Designing a Smartphone Application for Identification of Network Devices

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Designing a Smartphone Application for Identification of Network Devices

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Designing a Smartphone Application for Identification of Network Devices

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Abstract

Today, an increasing amount of physical devices are obtaining Internet connectivity for more efficient management and device communication. In home environments, users may manage devices by providing them descriptive names such as *living room speaker*. For a limited set of devices such a solution is often sufficient. However, in a case where one wants to individually manage a very high number of devices one must keep track of individual device identification numbers. Obtaining this information may be challenging and time consuming if the devices are installed in inaccessible places. This is a present issue for Axis Communications which offers network audio systems for enterprise customers where devices are often mounted in ceilings before they're identified and configured. In this thesis, the authors have investigated novel solutions for network device identification in regards to both different user prerequisites as well as to limitations in different technologies.

Two smartphone application concepts with the purpose to perform identification have been proposed by the authors, of which one has been implemented. The implemented solution consists of an iPhone application prototype communicating with Bluetooth Low Energy (BLE) beacons, which would have to be incorporated in the physical speakers. One of the main advantages of the BLE beacon solution is that speakers do not require power in order to be identified.

Usability tests were held with the implemented prototype, in which the application was considered intuitive and easy to use. However issues with technical accuracy remain to be solved before the solution could be launched on the market. Furthermore, due to insufficient access to the actual target group and to real case environments, the usability of the application has to be further investigated.

Keywords: network device identification, network device installation, IoT, iOS, iPhone application, interaction design, user experience, usability testing, Bluetooth Low Energy, iBeacon.

Sammanfattning

Idag kopplas allt fler enheter upp på Internet, vilket effektiviserar såväl enhetshantering som kommunikation mellan enheter. I hemmiljöer kan användare styra enheter genom att förse dem med beskrivande namn, som till exempel *högtalare vardagsrum*. Så länge antalet enheter är begränsat är en sådan lösning ofta tillräcklig. I ett fall med ett stort antal enheter måste användaren dock hålla reda på enskilda identifikationsnummer för varje enhet. Att få tag på den informationen kan vara både utmanade och tidskrävande om enheter installerats på otillgängliga platser. Det här är ett problem för Axis Communications, som erbjuder nätverksstyrda ljudsystem till företagskunder. Deras ljudsystem monteras ofta i taket för att senare identifieras och konfigureras. I den här studien har författarna undersökt nya lösningar för identifikation av nätverksenheter med avseende på olika användares förutsättningar såväl som på tekniska begränsningar.

Två applikationskoncept för smartphones med syfte att utföra identifikationen har presenterats, varav en har implementerats. Den implementerade lösningen består av en iPhone-applikation i prototypstadie och Bluetooth low energy (BLE) beacons, som skulle behöva monteras i de fysiska högtalarna. En av de huvudsakliga fördelarna med en BLE beacon-baserad lösning är att högtalarna inte behöver förses med ström för att kunna identifieras.

Användartester hölls för den implementerade prototypen, i vilka applikationen uppfattades som intuitiv och lättanvänd. Tekniska problem med noggrannhet skulle dock behöva lösas innan produkten kan lanseras på marknaden. På grund av otillräcklig tillgång till den faktiska målgruppen och miljöer i vilka lösningen skulle kunna användas i praktiken, behöver användbarheten hos applikationen undersökas vidare.

Nyckelord: identifiering av nätverksenheter, installation av nätverksenheter, IoT, iOS, iPhone-applikation, interaktionsdesign, användarupplevelse, användbarhetstestning, Bluetooth low energy, iBeacon.

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Lastly we want to thank our friends and family for the support and endurance you have provided when we have complained about obstacles and setbacks.

Lund, May 2019
Ebba Busch & Richard Magnusson

Contents

List of Acronyms and Abbreviations

AoA	Angle of Arrival
AR	Augmented Reality
ASD	Axis Site Designer
BLE	Bluetooth Low Energy
GPS	Global Positioning System
GUI	Graphical User Interface
HiFi	High Fidelity
IoT	Internet of Things
IP	Internet Protocol
IPS	Indoor Positioning System
IR	Infrared Radiation
IT	Information Technology
LoFi	Low Fidelity
MAC	Media Access Control
NFC	Near Field Communication
PoE	Power over Ethernet
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indication
SUS	System Usability Scale
TDoA	Time Difference of Arrival
ToA	Time of Arrival
UHF	Ultra High Frequency
UX	User Experience
VLC	Visible Light Communication
WSN	Wireless Sensor Networks

Chapter 1

Introduction

In this chapter, a background for the thesis is presented together with an introduction to Axis Communications. Thereafter follows the scope and objectives of the thesis and some early research questions based on the background. Further, some Axis products and tools relevant for the thesis work are presented. Finally comes a description of the thesis work process and its phases.

1.1 Background

In the Internet of Things (IoT) era, physical devices are obtaining network connectivity which allows the devices to communicate and cooperate. The devices also become manageable remotely over a local network or the Internet [1]. Producers and manufactures of IoT devices may use any discovery protocol in their management applications to identify and to assign Internet Protocol (IP) addresses to all devices on the network which are to be managed. An example of such protocol is Apple's Bonjour Protocol [2] allowing for so called zero configuration networking. A user may just plug a new device into a local network and access the device through the management application on the same local network. If several devices of the same model are to be installed, one may plug in one device at the time and give them names such as *living room* or *kitchen*.

In a home environment with a limited set of devices such a solution is often sufficient. In order to individually manage a high number of devices of the same model however, one needs to keep track of the individual Media Access Control (MAC) addresses or IP addresses of each device. Obtaining this information may be challenging and time consuming, especially if the devices are not equipped with easily readable labels or if the devices are installed in inaccessible places.

1.2 Axis Communications AB

Axis Communications AB, hereafter referred to as Axis, is a Lund based industry leader in network video for surveillance. Axis' video solutions are installed worldwide in places such as public areas, retail stores, airports, trains and motorways [3]. Besides network video cameras, Axis offers products and services for access control and audio systems. Network audio systems from Axis consist of network speakers and can vary greatly in number of speakers. For example,

Figure 1.1: Speakers from Axis which can be used in an audio system [5].

an audio system can consist of two speakers in a small store or hundreds of speakers in a shopping centre or an airport. Audio systems are often separated into zones, which covers sub areas of the whole audio system area. Zones make it possible to play different music in different areas or keep certain announcements in different areas. An audio system can be used for security, announcements and background music. The audio systems can be used in combination with network cameras or as stand alone systems. The mission statement for Axis network audio systems is *audio made smart and easy*, meaning Axis aims for easy integration and simple installation [4]. Speakers from Axis which can be used as a part of a network audio system can be seen in figure 1.1.

