+07]. They set a grid of passive RFID tags, which are burrowed into the ground up to 4 cm. Figure 2.1 shows the grid and the orientation the RFID tags gave. To make it low-cost they used recycled animal identification RFID tags for the grid. The RFID tags had unique numbers and could thereby be associated with their location. To read the tags they modified a white cane. The RFID antenna was placed inside near the tip. The cane had also a RFID controller, a Bluetooth interface and batteries. To process the data they used a PDA. To test their system users had to orientate in the grid, find the path and follow it. As a result, they found that 1. speech is too long for navigational hints, 2. the cane has to be adjusted to the user, 3. the usage of the cane has to be trained, 4. the grid tags that were not on the central path are only used if the user gets lost and 5. a foresighted announcement for upcoming turns on the path is important.

A similar approach without white cane using antenna has been made by Tsimpras et al. [TRFK15]. The antenna worn on a belly bag was orientated towards the floor and could read the tags without the use of a modified cane.

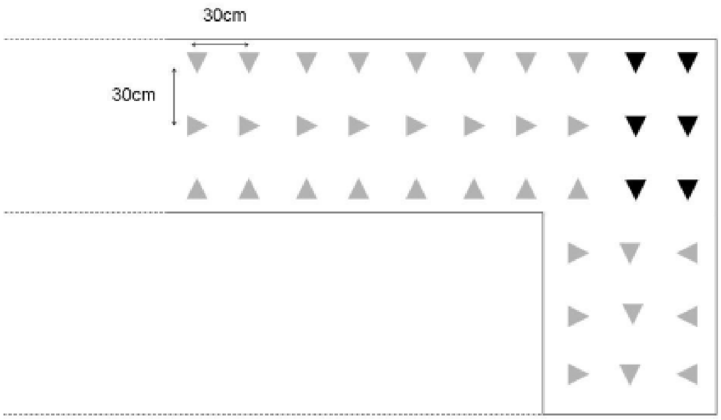


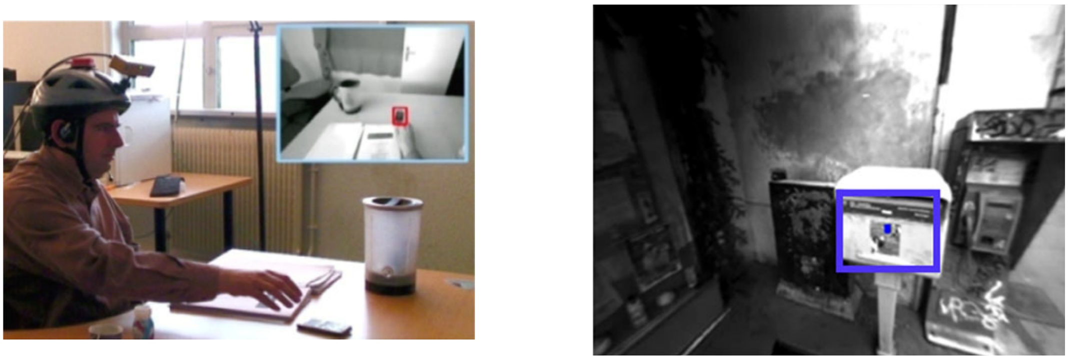

**Figure 2.1:** RFID orientation [DMS+07]

### 2.1.2 Object Identification

Another approach to orientate could be to identify scanned objects [KKP+12]. The NAVIG system they introduce can identify landmarks on the road compare it to its database and orient thereby. Figure 2.2b shows a mailbox that gets recognized by the system. As many buildings look the same on different floors or are even mirrored (e.g. the Computer Science Building of the University of Stuttgart), it is very difficult to orientate with that approach. However, the system Katz et al. introduced can also be used to ask questions about your surroundings. They use a head-mounted stereoscopic camera in combination with computer vision algorithms to identify objects requested by the user or geolocated landmarks requested by the system to compute the position. In combination with other positioning systems it could be used also indoors. Another benefit is what they call near-field assistive mode wherein the system can give you the position of an object for example on your desk or in your direct surroundings. It can also identify objects even if they have a similar shape like canned food or bank notes. In figure 2.2a a user asks for the location of his calculator and the system tells him where to find it.

### 2.1.3 Odometry

Pedometers and accelerometers lack sufficient accuracy due to high variation of velocity, trajectory, step length and heading [KKP+12]. Compasses do also not work with sufficient accuracy in indoor environments. The trajectories differ more and more the longer the way gets.



**(a)** indoor

**(b)** on the road

**Figure 2.2:** NAVIG object identification

### 2.1.4 radio frequency methods

Research has introduced several methods of absolute positioning using radio frequency (RF) devices (WiFi or Bluetooth). The internal clock of these devices is not exact enough to provide a position tracking like GPS. Another option is the received signal strength indicator which can compute the distance to the sender using the exponentially decreasing signal strength. This method is not very accurate due to reflection, refraction, noise, different radiation patterns and other electrodynamic difficulties. The three following methods base on RSSI and and are thereby also not very accurate.

Triangulation computes the location by using the RSSIs of at least three RF devices as distance indicator. The location of the three devices has to be known. Now the location can be computed.

Fingerprinting uses an approach of pattern matching. The RSSIs of all devices (pattern) in several locations are collected in a database. An algorithm computes the best matching pattern to get the most probable location.

ROCRSSI the ring overlapping comparison of RSSI presumes, that all RF devices can measure the RSSIs of the other devices. By using these measured RSSIs and the locations of the other devices the method can set ranges. With more than one RSSI the comparison of the overlapping ranges in an inequation creates fields in which the user has to be.

If the technology can provide absolute positioning, a path can be computed which can lead the VI from their starting point to their destination, tell them if they leave the path and compute a new one. For indoor use the solutions for this absolute positioning

**Figure 2.3:** Viibracane [Sch15]

presented in the recent years as mentioned seem promising, but not ready for the market.

## 2.2 Human Interface Devices

There were several approaches where sensors or actuators were attached to a white cane. For the RadioVirgilio/SesamoNet it was an RFID reader [DMS+07]. For the Viibracane [Sch10] - seen in figure 2.3 - a Nintendo Wiimote was attached to a white cane. The vibration of the Wiimote showed the user whether he is on the right path. This configuration can also be used for input and sound as the Wiimote also features an accelerometer, a gyroscope digital buttons and a directional pad.

## 2.3 Output methods

To represent data for the VI there are several approaches. In the following the relevant ones for this thesis are shown.

### 2.3.1 Auditory cues

There are several ways to represent information auditory. The straightforward method is Text-to-speech. The downside of text-to-speech is that it is too slow for most navigational requirements and you can represent only one data set at a time. Especially for pedestrian navigation, longer indications can only be given at certain waypoints. A faster representation would be better while the person is moving. There has been a lot of research in this topic. The most important one for this thesis are explained in the following. In 1986 Gaver described Auditory Icons [Gav86]. These Icons represent computer events by analogy with everyday sounds. E.g., the sound of crumpling paper when a file is put to the recycle bin.

In 1989 Blattner et al. described Earcons [BSG89]. A sound grammar represented by abstract, synthetic sound patterns, mostly musical tones. They represent objects, operations or interactions. There is no analogy to the tunes, so the user has to learn them.

Walker et al introduced so-called Spearcons in 2006 [WNL06], which are short auditory cues that can be learned easily. They use spoken phrases by a Text-to-speech software that were sped up. Although they mostly cannot be recognized as speech, only a short training is required.

Several studies have been conducted on the various sonification methods (e.g. [DLW08] or [TLA00]). The NAVIG (Navigation Assisted by artificial VIsion and GNSS) introduced by Katz et al. which uses a combination of different tools for micro- and macro-navigation [KKP+12] also uses a combination of auditory cues. The System seems to be so exact that it can use an augmented reality approach, which uses 3D spatialized sounds to guide the VI. They used five categories for the interest points for the navigation. Itinerary Points that represent the path, Difficult Points that show possible difficulties for the VI, Landmarks that can be identified by the system via object identification, Points of Interest that show possible destinations or interesting features and Favorite Points that can be added by the user himself. They use so-called Morphocons as an auditory representation for these points. Each category has a specific sound grammar so it can be easily differed. These sounds have a length of 0.2s to 1.5s and can be placed in the virtual 3D space using stereo bonephones.

The SWAN (System for Wearable Audio Navigation) [WWL+07] relies only on an auditory display. To indicate directions they also use virtual auditory beacons placed in an augmented reality using bonephones. These virtual auditory beacons represent waypoints. If the user approaches a waypoint the beacon tempo increases, if he reaches the waypoint the system plays a subtle success chime, if overshoots the waypoint the beacon sound changes timbre. The system also represents other points in the environment by a combination of auditory icons, Earcons or Spearcons. The user can also add annotations in a location and associate it with an auditory cue by selecting a category for it.

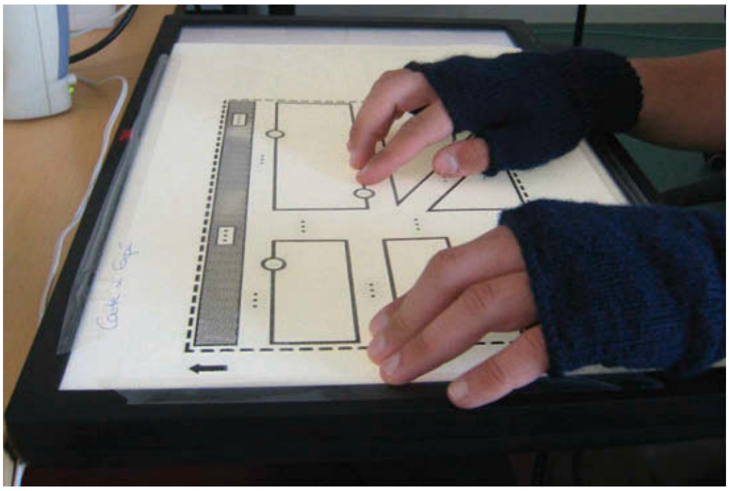


**Figure 2.4:** interactive map [BTO+15]

### 2.3.2 Tactile maps

Tactile maps exist in different occurrences. The classic form is a paper map with raised lines and a legend in braille. These suffer of several limitations: like regular maps for seeing people, some training is required to use these maps. The resolution perceived by touch is much lower than of the eye, so the displayed data has to be reduced or the map has to be much bigger. Braille needs a lot of space (one letter is about 4x6mm, space between letters should be 3mm, space between lines 4mm), so a legend has to be attached. For using a legend the exploration of the map has to be interrupted, which results in a longer processing time and dissatisfaction. In addition, fewer than 10 percent of the 1.3 million people who are legally blind in the United States are Braille readers. Further, a mere 10 percent of blind children are learning it [NFB09].

Simple interactive maps do not change the content of the map, but they can work without labels and a legend. They give feedback to the items touched on the map. Brock et al. compared traditional tactile paper maps to interactive ones [BTO+15]. The interactive map for comparison was a raised line map attached to a multitouch touchscreen (figure 2.4). The results showed that the learning time was significantly shorter while efficiency was higher. The effectiveness was on a par. The satisfaction for the interactive map was much higher. Viibracane [Sch10]

There are also attempts to make touch sensitive devices accessible by using vibration ([PMPR11], [YBT12], [GPBK12]). These seem to be less efficient than raised line paper maps, but there was no comparison made between the methods.

The HyperBraille is a touch sensitive pin-matrix display [Sch15]. It can work like an touchscreen for the blind. The resolution is only 120x60 pins and the pins can only be

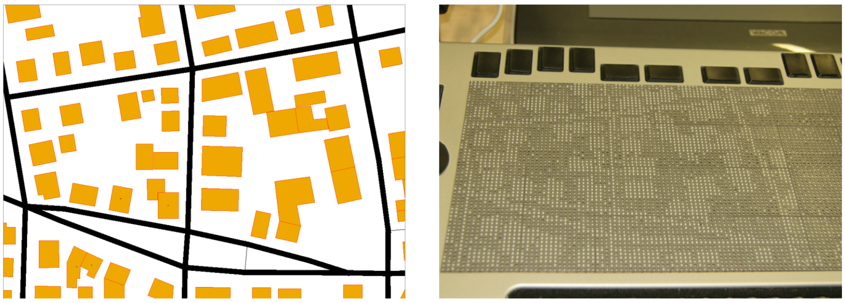


**Figure 2.5:** HyperBraille - interactive pinned display

**Figure 2.6:** thumbwheel input device [WWL+07]

adjusted binary, so the graphic would resemble a black/white-image, but every graphic output can be converted to this device 2.5.

## 2.4 Input methods

For the SWAN [WWL+07] was a special input device designed using a thumbwheel and two buttons (figure 2.6). This device is used to access the audio menu of the system, which consists of Spearcons in combination with spoken text. The system is supporting preemption. That means the playback of a menu item stops when you select another. This enables the user to navigate quickly through the menu. This use is also documented in [WNL06]. If the user reaches the end of the list and goes on, the system starts over at the first item playing an audio notification beforehand to avoid confusion. The NAVIG [KKP+12] uses also haptic input device with buttons, but sadly, there is no further explanation of it.

Speech recognition can be used to interact with the system for basic data, in case of the NAVIG [KKP+12] the user can even ask questions about his environment or even about a specific object. The biggest advantage for the use of Speech as input is that you can keep your hands free. Other developers like Wilson with SWAN do not think of speech as a good option, because they assume it not to be reliable or private enough for the users.

## 2.5 Accessibility

Accessibility for smartphones is an important task not only to include the VI but also people with other disabilities. Smartphones are not only communication devices but also full-fledged computers with operating systems that support all kinds of software. Most of the smartphones available on the market have only few hardware buttons left (mostly power and volume). To make the Touchscreen accessible for VI the system must provide a screen reader. To get from item to item swiping gestures can be used. All kinds of gestures can be used to create shortcuts and increase the usability. Different sound cues for system events like list scrolling can also increase the usability.

## 2.6 Smart environments

More and more devices can connect to each other and the web directly or indirectly via smartphone or personal computer. These tags, displays, sensors, actuators and controllers can enrich our lives via direct interaction or automation.

## 2.7 Summary

The research presented in this chapter described a wide variety of methods and technologies to help VI navigate autonomously in indoor and outdoor environments. To use these methods and technologies the user has to carry special equipment with many sensors that cooperate in complex algorithms. The approach in this thesis is to use only a smartphone and the smart environment in the building to get a navigational aid in the building.

There were also technologies presented that try to use the present radio frequency devices for absolute positioning. If that succeeds, indoor navigation can be realized in the same way it has been realized for outdoor applications. However, the approach in this thesis uses the devices for relative positioning. A cloud service provides a database in which all necessary static devices of the building are registered. The data contains a description of the location and a list of all direct neighboring devices and how to get to them. This way some kind of turn-by-turn route description from one point to another can be realized.

The third important research topic related to this thesis is the output representation of beacons for navigation. The research described beacons as auditory cues in 3D-spatialized augmented reality. The approach of this thesis is to make use of the interactivity of smart environments and let tangible beacons give their cues in reality.

The last important topic is the human interface device. The approach of this work is just to use a smartphone with an accessible application as interface. The users can use a interface device they are used to with a operating system they know.

# 3 Concept

In this chapter, the concept of an indoor-navigation application using smart environment devices is introduced. First, the concept of a navigation using existing infrastructure is presented, then some use cases are discussed. After that, the use of Blidget as interactive smart environment is explained. Finally, a preview on the application design is given taking into account the special requirements for VI.

## 3.1 Navigation using static BLE devices

VI compensate their lack of sight by augmenting the capabilities of their other senses. By using tact, hearing and even olfaction they can orientate themselves in their environment and avoid obstacles in their surroundings. Orientation or Macronavigation is the ability to know the own positioning in reference to a starting point and a destination or in an absolute manner. For orientation, the VI can make use of a mental map. Using an imaginary grid like a floor plan would require them to know their absolute position all the time they are traveling, this position has to be found and needs afterwards a high degree of concentration to maintain (figure 3.1). An easier way is to explore the way to a destination by using subjective factors as reference points to picture a path. This method only needs relative positioning. (figure 3.2)

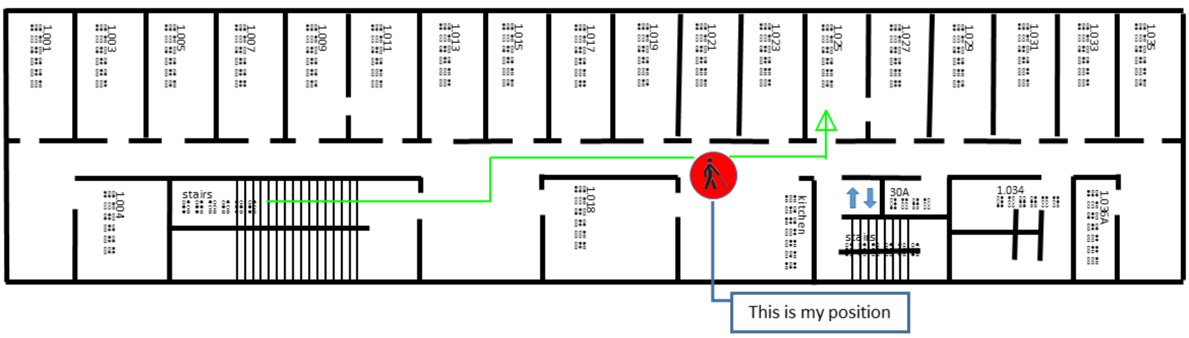



**Figure 3.1:** Absolute positioning

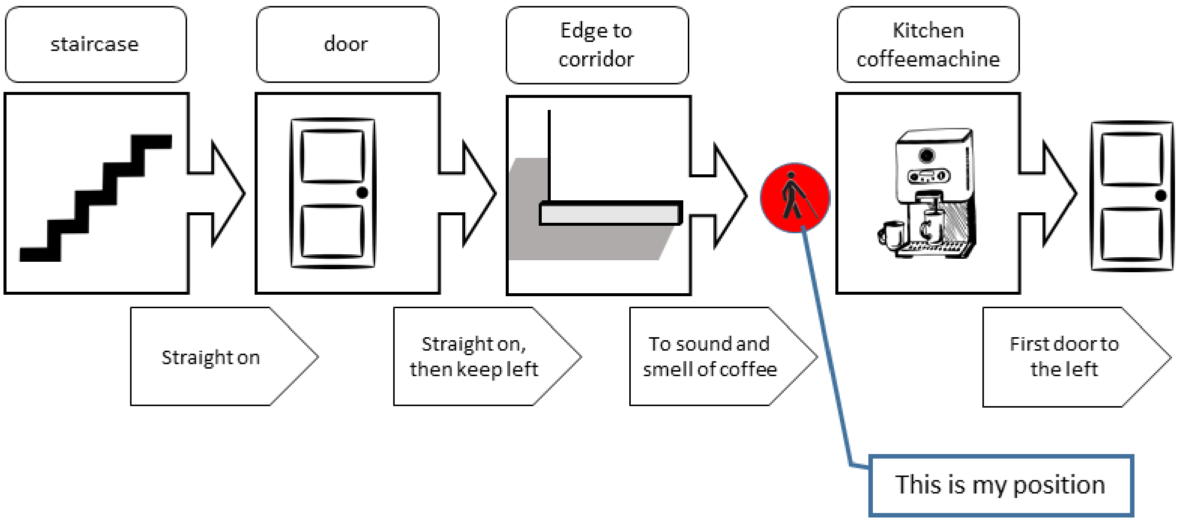



**Figure 3.2:** Relative positioning

This thesis presents an approach, which reflects the relative positioning and tries to present the reference points for the VI. Several systems were presented using radio frequency methods or light. This thesis wants to make use of the interactivity of smart environments for indoor navigational use. Not only by representing data but by giving actual feedback from the environment.

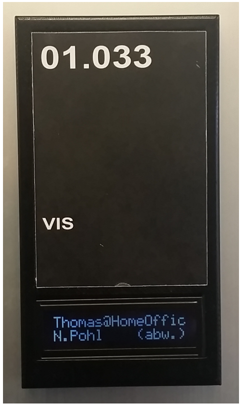
In the last years, Bluetooth Low Energy devices became available for everyday use. Several vendors produce beacons mainly for advertisement or educational use in museums or universities. These beacons are already thought to stay on a specific place.

In a smart environment many more devices are available indoors. Devices that stay in a specific place, like interactive door plates(figure 3.3), keyless entry or desktop computers, could be used for navigational purposes. That presumes that the BLE devices are detectable or even advertising like beacons do. If a database would know the devices, its neighbors and how to get from one to another, a path could be computed. The more dense a network becomes the merrier becomes the resolution (figure 3.4).

## 3.2 Use cases

### 3.2.1 Getting information about your surroundings

In an unknown building, VI would most likely try to orientate on their own or by asking someone for help. If that fails, they would resort to their smartphone to get more




**(a)** interactive door plate in HCILab


**(b)** Update Office Door Note via Twitter [NFB12]

**Figure 3.3:** interactive door plates

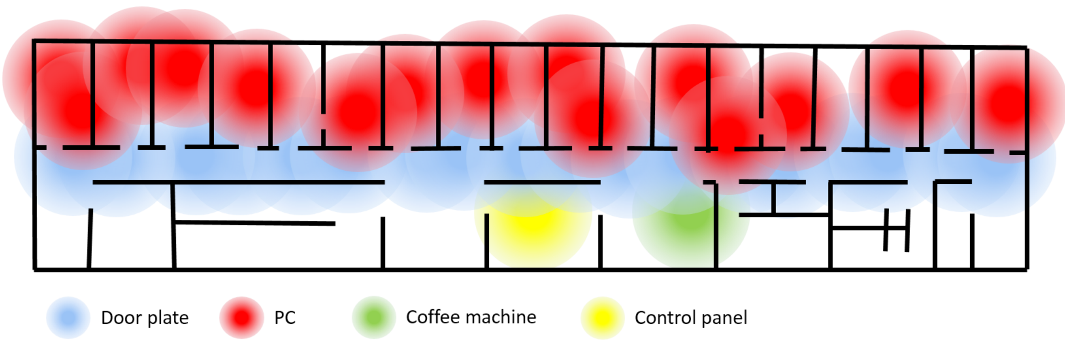



**Figure 3.4:** network coverage of BLE devices

information or to call someone for help. An indication on the homepage of the building or institution could reference on this application. In a more advanced approach, a beacon at the entrance could pipe up as the user enters the building using a protocol supported by the operating system of his smartphone.

After installing, the application scans for BLE devices in range. If they are in the database, the user will get information about the location, the estimated distance and additional details, if wanted.

### 3.2.2 Getting information about the whole building

Most VI plan their routes beforehand to avoid surprises. To do that even inside one building they need specific information about the building. The application can show the user all locations for the building he is in. The user can explore the locations, search for persons and get information about rooms. E.g. whether the person he is searching for is placed alone in an office.

### 3.2.3 Searching for a path

The user can plan a path through the building. For the starting point, he can choose between the Blidgets in range. For the destination between all locations in the building. He can conduct a search, which includes additional information about the locations. The application will give him a path from location to location, describing the locations themselves as well as the route from one location to the next. He can read the path before or while moving.

## 3.3 Using Blidgets

A great benefit of smart environment is interactivity. The devices such as tags, displays, controllers, actuators and sensors communicate. They can be controlled or act “smart” and make their own decisions. This interactivity is not restricted to data exchange in between devices, like temperature sensor with activity tracker. The smart environment can also give feedback to the user in all possible ways. Dimming the lights, changing the pictures in a digital picture frame, changing temperature, blinking, beeping or vibrating devices for notifications or stati.

In the chapter previous work, several approaches have been presented using augmented reality to place virtual auditory beacons for the VI. Smart environment gives the opportunity to interact with physical devices in the environment using the own smartphone instead of a specialized hardware. Thereby the VI can get the location of a beacon without the need of complex 3D spatialized computation.

The Blidgets used for this thesis can divulge their position by beeping, emitting light or vibrating. For navigation for VI only the beeping was used. It will be activated, when the user comes in range or if he asks for it explicitly. He gets additional information for each location from the application on his smartphone.

### 3.3.1 Benefit for seeing people

There are also situations this kind of navigation could be helpful for the seeing. For example in an emergency situation, when vision is severely limited by a smoke screen or a power breakdown. E.g. a fire in the building, the user could activate a fire alarm mode in the app and the Blidgets could lead him on the escape route using cascading light and beeping.

### 3.3.2 Maintenance

An important issue with remote devices is maintenance. The devices have to be registered, deployed and maintained. The system should be designed to be easy to manage for every mandatary. Be it the facility manager of the building or the equal opportunity commissioner.

#### Registering devices

Registering the devices should be possible using the app in an admin mode or in a web application. This mode should only be accessible to the persons in response. To register and administer beacon locations it is necessary to show and edit additional information. Device specific data like MAC-address and the ability to beep and location specific data like room description, room ID and neighboring beacons should only be edited in admin mode.

#### Check Battery Status

The Blidgets can report their battery status to any connected device using the standard BLE protocol. The Application reports the battery status to RESTful API and it will be stored in the database. The maintenance staff can see the states of the beacons from the database and schedule their timetable according to it.

## 3.4 Input/Accessibility

The Application should be designed in a way that very few gestures are needed. The structure should be self-explanatory. If that is not possible or problems in understanding the structure are reported, an initial explanation is required.

## Summary

In this chapter three modes for the users and one for administrators were introduced: 1. a Scanning Mode to get information about the surroundings, 2. a Search Mode to explore the beacon locations in the whole building, 3. a Navigation Mode to get a path from a starting location to a destination and 4. an Administration Mode wherein registering new beacons and getting additional information is possible.

# 4 Technology

In this chapter the technology is described, which were used to capture and present the BLE devices and the Blidgets themselves. First the platform and the reason for choosing it is depicted. Then a short overview of the connecting technology Bluetooth Low Energy is given. Finally, the Blidgets are presented. For the implementation an Android smartphone, precisely a Nexus 5X was chosen.

## 4.1 Android

Android is the Operating System with the biggest market share for mobile phones and tablets. There is a big scope of devices in all sizes from different vendors. It is based on a Linux kernel and released under open-source licenses. So the system is transparent and most of it can be comprehended. The Nexus 5X was chosen, because it provides pure Android without a firmware interfering .

### 4.1.1 TalkBack

TalkBack is an accessibility service from Google Inc. It is inherent part of Android. It features screen reading, explore by touch, explore by swipe gesture, vibration feedback, keyboard echo and customizable gestures. It has a build-in context menu for text reading, text input and screen navigation. Unfortunately, there are no comparative studies or case studies regarding TalkBack.