Axis' business activities includes research and development only, which means that Axis do not manufacture devices, manage distribution, resell the products or perform installations. These activities are performed by Axis' business partners and customers. Rather than targeting end customers, Axis are providing solutions for system integrators, that is companies specialising within installation and system management. System integrators may or may not outsource the mounting of devices to fitters in an installation process, however they do manage the configuration and commissioning [6].

1.2.1 Audio Device Identification

Network audio speakers in an audio system from Axis are managed individually using individual identification names which are called *nice names*. These are assigned to the speakers in the configuration process. If speakers are managed in zones, they are assigned to the zones in the configuration process as well. The nice names and zone names are used for knowing what device belongs to which physical position. One might use a physical map with corresponding nice names, or descriptive names such as *Kitchen Speaker*. The nice names are assigned in the configuration process. Before then, the speakers are identified using their MAC addresses. The enterprise customers of audio devices are performing large scale installations within limited time spans, introducing an increased demand for efficient installation and configuration solutions adaptable to individual circumstances. Because of logistic factors, speakers are most often configured and assigned nice names after being mounted which requires identification of a device's MAC address when the speaker is already mounted. Sometimes the speakers are mounted in buildings with high ceilings, forcing someone to climb a ladder in order to access them. In a case with a high amount of speakers such process is both time consuming and inconvenient [6].

1.3 Scope and Objectives

The objectives for this thesis were the following: gaining a deeper understanding of the installation process including assisting software, hardware and the needs of participants in the installation process. Based on the target groups and their prerequisites, design and investigate one or several solutions for improving the device identification and in any other way ease the installation process. The main focus for the investigation will be audio systems and the presented solution will primarily be designed for audio installations.

1.4 Research Questions

Based on the stated scope and objectives, the following research questions were constructed:

- What problems do the installers experience and what needs are there?
- How can a technical aid assist the installers in order to minimise problems?
- What ergonomic, cognitive, technical, auditory and visual prerequisites of the installers affect decisions during the design process? How should the interaction be designed to meet these prerequisites?
- What technical opportunities and limitations can be found in the network devices?
- What technical opportunities and limitations can be found in the application platform?
- What techniques can be used to evaluate possible solutions during different stages of the design process? How should the evaluation results affect decision making during the design process?

The research questions steered the direction of our investigation and acted as a foundation for the thesis work.

1.5 Axis Devices and Tools

This section describes some background about the different devices, software and tools that Axis provide and which are relevant for the thesis work.

1.5.1 Axis Audio System Devices

At the time of writing this thesis, Axis offers the following audio system devices:

Two models of network speakers for announcements and background music; one cabinet speaker which can be mounted in the ceiling or on the wall and one ceiling speaker to be mounted in the ceiling only. The frequency response of the cabinet speaker is 60 Hz to 20 kHz. The frequency response of the ceiling speaker is 45 Hz to 20 kHz. Both speakers have built-in microphones listening to a frequency range of 50 Hz to 20 kHz and are powered by Power over Ethernet (PoE), thus being powered and connected to the network by the same cord. The cabinet has a small light on the back of the speaker which for instance indicates network connection. The light is covered when the back cover is mounted [5][7].

One horn speaker, a loudspeaker for outdoor messages in video monitoring systems. The frequency response of the horn speaker is 280 Hz to 12.5 kHz. The horn speaker has a built-in microphone listening to a frequency range of 50 Hz to 16 kHz and is powered by PoE [8].

One network audio bridge which allows managing analogue audio systems with the same tools as an IP audio system from Axis. The bridge also allows for connecting any digital source to an analogue audio system. The bridge has a frequency response of 20 Hz to 20 kHz and no built in microphone. It has a small light on the front which for instance indicates network connection [9].

A microphone console for making public addressing on a network audio system. The microphone pages up to 12 zones and requires no server [10].

1.5.2 Axis Audio System Software

Axis also offers a set of software tools for installation, management and system maintenance. During the work with this thesis, the following audio system software has been investigated and considered:

Axis Site Designer (ASD) is a web tool allowing system integrators to design end-to-end systems. The tool helps the customers to pick the right devices and accessories given their requirements and prerequisites. ASD estimates the customer's bandwidth and storage needs based on scenarios. One may also be assisted in choosing server hardware for storage. The functionality of ASD related to audio systems is limited to general advice of placement and recommended amount of speakers given the size and shape of the site. ASD can also provide limited technical information about the speakers available [11].

Axis IP Utility is a Windows application helping customers discover Axis devices on the network, assigning them IP addresses, subnet masks and default router. The Axis devices and the client computer running the software must be connected to the same network [12].

Axis Device Manager is an overall tool for managing installation, security and operational tasks for most Axis devices. It can be used for certificate management and third party application installations. The tool allows for performing tasks on several devices at the same time. Otherwise this has to be done in the web interface of each individual device [13].

Axis Audio Manager, hereafter Audio Manager, is a tool for managing and controlling audio systems. Features include device discovery, similar to Axis

IP Utility, zone management, scheduling and priority settings as well as network settings such as assigning multicast addresses [14].

Axis Audio Player is an application preinstalled on Axis audio devices for scheduling playlists and announcements in an audio system or for a single speaker. Axis Audio Player has support for one zone only making it a simple management alternative for Audio Manager [15].

1.5.3 Device Identification Tools

Device identification tool refers to any tool dedicated to identify MAC addresses of individual devices on the network. At the time of writing this thesis, Axis do not provide any device identification tool although there exists not yet launched initiatives which are aiming to solve the problem.

This thesis will explore solutions which are not related to or based on the currently existing initiatives.

1.6 Master Thesis Process

The thesis work was parted into six main phases, each described in its own chapter in this report. A chart illustrating the master thesis process can be seen in figure 1.2.

We started with the *Establish Requirements* phase during which we in an iterative way altered between gathering data and understanding the problem. The data gathering consisted of interviews and meetings with the purpose to investigate and identify problems related to the installation of network speakers. As we learned more about the problem we could further extend and streamline our data gathering. The *Establish Requirements* phase is described in chapter 4.

We continued with the *Conceptual Design* phase consisting of exploring and evaluating potential solutions, also performed in an iterative manner. This is described in chapter 5. We then moved on to the *LoFi Prototyping and Technology Evaluation* phase during which we in parallel worked with low fidelity (LoFi) prototyping and evaluation of technologies supporting our proposed solutions from the *Conceptual Design* phase. The LoFi work was performed as an iterative process moving between prototyping and evaluation. The technology evaluation consisted of research about different technologies which further were compared and evaluated, so that a suitable technology could be chosen for our proposed solution. The outcome of the research is described in chapter 2 and the *LoFi Prototyping and Technology Evaluation* phase is described in chapter 6.

The next phase was the *User Interface Design and Bluetooth Evaluation* phase. This phase consisted of designing and evaluating a Graphical User Interface (GUI) for the proposed solution, as well as developing a test application to evaluate the chosen technology, which was Bluetooth Low Energy (BLE). The processes were performed in parallel, both in an iterative manner. The phase is described in chapter 7.

The next phase to come was the *HiFi Prototyping and Usability Testing* phase consisting of high fidelity (HiFi) prototyping and evaluation. The process was performed in an iterative manner and is described in chapter 8. The whole

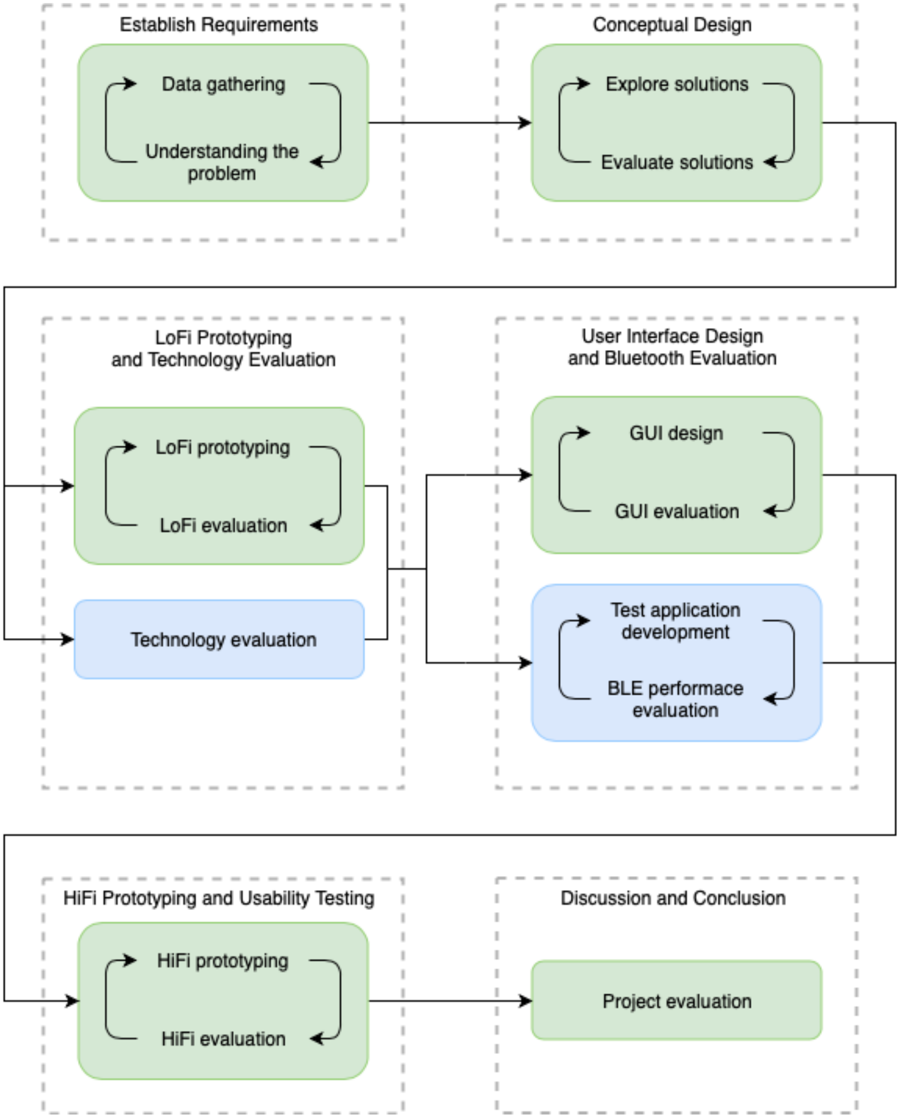


Figure 1.2: Chart illustrating the work process of this master thesis.

thesis work was thereafter discussed and the project evaluated. This is summed up in the last chapters 9 and 10.

Further, some theory of cognition and interaction design is described in chapter 3.

1.6.1 Work Load Distribution

Most of the time the different tasks were equally shared between us and performed together. During the *User Interface Design and Bluetooth Evaluation* phase Ebba focused more on the GUI while Richard focused on the development of the test application, however the time invested did not differ.

Chapter 2

Technical Background

In this chapter, technical background relevant for the master thesis is presented. That includes a number of wireless transmission technologies and computation methods for indoor positioning as well as some fundamental information about iOS development.

2.1 Transmission Technologies

Since the presented problem involves positioning of objects, a digital map based solution may be relevant for the identification tool as a complement to the nice names and physical maps used today. Further, as installations are performed in a variation of places, portability may also be an important feature for the tool. This section therefore describes different techniques and technologies for indoor positioning and information transmission, available for smartphones.

Section 2.1.1 describes different computation techniques for indoor positioning and sections 2.1.2 to 2.1.8 describe different technologies which, stand-alone or combined with one or more of the computation techniques described in section 2.1.1, approaches the indoor positioning problem.

2.1.1 Indoor Positioning Computation

The low accuracy of the Global Positioning System (GPS) in indoor environments has put high demands for functioning Indoor Positioning Systems (IPS), aiming for accurate and robust indoor navigation. As of today, no universal solution exists and the topic is actively researched [16]. A variety of different technologies and computation methods can be used, stand-alone or combined, in order to achieve indoor positioning with various accuracy and precision. Some common computational methods are described below.

Triangulation [17] can be used to calculate the position of a target relative to two reference points with known locations. The method uses geometric properties of triangles to compute angles to the reference points.