### 4.1.2 Eddystone

Eddystone is a protocol to advertise data with Bluetooth Low Energy devices. It uses three frame types and a few abbreviations to keep the data size small and thereby the battery life long. The first frame type is Eddystone-URL. It represents a compressed URL and is the backbone of the Physical Web, an open source approach for interaction on demand in a context with smart devices [GPW15]. The second is Eddystone-TLM, which transmits telemetry data. The contents are battery voltage, temperature, advertising count and time since power-on or reboot. The last one is Eddystone-UID a 16-byte Beacon ID composed of a 10-byte namespace and 6-byte instance. [GEd15]

If Eddystone meets the expectations, there is a good chance that it will become an inherent part of Android. This would open up new possibilities, e.g. interacting with beacons without the need of a special application by using the web browser.

## 4.2 RESTful API

A representational state transfer application programming interface enables an application to access a database on a specific URI with simple commands like GET, PUT, POST and DELETE. There is no need to know any structure of the database. There are several APIs used for this application. They are described in brief in the following:

### 4.2.1 Proximity Beacon API

The Proximity Beacon API is a cloud service provided by Google Inc. using a REST interface. It can manage the data attached to the beacons. The API also includes Eddystone and can use this protocol interpret the data advertised by the beacons. To connect to the beacons the Nearby API can be used. To store the locations the Google Places API can be used.

### 4.2.2 Nearby

Nearby consists of two APIs the Nearby Messages API and the Nearby Connections API [GNe16].

The Nearby Messages API is a publish-subscribe API. It uses a combination of Bluetooth, Bluetooth Low Energy, Wi-Fi and near-ultrasonic audio to communicate. This API is used to subscribe to Bluetooth Low Energy beacon messages from the beacons registered in the Proximity Beacon API without implementing the whole Bluetooth Low Energy Adapter.

The Nearby Connections API enables an application to discover other devices on a local network. The application can connect and exchange messages in real-time. This API is of no use for this application.

## 4.3 Bluetooth low energy

Bluetooth low energy (BLE) is a wireless standard with low energy functionality. It works in the same spectrum range but uses a different set of channels. It works in a client-server structure using the Generic Attribute Profile. The client, typically a computer or smartphone, initiates commands and requests. The server, typically a beacon, a sensor or an actuator, receives the commands and requests and returns responses. The GATT server provides Services, which contain characteristics. Universally unique identifiers (UUIDs) identify both services and characteristics. Descriptors can provide additional information about a characteristic, for instance min- and max-values or the unit of measurement.

BLE comes also with a set of profiles to specify how a device works in a particular application. For this thesis the only relevant profile exposes the Battery State and Battery Level.

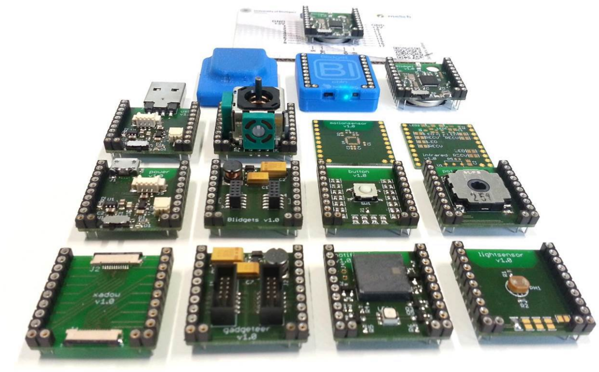
## 4.4 Blidgets

There are several platforms that have heralded a new wave of Ubicomp Products [KPD+13]. They are characterized by easy access, low cost and a great variety of displays, sensors and actuators that can be attached. There are even approaches with conductive ink that could close the gap between traditional work on paper to digital documents [Tick15].

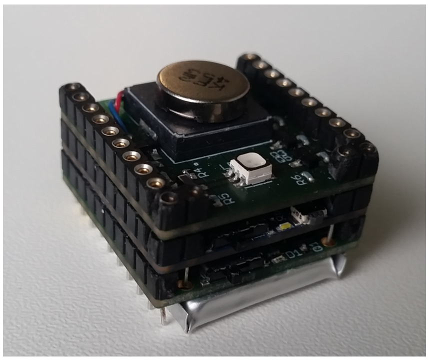
The Blidgets platform is a new modular and ultralow power platform to create devices that communicate with smartphones, tablets, etc. using BLE. It was implemented as part of the meSch EU project by Thomas Kubitza and Norman Pohl. The modular concept of Blidgets allows assembling small sensors and/or actuators in very little time (figure 4.1a), which typically run a year from a coin cell and can be deployed almost everywhere. [KSP+13]. By using the tools from the meSch project, these devices can be configured and brought on line easily via BLE.

The Blidgets are used for several purposes in the HCILab. E.g. to connect the conductive ink papers to the network [Tick15] or as a key fob for connection to a door screen to display availability. For this thesis, a configuration with a notification and a power module was chosen to give the Blidgets the ability to beep (figure 4.1b).

The power module consists of a lithium polymer battery and a board with the circuits to recharge and supply power. The notification module inherits a piezoelectric speaker, a vibration motor, a RGB LED and a pulse width modulator. To enable the modules the



**(a)** Blidget modules



**(b)** Blidget with power and notification module

**Figure 4.1:** Blidgets

PIN-configuration of the 18 PINs has to be set. To activate the notification module a command has to be sent.

## Summary

By using the technology and services provided by Google the majority of the smartphone users can be reached. Some of these services are still under heavy development, therefore a further evolution has to be considered.

# 5 Implementation

In this chapter the implementation of an Indoor navigation application as described in chapter 3 is presented. The Application based originally on the code of Hanwen Chen, made during his work as research assistant in the HCILab. This approach showed all BLE devices in range, as well as a list of all registered beacons. The code was revised. Architecture, data structure and layout were remade. The final application has nearly nothing left of this first approach.

## 5.1 Architecture

The system consists of three components. A navigation application on the smartphone, a database in the web provided by a RESTful API and advertising BLE devices in the building.

The BLE devices are visible to smartphones. The smartphone identifies them by their MAC address or the send UUID. Using that ID they get additional information from the database using a RESTful API as cloud service (figure 5.1).

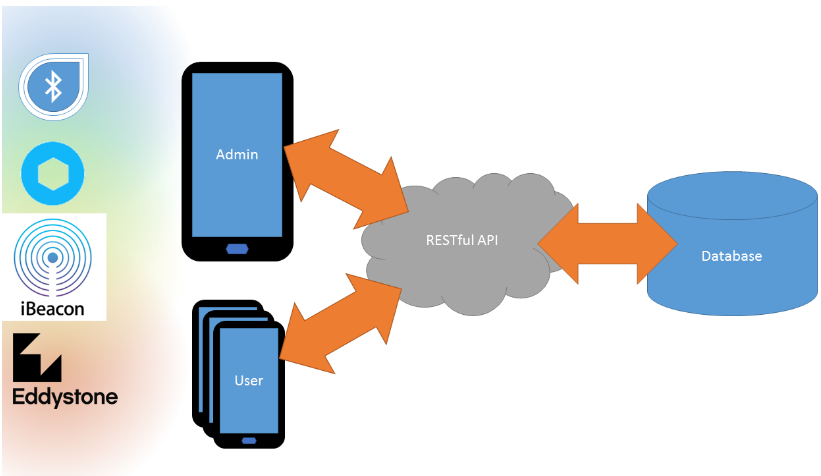



**Figure 5.1:** Architecture scheme

The devices need to have a unique ID. As the MAC address for each device is unique, it qualifies as UID. Another possibility would be the UID advertised by the devices. Eddystone provides a frame for this. To use a greater diversity of devices the MAC address was chosen as UID.

As RESTful API the Proximity Beacon API by Google was chosen. This API should be used for beacons that use the Eddystone protocol. The API is still in a beta-version, so documentation is incomplete and a bit more costly than the released version will hopefully be.

The Application should provide the four modes presented in chapter 3. The four modes will be explained separately as they build up on each other.

## 5.2 Input/Accessibility

The Application was designed to function with only four gestures: (1) swiping to the right/left to the next/last item, (2) tap to read item, (3) double-tap to select item and (4) 2-finger scrolling to change fast between the modes (left/right) or scroll lists (up/down). Changing between modes can also be done by selecting the tab with (1) and double tapping it (3); scrolling can be done by swiping when an element of the list is selected. So, the last gesture (4) can be left out if necessary.

TTS output was generated in development, but finally only TalkBack was used for the Speech output because of two reasons. (1) The build in accessibility service is used by the VI for working with their smartphone so they are used to the way it acts. To implement an other way of speech output could be more confusing. (2) The TTS and Vibration output generated by the app gets often in conflict with the build-in accessibility service as they start to interrupt each other. The TTS-functionality is still available in the code, so it can be used easily for future development. Other output methods like auditory icons [Gav86], Earcons [BSG89] or Spearcons [WNL06] would also be possible. For this first approach, TalkBack is sufficient and hopefully known by the participants, to use other output methods a focus group would be recommended.

## 5.3 Application usage

A class diagram of the application can be found in the appendix: figure A.1.

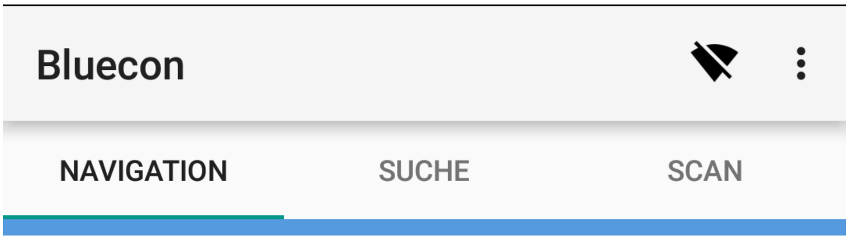



**Figure 5.2:** Action bar and tabs

### 5.3.1 Starting the Application

When the application starts the current version of the database will be downloaded. If not already enabled, the application asks for permission to start Bluetooth. Another possibility would have been to use the Nearby Messages API by Google. As nearby searches for devices with Wi-Fi, Bluetooth, BLE and near-ultrasonic audio, it is very power consuming. To prevent that, we stack to a simple BLE connection. The application does also not scan right from the start. There is a toggle button in the action bar, which starts the background service of the application. The background service “BlueconService” scans constantly for devices and adds them to a list of currently in range beacons. The tabs show the current mode of the application and give an overview of the modes (toggle and tabs - figure 5.2). The items of the beacons show different data depending on the chosen mode. An overview over the data representations can be seen in figure 5.4.

### 5.3.2 Scan mode

When in Scan Mode all active Blidgets in range were enlisted. The items show the name, RSSI, current proximity hint, room number and description of the room. By clicking on the items of the list the beacon will start beeping for the adjusted time.

### 5.3.3 Search mode

When in Search Mode all registered beacons will be enlisted. The items show the name, room number and description. The user can filter the list by entering search terms. The search is not case-sensitive. The search will be conducted on name, room number and description, so the user can even search for the first name of a person. (figure 5.3)

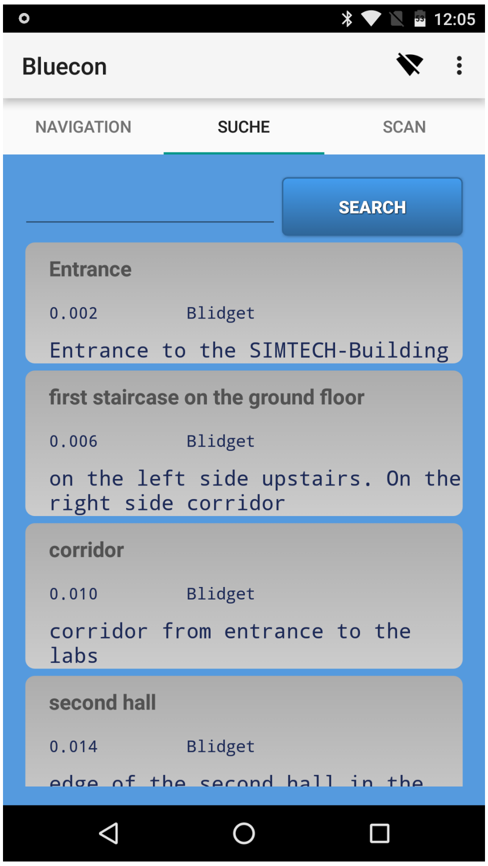



**Figure 5.3:** Search mode

### 5.3.4 Navigation mode

In the navigation mode the user enters a starting point and a destination and lets the application compute a path. The dialogs closely resemble the Scan and Search mode. For the starting point the user can choose from the beacons in range. For the destination from all beacons. In the second dialog he can also filter the content of the list. By pushing calculate a breadth-first search from starting point to destination is conducted. The algorithm is shown in listing 5.1. The distances are not weighted, so the distance is defined by the number of beacons on the path. As soon as the destination is found the search is interrupted and the path returned. The complexity of this search is $O(|V|+|E|)$. V represents the number of beacons and E the number of connections to their neighbors. For thin graphs like this the algorithm is more than adequate. If the network gets denser and the buildings get bigger a Dijkstra or Floyd-Warshall algorithm would be more suitable. The calculation could even been done beforehand and only the adjacency matrix could be delivered. The list shows the path from the starting point to destination. The items show name, room number proximity hint, description of the room itself and


**(a)** Scan mode **(b)** Search mode **(c)** Navigation mode

**Figure 5.4:** different data representation for the different modes

the way from this beacon to the next beacon. If the beacon is in range tapping on the item results in beeping. (screenshot - figure 6.2a)

The focus returns to the next item on the assumed line of action. That had to be made for TalkBack as it was not innately done.

While moving in the building, the user gets messages when he gets “in range” of a beacon, “near” a beacon or “close” to a beacon. When the user gets near the beacon, it also starts automatically to beep for the adjusted time and with the adjusted frequency.

### 5.3.5 Admin mode

An admin mode has not yet been implemented.