Trilateration and multilateration [17] uses, like triangulation, geometric properties of triangles in order to compute positions. However, three known reference points are needed and the position is computed by using the attenuation of the transmitted signals rather than angles. Multilateration works in the same way but with four or more reference points.

Angle of Arrival (AoA) [17] decides the position of a target relative to two or more reference points by calculating the angles of the incoming signals.

Time of Arrival (ToA) [18] is computed using one transmission unit (target) and multiple receivers (reference points). Using propagation time and transmission speed of signals the distance between the target and the reference points can be computed. With these distances the position of the target relative to the reference points can be decided using triangulation. The ToA method delivers high accuracy but in order to achieve exact signal propagation time the clock of the transmitter and the receiver must be perfectly synchronised, often implying expensive equipment.

Time Difference of Arrival (TDoA) [18] uses, like ToA, the propagation time and transmission speed of signals to compute distances. TDoA however uses the difference in time at which the signal arrives to different reference points to compute the position rather then absolute distance like when using ToA.

Received Signal Strength Indication (RSSI) [18] uses the received signal strength in order to calculate distance. Determining positions with RSSI using triangulation or trilateration is cheap and easy to set up, but tend to have low accuracy due to multipath and shadowing problems. In order to determine distances based on RSSI, one needs to estimate what RSSI corresponds to what distance using a path loss model. A very common path loss model is the log-distance path loss model [19]. The model requires a known RSSI value corresponding to a predefined distance and an environmental variable as input.

Dead reckoning [16] means that a user's current position can be derived using the previous position together with the user's walking length and walking direction. This can be computed with the user's starting position as input together with the built-in sensors of modern smartphones. However, this method comes with a drifting problem due to the low accuracy of movement determination.

Kalman filtering [20] is a state estimation method which utilise data observed over time in order to estimate unknown variables such as a noise free signal. The method can be applied in real time and is fast and efficient. It may be used to e.g. decrease stationary dead reckoning errors or to decrease noise in RSSI signals.

2.1.2 Radio Frequency

Radio frequency is a set of frequencies in the electromagnetic spectrum ranging from 10 kHz to 300 GHz [21]. In this section different wireless technologies using radio frequency is presented. These are Radio Frequency Identification, Bluetooth Low Energy, WiFi and 5G.

Radio Frequency Identification (RFID)

RFID [22] systems use readers and low cost tags in order to localise objects. All targets carry an RFID tag that can be detected by an RFID reader once the tag enters the vicinity of the reader. RFID tags can be parted in two categories: passive and active. The passive tags do not have batteries and are dependent on the readers to induce current in order to transmit information.

Active tags have a battery and are therefore more reliable since they use their own current for transmission. RFID tags can use three different frequency bands: Low Frequency (LF), High Frequency (HF) and Ultra High Frequency (UHF). Passive LF tags have a very short range while passive HF tags have a longer range of up to one meter. Passive UHF tags have a range of up to 10 meters. Further, Near Field Communication (NFC) is a technique which implements the RFID standard. Therefore NFC is able to interact with RFID tags. Modern smartphones can act as both NFC readers and tags. However, NFC has a very limited range [22, pp. 1–5, 43–45, 78–79].

UHF RFID readers require a lot of power and are not deployed in smartphones. Thus an external reader is necessary in order to detect UHF tags [23].

Bluetooth Low Energy (BLE)

BLE is a technique for short range data transfer with low power consumption [24]. In the field of indoor positioning BLE beacons are common. BLE beacons are small, cheap devices operating on battery. The beacon has a known position and transmits data using BLE [25]. Further in [25], a comparison between the accuracy of different RSSI indoor positioning systems was made. One of the evaluated technologies was BLE beacons used in a system where the position of a target was computed using trilateration with the help of three known BLE beacons. In order to achieve accurate position estimation the system needed configuration consisting of determining the path loss model of the experimental environment. The system was concluded to consume very little energy, but was not as accurate as WiFi, to which it was compared.

Apple provides the iBeacon [26] protocol, which enables position estimation for iOS devices relative to a BLE beacon running the iBeacon technology. Similar, Google has released Eddystone [27] for the same purpose.

WiFi

In a WiFi indoor positioning system [25], one approach is to use RSSI and trilateration with three known access points, like in the BLE beacon case. The WiFi setup then also needs configuration of the path loss model for the specific environment in which it is used. Compared to BLE beacons it is concluded in [25] that WiFi has a higher accuracy but consumes more power.

Another approach to WiFi indoor positioning is RSSI fingerprinting [18]. Like RSSI triangulation this method uses the RSSI from different access points in order to estimate positions, however the method demands an offline training stage. The training stage consists of creating an RSSI map of the entire environment which means recording RSSI values for every access point in every position of the environment. The RSSI map is later used to estimate positions in the system, this is done by comparing the current RSSI values of a target with the RSSI map [18].

5G

5G refers to the next generation of wireless networks, planned to be commercially deployed in 2020 [28]. The idea is to provide mobile users with higher data rates and lower latency compared to today's system. Apart from this, 5G is said to have the potential to boost other technologies such as autonomous vehicles and IoT. One way to achieve this is to use millimetre waves (mmWave), which means broadcasting on high frequencies in the range from 30 to 300 GHz [28].

The properties of the mmWave also allows it to be used for accurate positioning. In [29] a simulation of a 5G indoor positioning system using AoA and ToA was made, achieving centimetre positioning accuracy. However, the simulation scenario was a simplified indoor office and would further require synchronised clocks and extensive antenna equipment.

2.1.3 Augmented Reality and Image Detection

Augmented Reality (AR) is digital content, such as images, animations or text, overlaying a view of the real world. The technique includes one or several cameras which register the view the user is looking at and any identification or categorisation system able to identify elements of the view. This allows for real time rendering of digital content blended into natural places of the view. Devices used for AR experiences includes smartphones and smart glasses [30]. The AR technology can be used not only for displaying information but also for collecting useful information about the environment in which the service is used.

Camera scanners allow smartphone users to utilise their phones to obtain information which is linked to bar codes or QR codes. The scanner applications are integrated in or provided for the major smartphone operative systems [31] [32].

2.1.4 Infrared

Another solution for wireless information transmission is infrared radiation (IR), which are longer wavelengths than visible light but shorter wavelengths than WiFi. This make them less likely to reflect on surfaces than radio frequency technology while also costing less [33]. IR does however require custom receiver equipment as most smartphones do not support IR. A particular solution is proposed in [33] suitable for indoor navigation with low interference and at a lower cost than RFID.

2.1.5 Visible Light

In Visible Light Communication (VLC), or LiFi, information is transmitted through the medium of light at wavelengths between 375 nm and 780 nm [34]. Visual light has the main advantage of not being affected by electromagnetic waves. When used in an indoor environment, information cannot be accessed from outdoor as light does not pass through walls, which provides higher safety. Information can be transmitted from custom indoor lighting and received using the camera of a smartphone. The information is thereafter decoded in an application [35]. The positioning using VLC systems is said to be ”quite accurate” however at relatively short distance [34]. The distance between transmitter and receiver in [34] is 300 cm.

2.1.6 Sound

Sound can also be used for indoor positioning and in this section two different approaches for sound positioning is described: ultrasound and audible sound.

Ultrasound

Ultrasound exploits frequencies above 20kHz which is higher than the human ear can perceive [36]. Unlike audible sound, ultrasound transmissions can avoid interference with conversations or audible noise while not contributing to unpleasant noise levels. Compared to radio frequency technologies, such as WiFi, ultrasound has a slow propagation speed, which allows for simpler receiver hardware and lower time synchronisation accuracy between nodes. Ultrasound also does not penetrate walls significantly which minimises risk of interference between rooms and floors [37]. Because the speakers and microphones of smartphones are designed for audible sound, they are not suitable as transmitters and receivers however work has been presented which allows for translating ultrasound waves into lower frequencies which may be interpreted by a smartphone using additional less portable equipment [38].

Audible sound

Audible sound share the same characteristics as ultrasound but is more supported by off-the-shelf devices due to its more common frequency range [39]. It provides very high accuracy, reliability and practicality as well as coverage. The most obvious weakness of the technique is the noise caused by the audio signals, however techniques claiming to have produced signals almost non-perceivable by the human ears have been presented [39]. Such solutions are based on psychoacoustic techniques in which audio data is embedded in e.g. background music.

2.1.7 Wireless Sensor Networks

Wireless Sensor Networks (WSN) is characterised by the connection of spatially distributed cooperating network nodes, communicating with each other through any wireless communication, e.g. radio or light. Each node interacts with its environment by sensing or controlling physical conditions [40, pp. 2] and routes the data to the desired destination through neighbouring nodes. Several applications of WSNs require or may gain advantages of knowing the spatial positions or coordinates of the individual sensors within the network. Solutions for the localisation process can include ToA, TDoA, RSSI and AoA and may involve mobile or fixed targets, which are to be identified, and mobile or fixed anchors, which are known. Several solutions require at least three anchor points for successful identification, however a recent method proposes solutions utilising two mobile anchor points and 20 target nodes with a slightly higher mean error value [41].

2.1.8 Robot Vacuum Cleaners

Advanced robot vacuum cleaners (RVC) utilises sensor inputs and internal maps to alter and impact their routes for the sake of maximising reach of all horizontal spaces in which they operate. This is done without any reference nodes with predefined locations in the space. A range of technologies are used by RVCs for achieving indoor navigation. RVCs use touch sensitive bumpers to "feel" if they approach any objects. They use infrared to measure the distance to the floor so they can avoid falling down stairs. They also use infrared to detect walls, which they follow to find their way around a room. RVCs may perform dead reckoning by using light sensors to track their own wheel rotations. Maps are used in more sophisticated models in order to improve the route compared to an RVC using only sensors. Maps are created using a combination of sensors and light detection (LIDAR) to measure distances to walls. Another way for RVCs to create maps is to use cameras for taking pictures of walls and landmarks [42][43][44].

2.2 iOS Development

Designing an identification tool as a smartphone application is a suitable choice as smartphones are portable, powerful and support wireless communication with their surroundings. One of the most common platform for smartphone applications is iOS. iOS is the smartphone operating system which runs on all mobile devices developed by Apple Inc., including iPhone. All iPhone applications must be implemented in the integrated development environment Xcode provided by Apple. One of the programming languages supported by Xcode is Swift [45] which is Apple's recommended programming language for iOS applications.

Apple provide human interface guidelines for iOS applications to have consistent appearance. Thus, there are design elements which are commonly used for specific types of actions in iOS applications. One of those is the *action sheet* which is a specific kind of alert presenting one or more choices to the user depending on the specific context [46]. An action sheet typically appears in response to an action such as a button click. Figure 2.1 illustrates an action sheet in iOS.

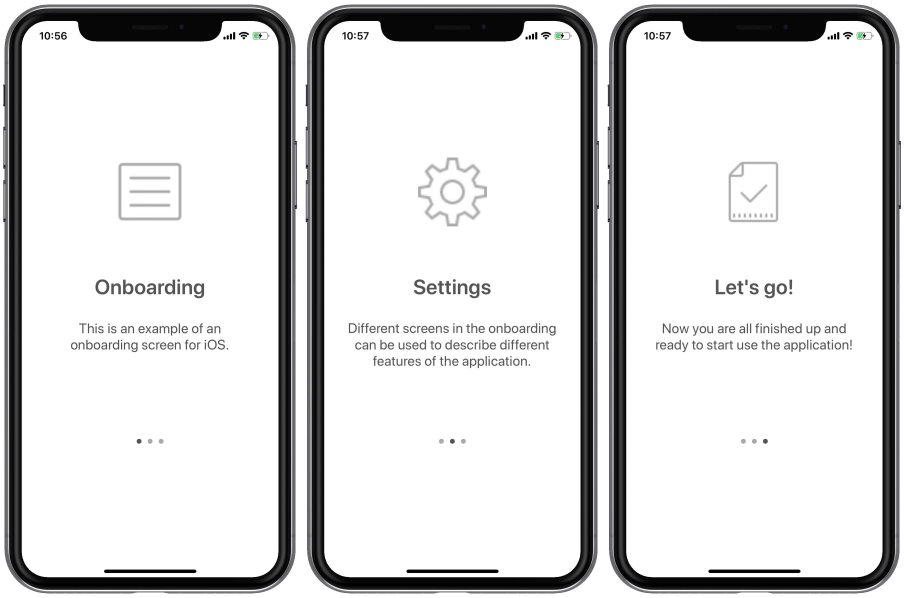
Another element common for iOS applications is a set of *onboarding* screens which precede the home screen of the application at launch. Those allow the developer to provide the user a simple tutorial or guide of how to use the application for first time users and serves as a complement to run time instructions [47]. Figure 2.2 presents what onboarding screens may look like in iOS.