## 5.4 Auditory Feedback

Blidget sound: as the Blidgets are only capable of single tunes in one sound level, the auditory feedback was implemented in variable frequency (in respect to the piezoelectric speaker) and duration. The user can then try the duration and frequency and adapt it for best perception. As the sounds are produced by a PWM and a piezoelectric speaker, the signal has the shape of a square wave. That makes the sound a bit annoying. To make the sound less annoying we recommend to use the musical scale based on the standard pitch A 440Hz. The other tunes can be easily computed with $440\text{Hz} \cdot 2^{(\frac{x}{12})}$ with x as the distance of semitones away from A. (x=12 doubles the frequency of course, which makes the tone one octave higher). A better representation for the frequencies will be done in the aftermath of this thesis.

Another implementation with more than one tune in sequence (Earcon) would be possible but was not implemented yet.To let the Beacons beep several characteristics of the Blidget Service have to be sent using the GATT profile. First the PIN setting of the Blidget has to be set by changing the Pin Configuration Characteristic. The PWM has to be connected to the piezoelectric speaker. Then the PWM has to be activated with the

**Listing 5.1** breadth-first search

```
allBeacons = BeaconHolder.beaconLocations();
Map<String, BeaconLocation> allBeaconsMap = new HashMap<>();
for (BeaconLocation aB : allBeacons) {
      allBeaconsMap.put(aB.roomId, aB);
}

SearchObject startObj = new SearchObject();
startObj.active = start;
startObj.pre = start;
startObj.path = new ArrayList<>();
startObj.path.add(startObj.active);
List<SearchObject> oneLevel = new ArrayList<>();
oneLevel.add(startObj);
List<SearchObject> next = new ArrayList<>();
boolean       stop = false;
while (!stop) {
      for (SearchObject ol : oneLevel) {
            Set<String> neighbors = ol.active.neighborhood.keySet();
            for (Object n : neighbors) {
                  if (!ol.pre.roomId.equals(n)) {
                        SearchObject nextObj = new SearchObject();
                        nextObj.active = allBeaconsMap.get(n);
                        nextObj.pre = ol.active;
                        nextObj.path = new ArrayList<>();
                        for (BeaconLocation p : ol.path) {
                              nextObj.path.add(p);
                        }
                        nextObj.path.add(nextObj.active);
                        next.add(nextObj);
                  }
                  if (target.roomId.equals(n)) {
                        stop = true;
                        break;
                  }
            }
            if (stop) {
                  break;
            }
      }
      oneLevel.clear();
      for (SearchObject n : next) {
            oneLevel.add(n);
      }
      next.clear();
}
return oneLevel.get(oneLevel.size() - 1).path;
```

adjusted frequency. To get the frequency the max_value of the PWM has to be calculated by

$$\text{(5.1)} \quad max\_value = \frac{\text{PWM}_{freq}}{2^{prescaler} \cdot Frequency} \begin{cases} \text{PWM}_{freq} = 16000000, \\ 1 \leq max\_value \leq 65535, \\ 0 \leq prescaler \leq 9 \end{cases}$$

The Blidget does not stop beeping by itself, so after the adjusted duration time the PWM has to be deactivated. Afterwards the connection has to be closed or the Blidget will not connect to another smartphone. The sequence diagram for the beeping can be found in the appendix figure A.2

## 5.5 Presumption

There are several features and code snippets in the application that were not used, but would be helpful for further development.

The Nearby Messages API is still connected to the cloud service. Near completion of this thesis an adjustment for the API showed up, with which the API can be used while the smartphone uses only BLE to search for advertising beacons. This change was not included.

A code fragment, which lets the smartphone produce the same sound as the Blidgets. So the user can try the frequency and duration on the smartphone while adjusting it. This was not attached to the settings activity.

# 6 Evaluation

By conducting a comparative study the workload and effectiveness of the application was tested. For comparison a verbal guidance system (VGS) was simulated. The other subject for comparison was a tactile map. The VGS represents an ideal indoor navigation system. The tactile map a method of wayfinding known by the participants. The duration for each participant was set for approximate 40-60 min. To meet the needs of impaired people it was recommended to keep the workload low and to have an observer available for every VI. Every participant should find two rooms for each navigational system, making it six rooms altogether. Subjective data (Santa Barbara Sense of Direction, NASA TLX) and objective data (task execution time) has been collected. The Santa Barbara Sense of Direction (SBSOD) was used to get a hint on the self-evaluation of the participants concerning orientation. For every navigational system, a NASA TLX was used to measure the workload. Also the performance was measured by the time the participant needed to perform the task.

## 6.1 Hypothesis

It is predicted, that the ideal system, the VGS, would have the lowest workload. The participants do not have to concentrate on their Macro-Navigation. They can just concentrate on the Mirco-Navigation. The tactile map should have the highest workload, as the participants have to find their destination on the map and then they have to imagine their position and their path while moving alongside. The application should be placed in the middle as it computes the path for the participants and gives them additional feedback from the environment.

## 6.2 Participants

There were five participants to the study. There was one female and four male participants. 4 of the participants were between 51 and 65 years old, one over 65. Their country of origin was in all cases Germany. All of these participants had a severe visual impairment. Only one had a 2% ability to see with one eye, which makes him also blind per definition. Only one of the participants had no hearing impairment, three had a mild one and one a moderate one. Two participants had their visual impairment from birth or very early in their lives, two later than their childhood and one just recently in the last years.

Four of the participants were frequent smartphone users. All of them use a white cane on regular basis as navigation assistance; two use frequently an app for outdoor navigation ("BlindSquare" for iOS). To get an idea of their opinion to navigational aids four questions about their attitude towards navigational aids were asked. Three of four questions showed a very positive attitude. "I am used to use aids for indoor navigation." (M = 5.2, SD = 1.6), "I consider that indoor navigation aids are useful." (M = 6, SD = 1.3), "I prefer the assistance of a human being instead of an automated system." (M = 5, SD = 1.7). The third question: "I am using indoor navigation aids." (M = 1.6, SD = 1.2) was answered with low ratings. The participants commented this with "I would, but there are none available.". This shows the need for an assistance system for VI, but the question was thereby not taken into account for positive attitude towards navigational aid (M = 5.4, SD = 1.5).

As this study focuses on navigation, we were also interested in participants' mobility and orientation skills. Participants' orientation skills were examined using the Santa Barbara Sense Of Direction Scale ([HRM+02]), which was translated into German. Questions 3 "I am very good at judging distances." and question 10 "I don't remember routes very well while riding as a passenger in a car." were left out.

## 6.3 Study design

The study was conducted in the SIMTECH building. This location was chosen, because it is a building the participants did not know and it was easy to deploy. The participants always had to start from the entrance. To get to the chosen rooms, the participants had similar distances to cover. There were no obstacles on the paths and an observer always accompanied the visually impaired participants. The distribution of the rooms they were searching for as well as the designated path is shown in figure 6.1.

The study should show if the auditory feedback gives any positive effect for the users. However, the application was designed to serve many needs. Therefore, to reduce the payload on the participants the app was reduced and not all functionalities were tested. It became also apparent that users, which are not accustomed to Android devices with TalkBack as accessibility service, tend to mingle with the items on the screen while

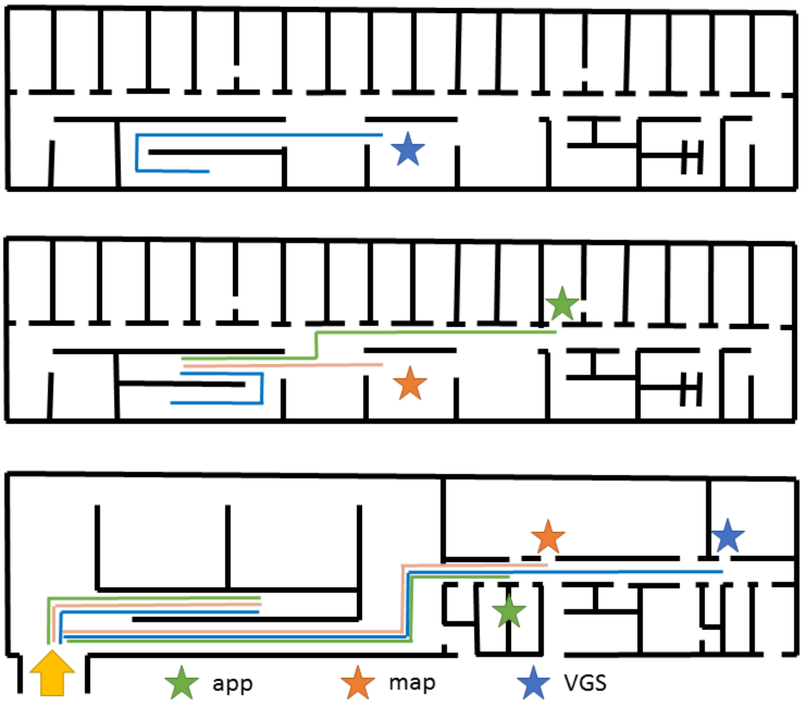
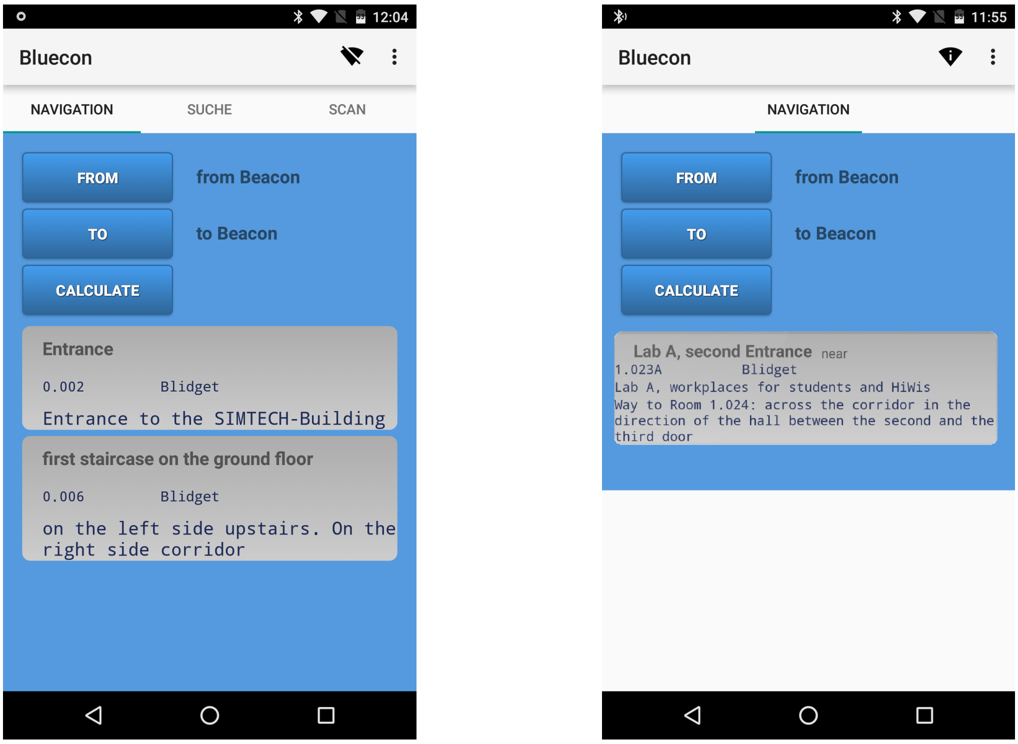



**Figure 6.1:** Set-up of room locations for the study

performing gestures. Therefore a blank space was included where they could perform gestures without interfering with the items of the application. (figure 6.2)

The three modes scanning for beacons in range, searching for all available waypoints and navigation from one waypoint to another were reduced to just one mode: navigation. The settings were only changed by the observer in the beginning of the test or if problems occurred. Because the "Explore and touch"-feature lets the unexperienced user select items unwillingly, an area on the display was left blank so the participants could perform gestures there. It was planned to change the configuration of the Blidgets during the study. So static JSON-files were used as database to change them in the settings. At the time the study was conducted, enough Blidgets were available to use only one configuration, but the code was not changed back. The application filters the Bluetooth devices, so that only Blidgets are visible.

Most VI use earphones for smartphone usage so they do not disturb people in their surroundings. Traditional earphones and especially in-ear earphones mask real sounds in a certain degree. That would also be disadvantageous for the orientation by hearing the beacons. To prevent that bonephones were used. These headphones work via the transmission of vibrations against the side of the head. All of the participants




**(a)** full App **(b)** Study version

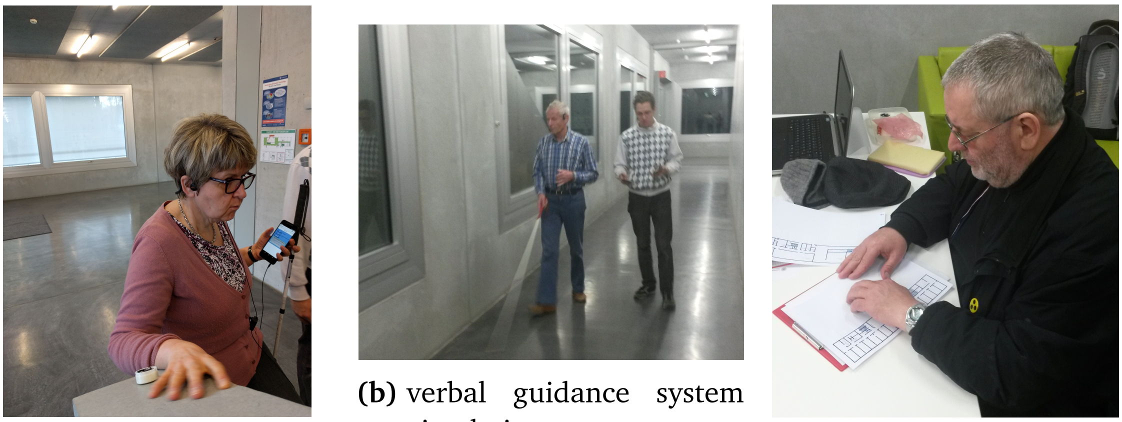
**Figure 6.2:** different versions of the design

already had experience with that technology; some of them do even possess bonephones themselves.