At the Apple Worldwide Developers Conference in 2013 [48], Apple introduced iBeacon, a protocol for BLE beacon broadcasting. Several BLE beacons on the market support the iBeacon protocol.

Action Sheet

This is an example of an action sheet

Figure 2.1: Example of an action sheet for iOS with the options *Save* and *Reset*.



Onboarding

This is an example of an onboarding screen for iOS.

Settings

Different screens in the onboarding can be used to describe different features of the application.

Let's go!

Now you are all finished up and ready to start use the application!

Figure 2.2: Example of onboarding screens for iOS.

Chapter 3

Theory of Cognition and Interaction Design

This chapter addresses the design process and some fundamental principles of design. Properties that affect the usefulness and the user experience of a product are mentioned as well as the cognitive aspects of design. Design decisions made throughout the thesis work are based on the theory presented in the chapter.

3.1 The Design Process

In [49], interaction design is defined as *designing interactive products to support the way people communicate and interact in their everyday and working lives.* Interaction design can be described as an umbrella term which include a number of different aspects such as interface design, web design and software design. Interaction design means creating user experience using different techniques, methods and frameworks. User experience (UX) can be described as the way people feel about using different products: do they provide pleasure and satisfaction? How good are they? User experience applies to all type of products, not only interactive objects. A good user experience can be provided by a cup, a bottle, a locker or a computer program. A user experience can not be designed, however it is possible to design *for* a user experience.

The process of interaction design, the *design process*, includes four basic activities according to [49]. These are:

1. establishing requirements,
2. designing alternatives,
3. prototyping,
4. evaluating.

The activities are meant to be performed in an iterative manner: design, prototype, evaluate, re-design and repeat. This pattern leads to many small iterations which push the process forward. The evaluation is particularly essential for the design process. Striving to involve users helps ensuring that the product development takes the appropriate direction and that the final product meets the established requirements and provides a good user experience [49, pp. 9–15].

Fundamental for the user experience is the usability. Usability can be defined as the ability of a product or service to be useful, efficient, effective, satisfying, learnable and accessible [50].

Usefulness describes a product's ability to enable the user to fulfil their goals. If a product is not useful, the user is not willing to use the product at all.

Efficiency describes how quick a user achieves their goal and is often measured in time.

Effectiveness refers to the simplicity of which a user can complete the intended task.

Satisfaction refers to the user's perceptions, feelings and opinions of the product.

Learnability concerns the ease of which a user can learn to use a product, from not having used it at all or from using it again after a time of inactivity.

Accessibility refers to the product's ability to be used by anyone, regardless of a user's prerequisites or disabilities [50, pp. 3–5].

3.2 Principles of Design

In order to properly interact with a product a user must understand how it works and what it does. How well a product achieves to mediate this is known as the *discoverability* of the product. Good discoverability is the result of appropriate use of five fundamental principles of design: *affordance*, *signifiers*, *constraints*, *mapping* and *feedback* [51, pp. 10].

Affordance can be described as what a product *is for.* Affordance is the functionality of a product for a specific user, meaning that a product can have different affordances depending on the capabilities of the user. Important to notice is that an affordance is not a property.

Signifiers refer to signs which communicate the correct behaviour to a user. While affordances describe what actions are possible, signifiers are used to mediate these possible actions to the user.

Constraints provide guides and obstacles in order to ease the interpretation of a product. Constraints can be physical, logical, semantic or cultural but they all aim to provide the user with clues and to limit the set of possible actions.

Mapping is a term describing the relation between two sets of things. Mapping is important when designing e.g. controls, since there is often a spatial correspondence between a control and the object it aims to control. In a design with good mapping it is easy to understand which control corresponds to which object.

Feedback can be described as *communicating the result of an action* and refers to the concept of letting a user know that a system is working on ones request. Feedback can be delivered using many different techniques like visual, auditory or tactile. In order for feedback to be good it has to be immediate, otherwise a user can't be sure if the request was accepted leading to the user abandoning the system or product. Feedback also has to be informative, so that a user knows how to react on an event. Further, too much feedback can be worse than no feedback at all, implying that feedback has to come in the right amount: not too much or to little [51, pp. 10–25, 123–125].

3.3 Conceptual and Mental Models

A conceptual model is a way to explain how something works, often in a simplified way [51]. One of the most common examples of a conceptual model is the folders of a computer system. While the system does not store files in actual folders, the folder concept is used to ease the user's interaction with the system. The folders become a conceptualisation of how the system works. A good conceptual model provides understanding so that products can be used in an appropriate manner even when things go wrong. A conceptual model does not have to be complex as a user does not have to understand the underlying technology, but only the relationship between input and output [51, pp. 25–31].

A central component of a conceptual model is metaphors. Metaphors aim to make users understand the conceptual model by providing familiar concepts helping the users understand the system behaviour [49, pp. 44–45].

In contrast to a conceptual model, a mental model is the user's internal understanding of the system and how it works [49]. Many times people's mental models of computer based systems are poor and incomplete which leads to users having a hard time to identify, describe or solve problems they encounter. Ideally, mental models should match the conceptual models. With better mental models, users are able to complete tasks more efficiently. However this is hard to achieve as people lack interest in reading manuals and spend time learning about how things work. One way to get around this problem is to design systems to be more transparent. Transparent systems include:

- useful feedback,
- easy and intuitive ways of interaction,
- clear and easy instructions,
- appropriate online help and tutorials,
- context-sensitive guidance providing help at the correct level of experience [49, pp. 86–88].

3.4 Cognition

Cognition is relevant to take into account when working with interaction design since the human capabilities and weaknesses limit how interaction with technology can be performed. In [49] some cognitive processes relevant for interaction design are described, including: *attention*, *memory*, *perception* and *learning*.

For an activity, several of the processes can be involved making them interdependent. It is further stated that attention and memory are the most relevant for interaction design. Therefore they are described in greater detail.

Attention refers to the process of deciding what to concentrate on, given a range of available options. It involves auditory and/or visual senses. How easy or difficult the attention process is depends on the clearness of the goal and how salient the wanted information is. Within interaction design it is important to keep people's attention in mind for example by making the most relevant information salient by using underlines, colours or sequencing. It is also important to keep the interface as simple as possible and avoid cluttering it with unnecessary information, graphics or colours.