## 6.4 Execution

The study was scheduled as follows

- Description of the study and consent form
- Initial questionnaire
- Testing of the first system and questionnaire
- Testing of the second system and questionnaire
- Testing of the third system and questionnaire
- Final questionnaire
- Discussion



(a) Bluecon App

(b) verbal guidance system simulation

(c) tactile map

**Figure 6.3:** participants in different states of the study

First the participants were told, that they were testing and comparing three different navigational aids. Their rights and duties were explained and they had the opportunity to ask questions. Afterwards they had to sign the consent form. Then the initial questions were asked, concerning statistical data and sense of orientation. The questions were presented in a verbal form for the VI. The questionnaire was presented by asking the questions respectively reading the statements and giving the answer options if present. After that they got the necessary equipment and started the test runs. The sequence of the test systems and rooms to search for was changed for every participant to exclude learning effects. After testing each system the NASA TLX questionnaire was filled to measure the workload. After all tests a few final questions for improvement were asked.

The participants were very interested in the technology and the opportunities it gives as well as giving advices to improve the application for VI. Therefore, with many good discussions in-between and after the tests it took about 90 min to perform the study for each participant.

### 6.4.1 Apparatus

A Nexus 5X was used as test device for the study. The Nexus devices by Google use pure Android without additional software. That is chosen to get to the abilities of Android without the advantages or disadvantages from the firmware of different vendors. The necessary equipment of the participant for testing the application was:

- Smartphone
- Bonephones

- White cane

Figure 6.3a shows a participant wearing the equipment and reaching out for a beeping beacon.

During the study we realized, that the participants had difficulties using the smartphone. Although most of them are using smartphones on a regular basis, they had trouble using the build-in accessibility service TalkBack. The four smartphone-users of the test group were all using iPhones. We assume that the differences in the accessibility services VoiceOver (iOS) and TalkBack (Android) are more difficult to overcome than to learn a new system, because the only participant without an own smartphone had the best performance with the application.

In addition, the gestures that were meant to be an easy way to navigate with only one hand through the application were not easy to perform. It is assumed that this results from three factors: (1) the white cane is placed in the dominant hand, so that the participants had to use their non-dominant hand to perform or they had to stop and use both hands. (2) the display of the Nexus 5X measures 13.21cm in diameter. This makes holding and using gestures difficult. (3) Walking, using the white cane with the dominant hand, using the smartphone in the other hand and orientating using auditory cues at the same time is a complex task.

However, to overcome these difficulties the participants had to run through the first two chapters of the TalkBack introduction. This introduction guides them through the navigation gestures and practices them. Afterwards the participants had less trouble using the phone, though the differences in the operating systems and the hardware still led to confussion.

After the introduction of TalkBack, the participants got an overview over the abilities and the structure of the application. An initial test with the beeping was made. Then they got the room number and had to start.

### 6.4.2 Tactile map

The tactile map consisted of three maps, one for each floor. The maps were manually produced. The base line was a floor plan. Window color was used to draw the walls, stairs and the elevator in a way the VI could feel them. In addition, a Direct Manual Braille Slate was used to create labels for the rooms and a legend that would give a description.

The necessary equipment of the participant for testing the tactile map was:

- Tactile map

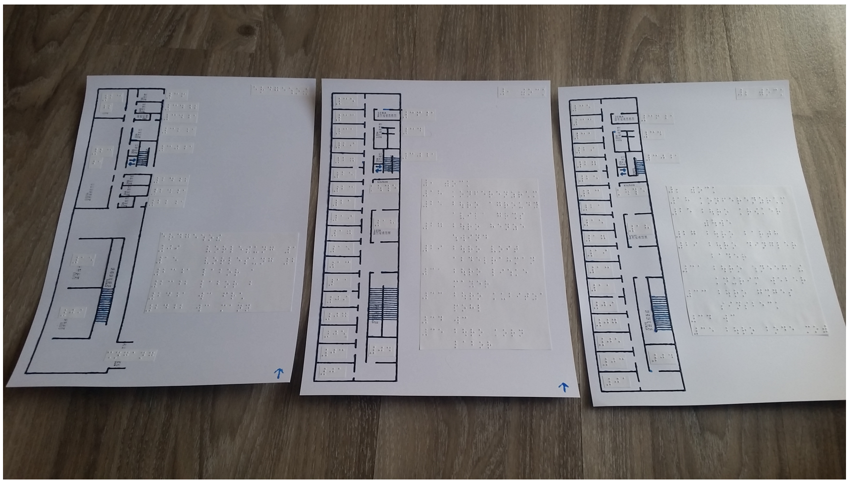


**Figure 6.4:** tactile map

- White cane

Figure 6.3b shows a participant reading the tactile map on a desk in the entrance hall before searching for the room. Figure 6.4 shows the three maps for each floor.

### 6.4.3 Verbal Guidance System

The VGS was realized in a Wizard of Oz setting. The participants got bone phones with a Bluetooth connection so they could still hear their environment. An experimenter followed the participants and gave the directions using six messages that were spoken by an artificial voice, so it would feel like a navigation system. The messages were spoken in German, saying, “Left”, “Right”, “Straight forward”, “Stop”, “Caution stairs” and “You have reached your target”.

The necessary equipment of the participant for testing the VGS was:

- Bluetooth intercom
- Bonephones
- White cane

Figure 6.3c shows a participant wearing the equipment and the following observer with the smartphone.

## 6.5 Results

The full questionnaire in English A.11 and German A.12 can be found in the appendix. Participant 4 could not hear the beeping of the Blidgets at all. We tried frequencies from 220Hz to 7040Hz but he could not perceive them. Hence he could not perform the test.

### 6.5.1 Orientation skills

Scores from the SBSOD obtained a mean of 5.2 (SD = 1.5). The maximum score is 7. This is an above average rating concerning mobility and orientation. Other studies showed that VI, especially the ones that take part in user studies for navigational aids, evaluate themselves with a high value [BTO+15]. This may result of a self-selection bias, because the visually impaired volunteers for a study concerning mobility and orientation are highly autonomous. Workload The NASA TLX showed that the VGS (M = 1.4, SD = 0.7) A.6 and the map (M = 1.4, SD = 0.4) A.7 had a low workload while providing a high feeling of success. Looking at the Median the map achieved only little worse values. The application (M = 3.3, SD = 1.4) A.5 was only slightly above average.

To analyze the NASA TLX for statistical significance a Friedman Test was performed. It showed a statistical significant difference in the used navigation system for the questions “How successful were you in accomplishing the task?”($\chi^2(2) = 6.533, p = 0.038$), “How insecure were you?”($\chi^2(2) = 7.538, p = 0.023$) and “How irritated were you?”($\chi^2(2) = 7.538, p = 0.023$). Post hoc analysis with Wilcoxon signed rank tests was conducted with a Bonferroni correction applied, resulting in a significance level of $p < 0.0167$. Nevertheless, there were no significant differences between the methods ($p \geq 0.059 \quad \forall$ pairings). This may result of the low number of participants.

### 6.5.2 Task execution time

The task execution time does not fully mirror the results from the workload analysis. VGS is on first, tactile map on second and application on last place. Although the rankings are the same the performance time of the tactile map is closer to the application than to the VGS. It took them in mean 8min 26s (SD = 145s) to look for the rooms with the application, 5min 31s (SD = 106s) with the tactile map and 2min 1s (SD = 21s) with the VGS. Figure 6.5 shows the deviation using quartiles in a box-whiskers diagram. The task execution times for each participant are shown in table 6.1.

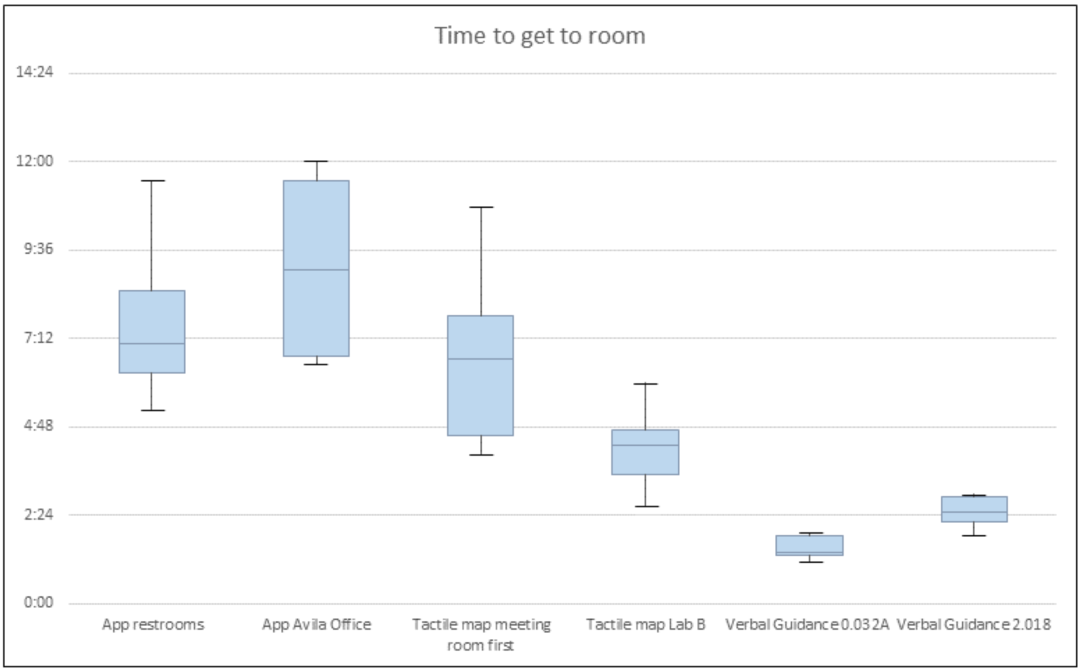



**Figure 6.5:** box-whiskers for task execution time

| | | Part. 1 | | Part. 2 | | Part. 3 | | Part. 4 | | Part. 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| aid | room ID | # | time | # | time | # | time | # | time | # | time |
| app | 0.024 | 5 | 7:30 | 1 | 11:30 | 3 | 5:17 | - | - | 2 | 6:37 |
| | 1.025 | 6 | 12:00 | 2 | 11:20 | 4 | 6:47 | - | - | 1 | 6:31 |
| map | 1.018 | 1 | 6:40 | 3 | 4:04 | 5 | 4:35 | 2 | 10:46 | 4 | 7:49 |
| | 0.023A | 2 | 3:30 | 4 | 4:18 | 6 | 2:40 | 1 | 6:00 | 3 | 4:44 |
| vgs | 0.032A | 3 | 1:20 | 5 | 1:23 | 1 | 1:51 | 4 | 1:56 | 6 | 1:09 |
| | 2.018 | 4 | 2:30 | 6 | 1:52 | 2 | 2:54 | 3 | 2:13 | 5 | 2:58 |

**Table 6.1:** task execution time

### 6.5.3 Ranking by participants

One of the last questions was to rank the aids. The VGS received a mean rank of 1.2 (SD = 0.4), the tactile map a mean rank of 2 (SD = 0.6) and the application a mean rank of 2.8 (SD = 0.4).

## 6.6 General discussion

Because of the low number of participants, the statistical data is not very significant. However the feedback they gave and the experienced behavior can be very meaningful for future development.

### 6.6.1 Behavior

The search option in the select destination beacon dialog was never used. It is estimated that they tried to find the destination by going fast through the list and because they succeeded early they had not to conduct a search. If there were more items in the list or they had to search for something that is only in the details of a location (like the first name of a person), they probably would have used that feature. Another explanation would be that they already know how difficult and time consuming it is to edit text on a touchscreen device. And so they tried to avoid that if possible.

### 6.6.2 User recommendations

For the application the participants wished

- for a route description right after calculation without the need to press another button.
- for different modes (beginner, advanced, expert) which would reduce the spoken messages to only the necessary information.
- for less system language: “item one of four”, “button” from, “alert” choose a beacon.
- for a possibility to repeat the speech/audio output in case something was misheard or there was noise
- for distance readings between the beacons

For the audio output from the Blidgets they wished

- to research other kinds of audio output that maybe could be better for localization. Speech, tunes, noises
- a louder sound

For the VGS they wished

- for angles for orientation (e.g. clock position)
- for indications on other possible obstacles (e.g. doors)

### 6.6.3 Comments

All of the participants assured that they liked the idea of an interactive environment, which could give them additional cues for navigation.

The Participants described the structure and design of the app as clearly arranged.

# 7 Conclusion and future work

## 7.1 Conclusion

Many VI use smartphones in their daily lives. By using an Android smartphone as stand-alone system without attachments for navigational aid, this aid is available for all Android smartphone users. The application has the ability to use existing facilities that use BLE for indoor navigation. The existing devices only have to be registered. The network of BLE devices like interactive door plates, iBeacons or Eddystone-Beacons will get more and more dense in the future. By using this dense network of BLE devices, the app can provide information about a building and a secure path through it.

The application has a simple structure and uses only few gestures to navigate in it. By that it achieved accessibility for the visually impaired. As this technology is still under development, it can not yet outrival an ideal system like the simulated verbal guidance system or a technique used for many years like the tactile map.

The interactivity with the environment was acknowledged by all participants as a valuable enrichment of the navigation task. Several of the participants had problems with localization of the beacons or hearing them at all. Because 82% of people living with blindness are over 50 years old [WHO16] that does not seem unusual and has to be taken into account in further development.

## 7.2 Future work

The comparison study performed in this study was too extensive to show significant results. For further research the several aspects of this thesis should be examined:

- What kind of gestures can be easily used on smartphones with big displays using only the non-dominant hand? That would represent the use case of a white cane user who uses his smartphone while walking. A focus group consisting of VI and seeing people could examine that specific use case or a comparison to a Viibracane or a Blidget with a directional pad.

- What kind of sound would be best to localize in indoor environments? This could research the sound itself (Beeping, clacking, Earcons, Spearcons, Speech, Noise, vibration on an empty box), the location and orientation of the speaker and the material it is attached to (concrete, wallpaper, tiles, hanging free)
- What design for a navigation application would be desirable for VI? A focus group and a study could confirm the recommendations made by the participants of this study. Can you achieve higher usability with an beginner, advanced and expert mode. Use the build-in accessibility service or use a own structure with Text-to-Speech and auditory cues like SWAN [WWL+07] but only using a smartphone. Use of individual information on locations.

Another approach of using smart environment for indoor navigation could be a situation with low visibility. For example a power breakdown or a fire when a smoke screen hinders vision. The Blidgets could mark the way alongside the emergency route with cascading sounds and lights towards the exit.