Memory refers to the process of recalling knowledge in order to act appropriately in different situations. Things that affect how well something is remembered and how easy it is to retrieve it from memory include the amount of attention paid to it and the context in which the information was encoded. The more attention paid to a subject increases the likeliness of remembering it and information encoded in certain contexts are often more easy to remember given the same context. Further, people are better at recognising pictures compared to for example text commands. Some design decisions for easing the memory process include not to use complicated procedures, in order to avoid overloading a user's memory and to design interfaces using consistently placed icons and menus to promote recognition.

Perception and **learning** refers to how information is acquired and how a computer system or a given topic is learned, respectively. Designing for the perception process can be done by using icons and representations with distinguishable meaning and effectively use border and spacing in order to group items making them easier to locate and perceive. Designing for the learning process includes making interfaces encouraging exploration and using constraints to guide users select the appropriate actions [49, pp. 66–82].

Chapter 4

Establishing Requirements

In this chapter, the initial data gathering and problem investigation is described. The outcome is presented in four user scenarios which describe different installation processes involving different actors. The chapter further includes an analysis of the scenarios and lastly a set of requirements for an assisting identification tool is presented.

4.1 Data Gathering

The first step for the thesis work was to gain a broad understanding of the installation process, variations in installation processes and the relevant tools Axis provide for installations today. The research consisted of reading public information about the different products and tools, five meetings and an interview. An introduction meeting about Axis audio systems was held with two software developers and one web developer at Axis. Further, two meetings with the product manager of Axis audio systems were held and one meeting with a product specialist of Axis audio systems. A meeting was also held with an experienced engineer working with ASD. In addition to the meetings, an interview was held with a product specialist of Axis access control system with previous experience as a system integrator. The questions for the interview can be found in appendix A.

4.2 User Scenarios

We used scenarios and personas [49] as a tool during the data gathering process. A scenario can be described as a story of human tasks and activities, providing information about context and needs for users in a certain situation. Scenarios can be used as basis for discussions about user goals, problems encountered or requirements. They are also a powerful tool for identifying stakeholders or involved products. Further, scenarios are a good way of communicating ideas and thoughts between different actors involved in the design process. Scenarios can be constructed to describe current situations in order to understand and analyse them but they are equally suitable for describing future visions. Personas are a good complement to scenarios. Personas describe typical users in a realistic manner and they serve as a target group which designers can focus on during product development. Personas can includes a specific user's goals, skills, attitudes or different prerequisites [49, pp. 374–377, 360].

The scenarios we created were based on the notes from all the meetings and the interview. They were formed to gain a deeper understanding of the installation process as well as to reveal incomplete understandings of the installation. Our incomplete understandings raised new questions to ask, which helped increasing the level of detail of the scenarios. Simple personas were written based on the collected data. The personas describe likely impairments and other characteristics which may affect the usage of an assisting tool. The scenarios and personas were used to share our interpretation of the installation process and when finished, they were used to identify problems during the installation process.

The user scenarios with associated personas presented below is the final result of the data gathering process. They describe four installation processes in different environments with varying actors and prerequisites.

4.2.1 Scenario One

A small tea shop wants to install speakers in order to play pleasant background music. The shop already has two Axis cameras installed. The following actor is involved in the scenario:

Eva, Projector - Eva is a craftsperson specialised within installation of IT equipment. She is 32 years old and has an education within IT and electronics. During a workday she often wears her special working trousers and a t-shirt. She has access to a work laptop and a work phone with a 5" touch screen, which she carries in a waterproof case. Furthermore, she has the possibility to bring a ladder to a site if necessary.

Action: The tea shop contacts the system integrator who installed the already existing Axis cameras and specifies that they want to install speakers in order to play background music in the entire shop. The system integrator assigns the project to Eva. Due to the small size of the project, Eva will be responsible for the whole installation process.

Eva travels to the shop in order to examine the spatial conditions of the shop and its existing network infrastructure. With her work phone she takes a photo of the evacuation plan of the shop to remember the floor plan. She also documents some possible positions to mount devices in by taking photos of the positions. With some help from Axis Site Designer she concludes that she will need to install four wall mounted cabinet speakers and pull cables to each of them. Eva orders the necessary materials and devices from the reseller. When the goods arrive she brings them to the shop. Since the shop is small the work takes place after the shop has closed for the day, so no customers will be disturbed by the installation. Eva uses the photos she took earlier to decide where to place the speakers. She starts with the cabling and thereafter moves on to mounting and connecting the speakers, one at a time. She needs to climb the ladder she brought in order to reach the mounting areas. For each speaker she connects, she presses the test button on the speaker to make sure it works correctly.

When all devices are mounted and connected Eva starts her work laptop and connects it to the same network as the devices are connected to. She runs Axis IP Utility in order to find the IP addresses of the new devices on the network.

She randomly chooses one of the discovered IP address and enters it in her web browser to reach its web interface. From the web interface she triggers a test tune on the speaker. As the speaker closest to the entrance is playing the signal, she names the speaker *Entrance* in the web interface. From the web interface of the entrance speaker she can access the remaining speakers in the network. Systematically she repeats the process of playing a sound, identifying the speaker and naming the speaker by its location, until all speakers have been assigned names. In the process, the speakers are added to the same sound system in order for them to play the same music and audio clips. Eva instructs the shop owner how to schedule music and announcements in Axis Audio Player and hands over the system.

4.2.2 Scenario Two

The management of a middle school with a total of 600 pupils wants to install speakers in the schoolyard for announcing the end of breaks and indoor for announcements and background music. The school currently has no Axis devices installed. The following actors are involved in the scenario:

Herman, Projector - Herman has a bachelor's degree in computer science and is 40 years old. At the office, Herman typically wears a button down shirt and dress trousers. At installation sites, he changes the dress pants for workwear trousers.

Emma, Nils & Carl, Colleagues of Herman - Emma, Nils and Carl work in the same office as Herman and their work tasks include mounting and configuration of IT hardware systems. They all have backgrounds as craftspersons with additional IT training.

Ulla, Fitter - Ulla is 42 years old and has a background as an electrician. She mounts network devices and cables on a daily basis.

Action: The school is referred to a system integrator through the municipality. Herman gets assigned to the project and is provided the blueprint of the school building with previously installed IT infrastructure plotted. He is also given the specification of requirements for the project.