# A Diagramms

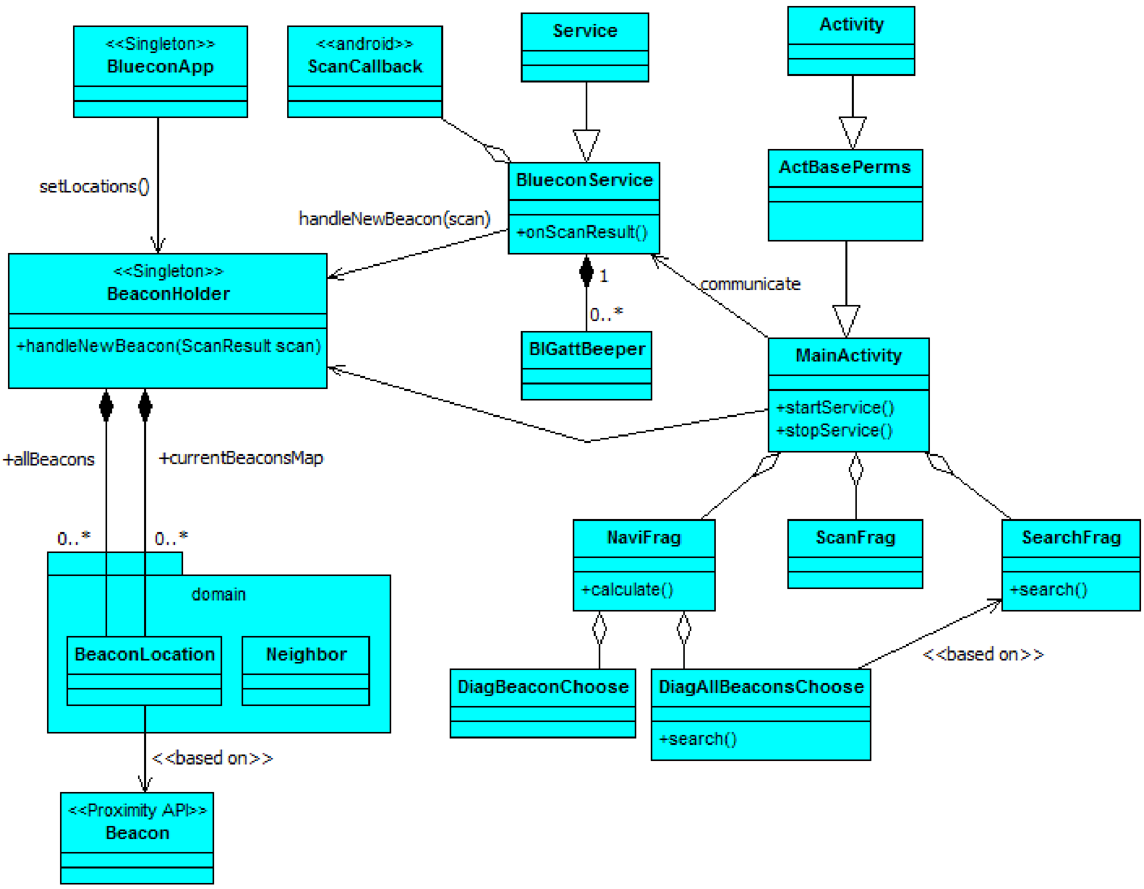



**Figure A.1:** class diagram of the Bluecon application

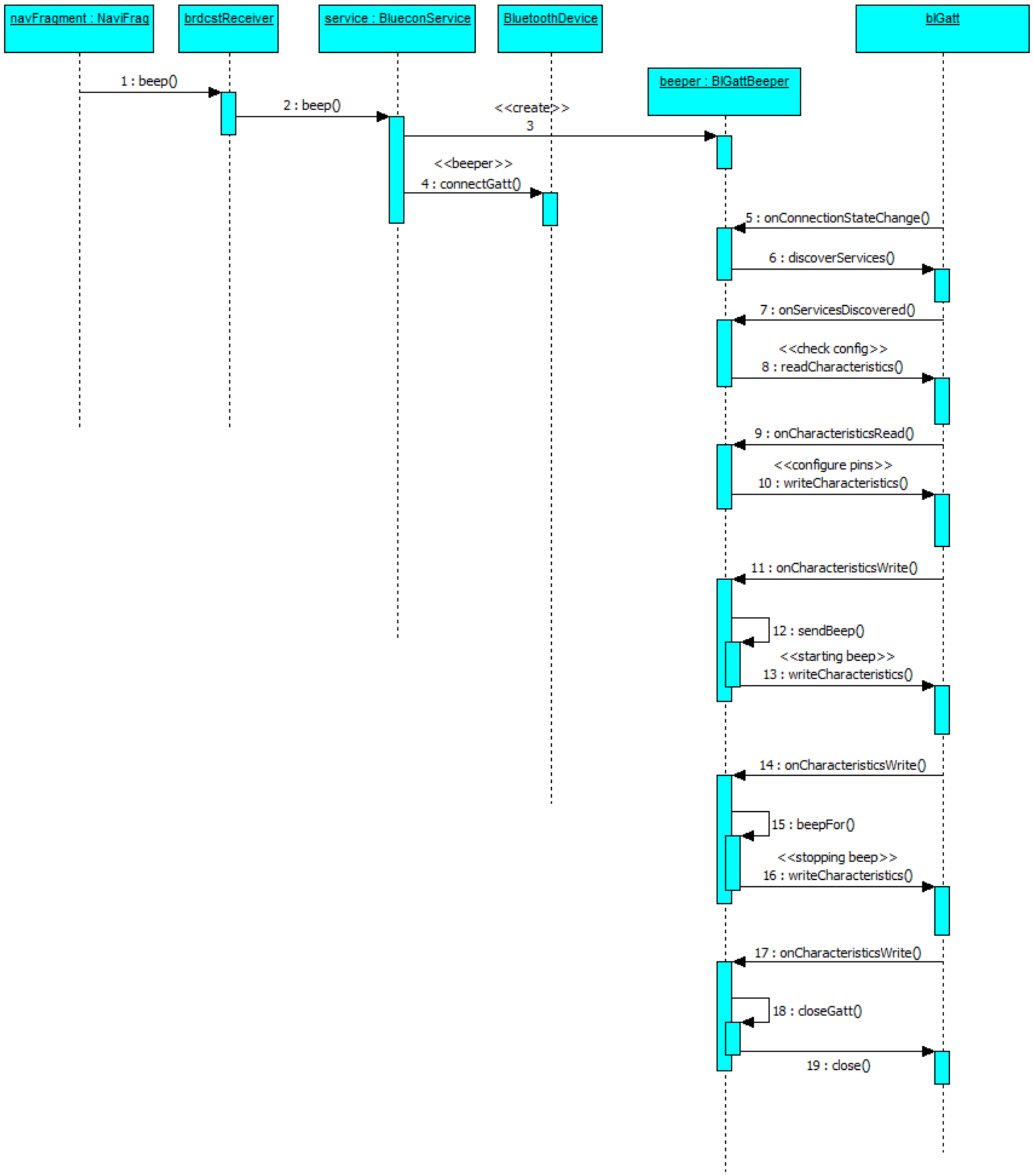



**Figure A.2:** sequence diagram for GATT-Beeping

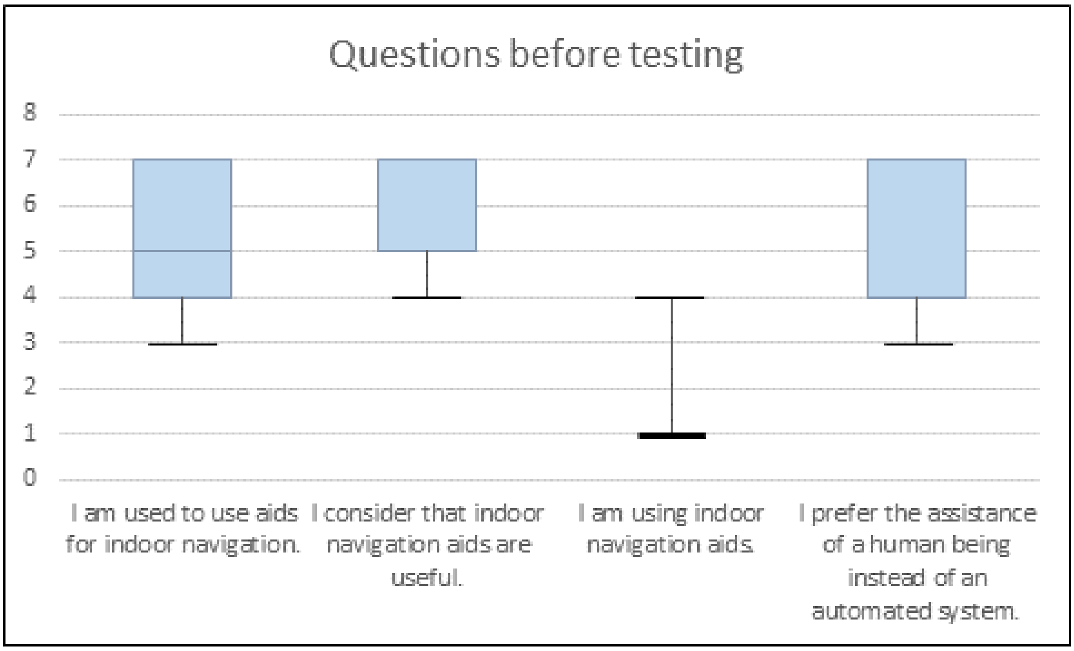



**Figure A.3:** box-whiskers for questions before testing

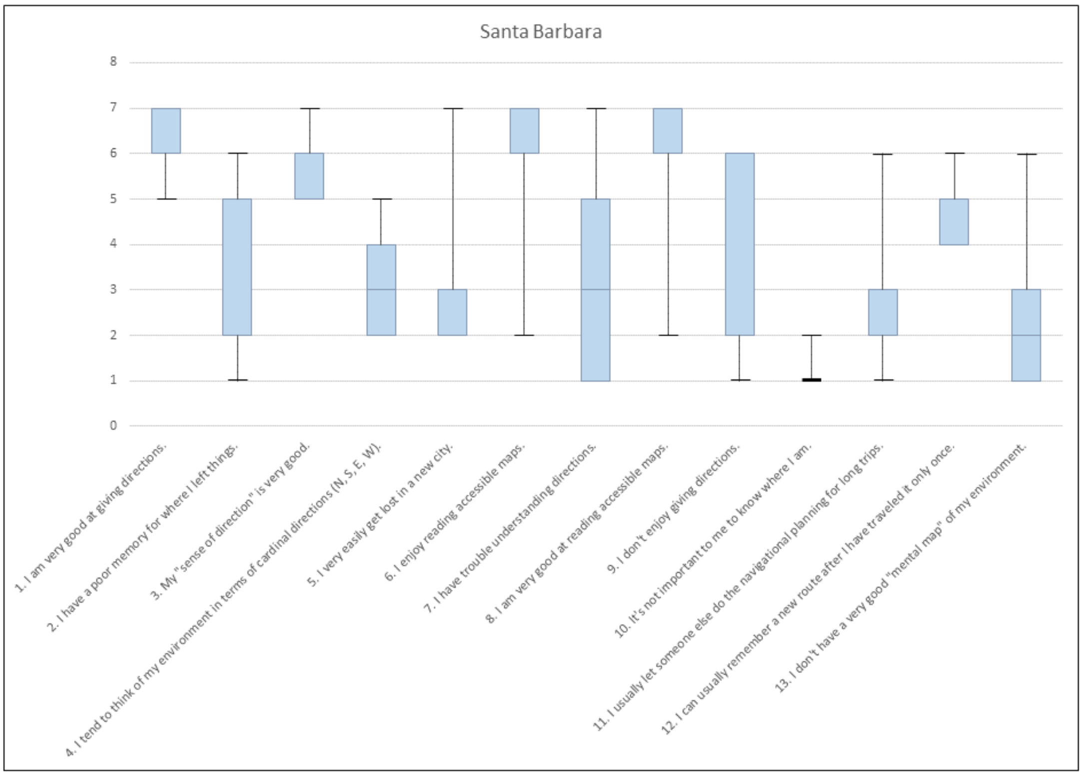



**Figure A.4:** box-whiskers for Santa Barbara Sense of Direction Scale

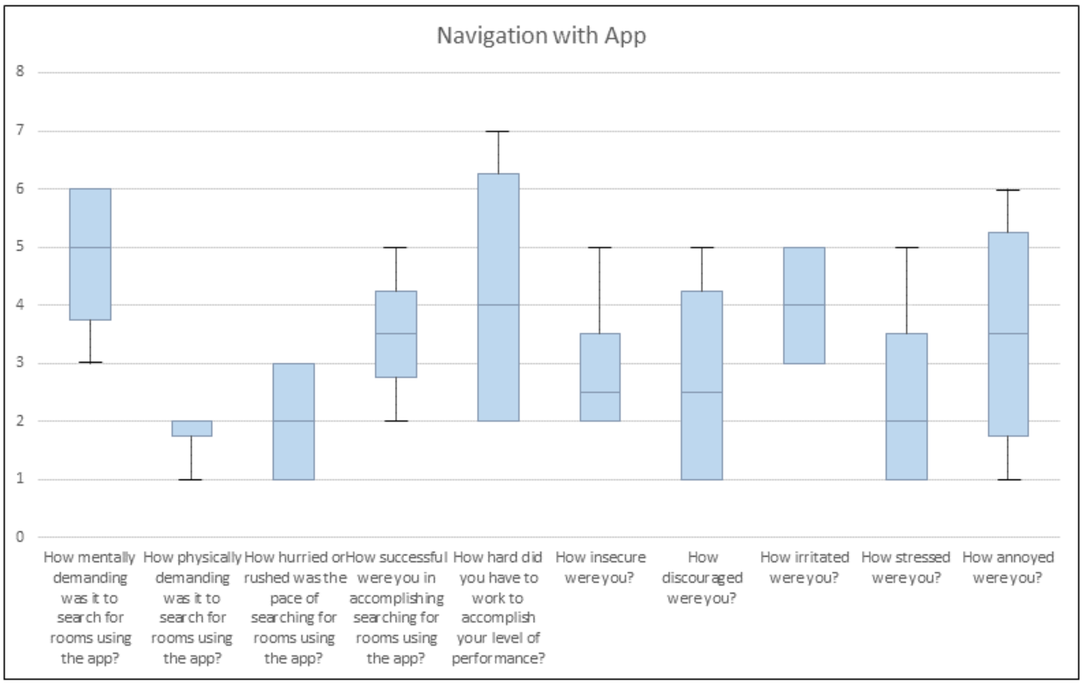



**Figure A.5:** box-whiskers for NASA TLX on navigation with Bluecon application

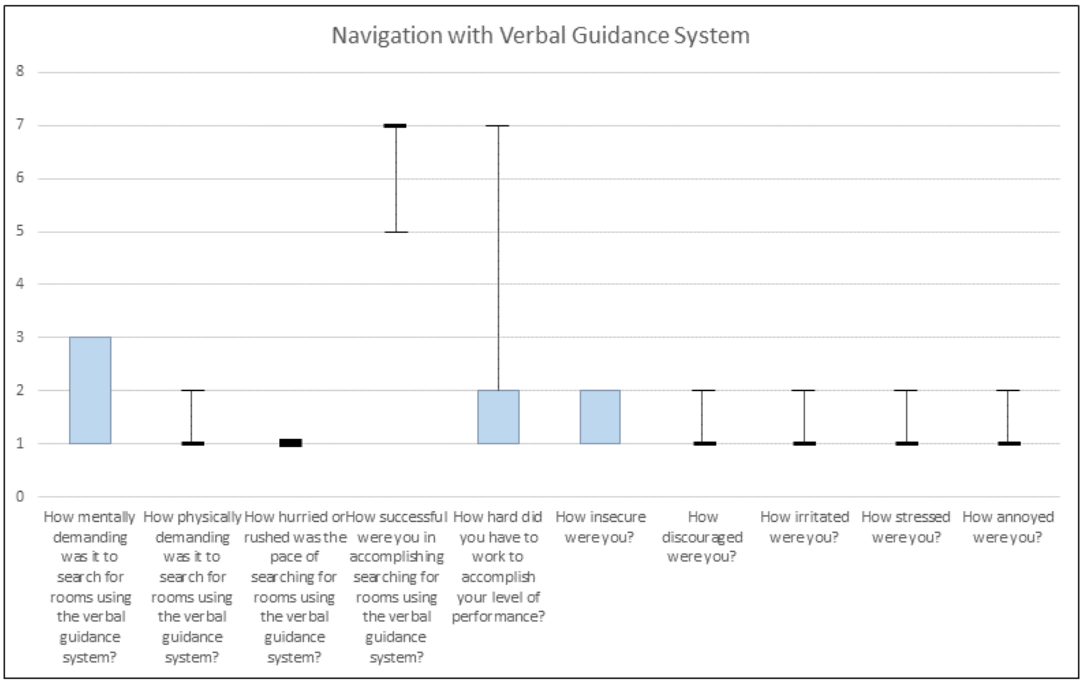



**Figure A.6:** box-whiskers for NASA TLX on navigation with verbal guidance system

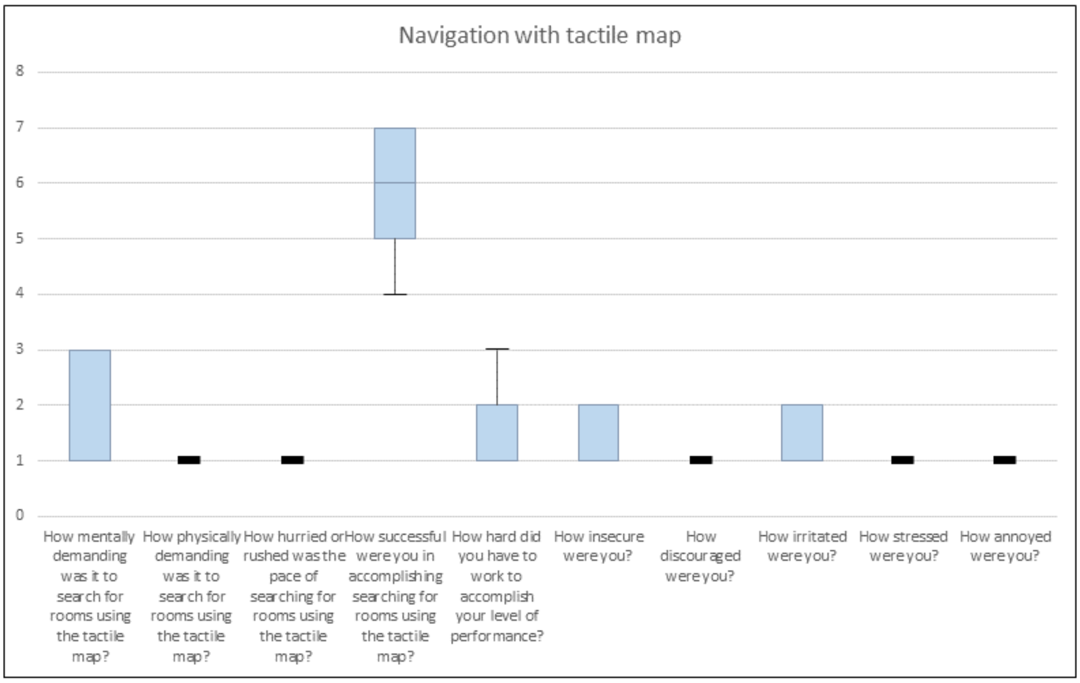



**Figure A.7:** box-whiskers for NASA TLX on navigation with tactile map

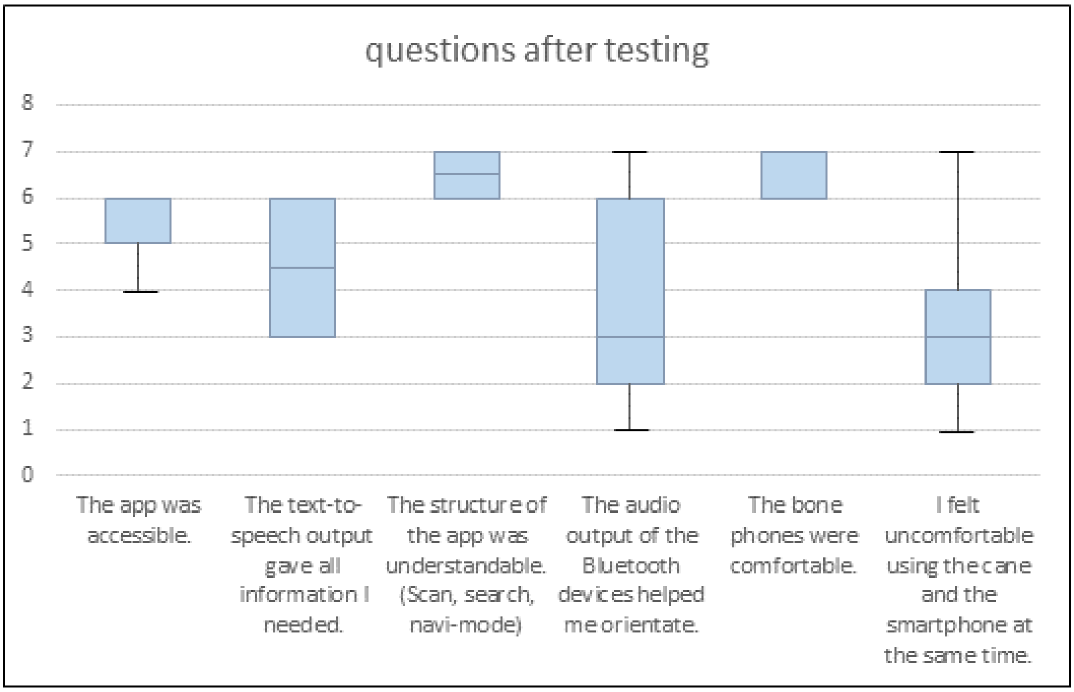



**Figure A.8:** box-whiskers for questions after testing

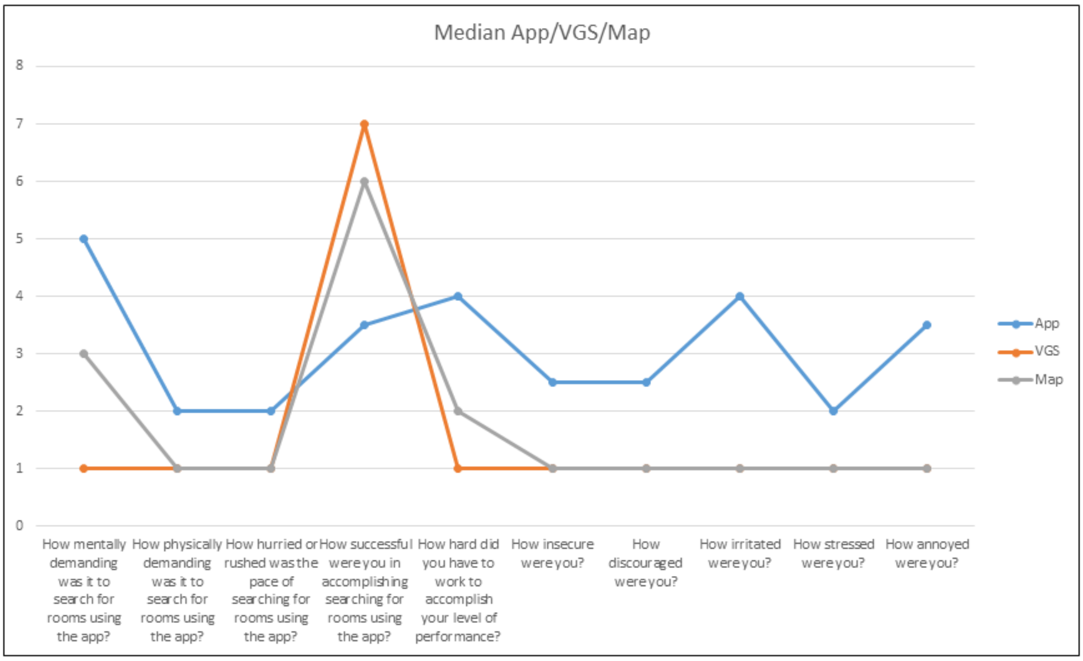



**Figure A.9:** Median for NASA TLX for all navigational aids

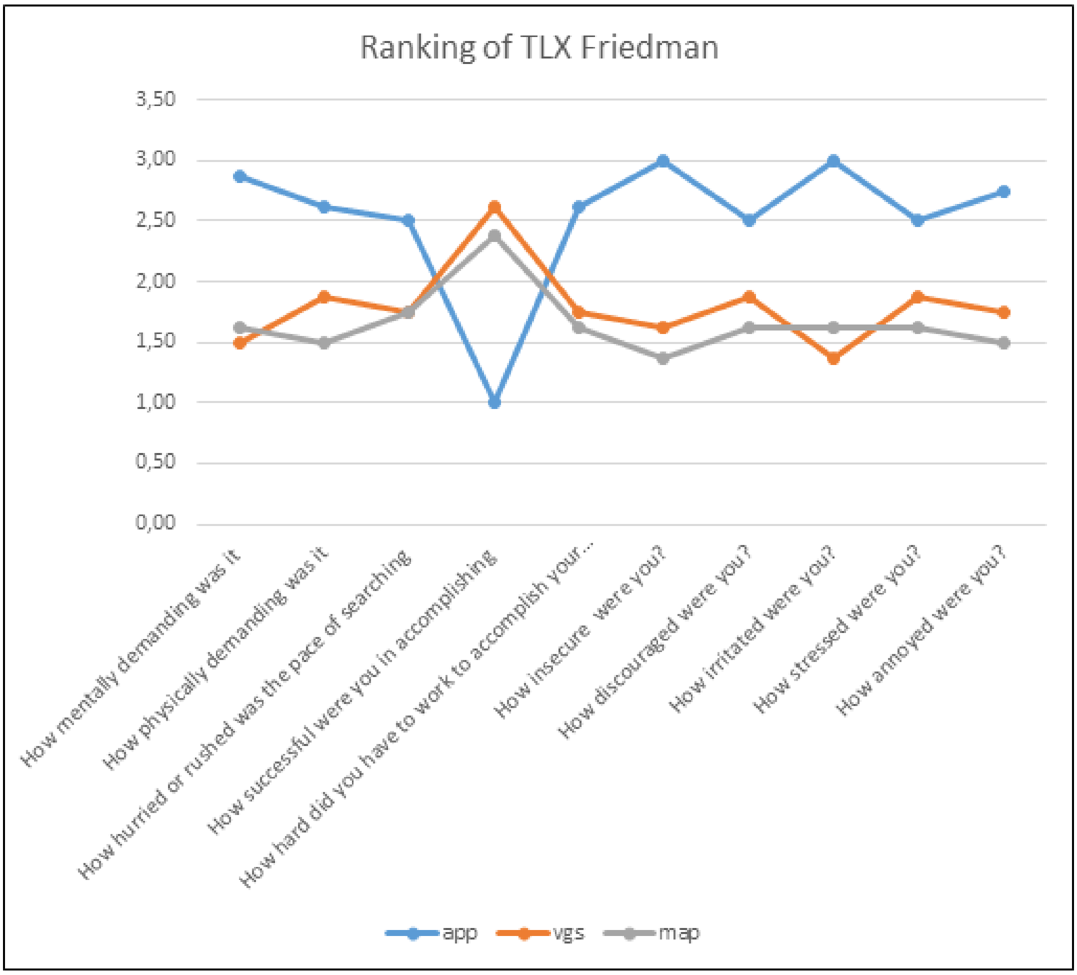



**Figure A.10:** Ranking of TLX Friedman

| Questions | Options |
|---|---|
| General information: | |
| Gender | Female/Male |
| Age | 18 to 25, 26 to 35, 36 to 50, 51 to 65, More than 65 |
| Do you have any visual impairment? | Not any, Mild, moderate, severe |
| Do you have any hearing impairment? | Not any, Mild, moderate, severe |
| Country of origin | |
| How many times have you done this test? Radial buttons | 0, 1, 2, 3 |
| Visual impairment | |
| I have my current level of visual impairment: | From birth or very early in my life. Later than my childhood. Recently in my life. |
| What type of navigation assistance do you use? | No assistance, Traveling cane, guide dog. |
| I am used to use aids for indoor navigation. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| I consider that indoor navigation aids are useful. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| I am using indoor navigation aids. | No experienceat all 1 2 3 4 5 6 7 Expert |
| I prefer the assistance of a human being instead of an automated system. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Orientation skills | |
| 1. I am very good at giving directions. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 2. I have a poor memory for where I left things. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 3. My "sense of direction" is very good. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 4. I tend to think of my environment in terms of cardinal directions (N, S, E, W). | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 5. I very easily get lost in a new city. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 6. I enjoy reading accessible maps. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 7. I have trouble understanding directions. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 8. I am very good at reading accessible maps. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 9. I don't enjoy giving directions. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 10. It's not important to me to know where I am. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 11. I usually let someone else do the navigational planning for long trips. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 12. I can usually remember a new route after I have traveled it only once. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 13. I don't have a very good "mental map" of my environment. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Questions after the study | |
| Tasks load: | |
| Navigation with App | |
| How mentally demanding was it to search for rooms using the app? | 1 very low - 7 Very High |
| How physically demanding was it to search for rooms using the app? | 1 very low - 7 Very High |
| How hurried or rushed was the pace of searching for rooms using the app? | 1 very low - 7 Very High |
| How successful were you in accomplishing searching for rooms using the app? | 1 Failure - 7 Perfect |
| How hard did you have to work to accomplish your level of performance? | 1 very low - 7 Very High |
| How insecure were you? | 1 very low - 7 Very High |
| How discouraged were you? | 1 very low - 7 Very High |
| How irritated were you? | 1 very low - 7 Very High |
| How stressed were you? | 1 very low - 7 Very High |
| How annoyed were you? | 1 very low - 7 Very High |
| Navigation with verbal guidance system | |
| How mentally demanding was it to search for rooms using the verbal guidance system? | 1 very low - 7 Very High |
| How physically demanding was it to search for rooms using the verbal guidance system? | 1 very low - 7 Very High |
| How hurried or rushed was the pace of searching for rooms using the verbal guidance system? | 1 very low - 7 Very High |
| How successful were you in accomplishing searching for rooms using the verbal guidance system? | 1 Failure - 7 Perfect |
| How hard did you have to work to accomplish your level of performance? | 1 very low - 7 Very High |
| How insecure were you? | 1 very low - 7 Very High |
| How discouraged were you? | 1 very low - 7 Very High |
| How irritated were you? | 1 very low - 7 Very High |
| How stressed were you? | 1 very low - 7 Very High |
| How annoyed were you? | 1 very low - 7 Very High |
| Navigation with tactile map | |
| How mentally demanding was it to search for rooms using the tactile map? | 1 very low - 7 Very High |
| How physically demanding was it to search for rooms using the tactile map? | 1 very low - 7 Very High |
| How hurried or rushed was the pace of searching for rooms using the tactile map? | 1 very low - 7 Very High |
| How successful were you in accomplishing searching for rooms using the tactile map? | 1 Failure - 7 Perfect |
| How hard did you have to work to accomplish your level of performance? | 1 very low - 7 Very High |
| How insecure were you? | 1 very low - 7 Very High |
| How discouraged were you? | 1 very low - 7 Very High |
| How irritated were you? | 1 very low - 7 Very High |
| How stressed were you? | 1 very low - 7 Very High |
| How annoyed were you? | 1 very low - 7 Very High |
| General experience: | |
| The app was accessible. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| The text-to-speech output gave all information I needed. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| The structure of the app was understandable. (Scan, search, navi-mode) | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| The audio output of the Bluetooth devices helped me orientate. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| The bone phones were comfortable. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| I felt uncomfortable using the cane and the smartphone at the same time. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Which navigational aid was the best in your opinion? | |
| Which navigational aid was the worst in your opinion? | |
| Do you have any comment or recommendation to improve the indoor navigation app? | |
| Do you have any comment or recommendation to improve the interactive bluetooth devices? | |
| Do you have any comment or recommendation to improve the verbal guidance system? | |
| Do you have any comment or recommendation to improve the tactile map? | |

**Figure A.11:** questionnaire English

| Questions | Options |
|---|---|
| General information: | |
| Geschlecht | Female/Male |
| Alter | 18 to 25, 26 to 35, 36 to 50, 51 to 65, More than 65 |
| Haben Sie eine Sehbeeinträchtigung? | Not any, Mild, moderate, severe |
| Haben Sie eine Hörbeeinträchtigung? | Not any, Mild, moderate, severe |
| Herkunftsland | |
| Haben Sie diesen Test schon einmal durchgeführt? | 0, 1, 2, 3 |
| Sehbeeinträchtigung | |
| Ich habe meine Sehbehinderung seit... | From birth or very early in my life. Later than my childhood. Recently in my life. |
| Welche Art von Navigationshilfe nutzen Sie? | No assistance, Traveling cane, guide dog. |
| Ich bin gewohnt Hilfen zu bekommen um mich in neuen Gebäuden zurechtzufinden. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Ich finde Navigationshilfen für Innenräume hilfreich. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Ich nutze Navigationshilfen für Innenräume. | No experienceat all 1 2 3 4 5 6 7 Expert |
| Ich bevorzuge die Hilfe eines Menschen gegenüber einem automatisierten System | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Orientation skills | |
| 1. Ich kann anderen gut den Weg weisen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 2. Ich kann mich oft nicht erinnern wo ich etwas hingelegt habe. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 3. Mein Orientierungssinn ist sehr gut. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 4. Ich stelle mir meine Umgebung mit Himmelsrichtungen vor (N, S, E, W). | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 5. Ich verirre mich leicht in einer neuen Stadt. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 6. Ich lese gerne Karten (für Sehbehinderte). | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 7. Ich habe Schwierigkeiten Wegbeschreibungen zu verstehen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 8. Ich kann Karten (für Sehbehinderte) gut lesen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 9. Ich gebe ungern Wegbeschreibungen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 10. Es ist mir nicht wichtig zu wissen wo ich bin. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 11. Ich lasse längere Reisen normalerweise von anderen planen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 12. Ich kann mir einen neuen Weg normalerweise merken, nachdem ich ihn nur einmal gefolgt bin. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| 13. Ich kann mir meine Umgebung schlecht "virtuell" vorstellen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Fragen nach der Studie | |
| Anstrengung: | |
| Navigation mit App | |
| Wie hoch war die geistige Belastung als Sie mit der App Räume gesucht haben? | 1 very low - 7 Very High |
| Wie hoch war die körperliche Belastung als Sie mit der App Räume gesucht haben? | 1 very low - 7 Very High |
| Wie gehetzt haben Sie sich gefühlt als Sie mit der App Räume gesucht haben? | 1 very low - 7 Very High |
| Wie erfolgreich waren Sie beim Suchen der Räume mit der App? | 1 Failure - 7 Perfect |
| Wie hart mussten Sie arbeiten um diese Leistung zu erbringen? | 1 very low - 7 Very High |
| Wie verunsichert waren Sie? | 1 very low - 7 Very High |
| Wie entmutigt waren Sie? | 1 very low - 7 Very High |
| Wie irritiert waren Sie? | 1 very low - 7 Very High |
| Wie gestresst waren Sie? | 1 very low - 7 Very High |
| Wie genervt waren Sie? | 1 very low - 7 Very High |
| Navigation mit Verbal Guidance System | |
| Wie hoch war die geistige Belastung als Sie mit Sprachunterstützung Räume gesucht haben? | 1 very low - 7 Very High |
| Wie hoch war die körperliche Belastung als Sie mit Sprachunterstützung Räume gesucht haben? | 1 very low - 7 Very High |
| Wie gehetzt haben Sie sich gefühlt als Sie mit Sprachunterstützung Räume gesucht haben? | 1 very low - 7 Very High |
| Wie erfolgreich waren Sie beim Suchen der Räume mit Sprachunterstützung? | 1 Failure - 7 Perfect |
| Wie hart mussten Sie arbeiten um diese Leistung zu erbringen? | 1 very low - 7 Very High |
| Wie verunsichert waren Sie? | 1 very low - 7 Very High |
| Wie entmutigt waren Sie? | 1 very low - 7 Very High |
| Wie irritiert waren Sie? | 1 very low - 7 Very High |
| Wie gestresst waren Sie? | 1 very low - 7 Very High |
| Wie genervt waren Sie? | 1 very low - 7 Very High |
| Navigation mit taktiler Karte | |
| Wie hoch war die geistige Belastung als Sie mit der taktilen Karte Räume gesucht haben? | 1 very low - 7 Very High |
| Wie hoch war die körperliche Belastung als Sie mit der taktilen Karte Räume gesucht haben? | 1 very low - 7 Very High |
| Wie gehetzt haben Sie sich gefühlt als Sie mit der taktilen Karte Räume gesucht haben? | 1 very low - 7 Very High |
| Wie erfolgreich waren Sie beim Suchen der Räume mit der taktilen Karte? | 1 Failure - 7 Perfect |
| Wie hart mussten Sie arbeiten um diese Leistung zu erbringen? | 1 very low - 7 Very High |
| Wie verunsichert waren Sie? | 1 very low - 7 Very High |
| Wie entmutigt waren Sie? | 1 very low - 7 Very High |
| Wie irritiert waren Sie? | 1 very low - 7 Very High |
| Wie gestresst waren Sie? | 1 very low - 7 Very High |
| Wie genervt waren Sie? | 1 very low - 7 Very High |
| General experience: | |
| Die App war barrierefrei. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Die Text-zu-Sprache Ausgabe hat mir alle notwendigen Informationen gegeben. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Die Struktur der App war nachvollziehbar. (Scan, Search, Navi-Mode) | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Die Audioausgabe der Bluetoothgeräte hat mir geholfen mich zu orientieren. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Die Knochenkopfhörer waren angenehm zu tragen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Ich habe mich unwohl dabei gefühlt den Stock und das Smartphone gleichzeitig zu benutzen. | Strongly disagree 1 2 3 4 5 6 7 Strongly agree |
| Welche Navigationshilfe war ihrer Meinung nach die beste? | |
| Welche Navigationshilfe war ihrer Meinung nach die schlechteste? | |
| Haben Sie Anmerkungen oder Empfehlungen um die App zu verbessern? | |
| Haben Sie Anmerkungen oder Empfehlungen um die interaktiven Bluetooth Geräte zu verbessern? | |
| Haben Sie Anmerkungen oder Empfehlungen um die Sprachunterstützung zu verbessern? | |
| Haben Sie Anmerkungen oder Empfehlungen um die taktile Karte zu verbessern? | |

**Figure A.12:** questionnaire German

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All links were last followed on March 30, 2016.

## Declaration

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

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