Herman uses Axis Site Designer to determine required devices. For the project, he orders 92 cabinet speakers for indoor use and two horn speakers for the school yard. The project is scheduled for a holiday week as the activity in the building will be minimised.

Herman orders the required devices and equipment from the reseller and sends Ulla and a couple of her colleague fitters to prepare cabling. Meanwhile, the new speakers are delivered. Herman, Emma, Nils and Carl arrive to the school to configure the speakers, that is giving them nice names, before they are mounted. Herman has mapped out the placement of each nice name on the blueprint for Ulla and the other fitters to know which speaker goes where. The nice name of each speaker is written on the speaker's box as they are configured. Herman, Emma, Nils and Carl have divided the map into four areas to configure one each. The configuration is made through the web interfaces of the devices by connecting the devices to computers, using ethernet cables. Ulla and her colleagues mount the speakers and Herman connects the cables to the right switches and establishes a working network connection to the speakers.

When everything is in place, Herman is using Axis Audio Manager to configure zones of the discovered network devices according to the blueprint. In order to ensure a correct installation, Herman triggers a test tune for each device through Axis Audio Manager.

4.2.3 Scenario Three

A famous furniture retail company is building av new, record-sized store of six floors in Eslöv. They need top modern speaker equipment for background music and announcements for customers and staff. The following actors are involved in the scenario:

Göran, Projector - Göran is 46 years old and has a background as an IT specialist. At the office, he typically wears jeans and a shirt. On installation sites he wears workwear trousers and, depending on the construction environment, earmuffs. Since the system integration company he works for always outsource mounting and cabling, he does not have access to a ladder.

Ingrid, Fitter - Ingrid is a 58 year old craftsperson who has been working in the construction industry all of her life. She has no education and lately her sight has become partly reduced. A typical work site for Ingrid is a building under construction. Thus she has to wear full workwear, earmuffs, visor and heavy boots. Furthermore, she doesn't have access to a work phone.

Action: The company contacts the same system integrator as they usually do when building new stores. The system integrator specialises within retail IT systems and will be responsible for all of the IT solutions and IT infrastructure in the building, including the network speakers. The system integrator is involved early on in the construction process so cabling and mounting of devices can take place as soon as possible. The system integrator assigns the project to Göran. Göran designs the audio system based on the blueprints he has received from the furniture company. He determines the building will need 2120 ceiling speakers for the actual store, 58 wall mounted cabinet speakers for the stock section and three horn speakers for the parking lot. An electric installation company Göran has hired arrives to do the cabling. Later, a construction company adds ceiling and mounts the speakers. During a couple of days about ten fitters perform the mounting; one of them is Ingrid. Ingrid and her colleagues have received blueprints of the building with all devices plotted. They have been asked to write a note of each mounted speaker's MAC address on the blueprint to show where the speaker was mounted. However, due to a misunderstanding the fitters only mark mounted devices with an *X*.

Göran arrives to the site when all devices are mounted and the IT infrastructure is in place. Since the fitters never took a note of which device was mounted where, he has to identify all the 2181 speakers. Göran climbs a ladder to reach each speaker in order to read the MAC address written on it. The ladder he luckily lent from some craftspersons on the site. A colleague of Göran which has access to a laptop helps out by locating each MAC address in Axis Audio Manager. He triggers a test tune on the identified device to ensure it is the correct one and thereafter he names the device according to a predefined naming convention. The laptop is placed on a table with wheels so Göran's colleague doesn't have to carry it in an ungainly manner. After the identification Göran uses Axis Audio Manager to configure zones. This is done remotely from his office.

4.2.4 Scenario Four

A large airport wants to replace their system of analogue speakers into IP network speakers. The transition into new speakers is planned to be made gradually over two years. The following actors are involved in the scenario:

Juno, Projector - Juno is 53 years old and has a degree in electrical engineering and has taken additional training in project management as well as in IT system design. He always wears workwear trousers and a flannel shirt. During his career, he has not been using ear protection in noisy environments which has caused a hearing impairment.

Hamid, Fitter - Hamid is 48 years old and has been working as a carpenter and electrician since graduating school. He always dresses in workwear clothes and gloves. He is semi-confident with IT equipment but uses a smartphone.

Action: The airport contacts a set of system integrators to evaluate and compare different offers. Going for Axis network speakers turns out to offer most value for money and to be the most suitable alternative. The system integrator offering Axis speakers assigns a projector, Juno, to the project.

Due to the large amount of speakers and the requirement of no down time, the board of the airport decides to upgrade the system step by step, which means several speakers from the analogue system will be connected to the network using Axis Network Audio Bridges. This solution allows for managing the new network speakers and the old analogue speakers from the same network connected system.

Juno is provided blueprints of the airport and designs the new system by adding cables, routers, switches, speakers and audio bridges to the blueprint, using design software from the system integrator.

Due to the no down time requirement, the new system must be configured and running before the transition between the two system is executed.

The identification of each audio device must be made during the mounting phase. This is because it will be difficult to play test tunes after the devices have been mounted due to the sound volumes and acoustics of the airport.

A local electrical installation company, speaking the local language only, has been hired to perform the mounting of the speakers and the cabling for the speakers. Hamid and his colleagues are asked to put the supplied MAC address stickers for each speaker on the blueprint to indicate where the speakers are mounted. The mapping process is explained through instruction images as Juno and his colleagues don't speak the local language. When the installation is complete, the blueprint with stickers is given back by Hamid to Juno.

For the next step, Juno and a couple of his colleagues return to the airport for connecting audio bridges to the amplifiers connected to the analogue speakers and for commissioning the system. Juno and his colleagues connect one audio bridge to each amplifier as well as to the correct switch or router. The audio bridges and the switches are placed in locked up rooms. The MAC addresses of the bridges are written down for the devices to be identified when the system is configured. Juno is turning on the network without switching over the analogue speakers to the new system. All network speakers are assigned nice names and added to a zone. Thereafter the zones are tested by playing test tunes zone by zone. Each set of speakers connected to a bridge is then tested by triggering a tone followed by being assigned to a zone and given a nice name to ensure the right speakers are announcing the right messages. During the transition phase, all messages are announced on the network audio system as well as on the analogue audio system.

When the remaining analogue speakers are later to be replaced, the new speakers are mounted by any fitter at Hamid's firm and assigned nice names by Juno or any of his colleagues. The speakers are tested using Axis Audio Manager and when confirmed correctly configured, they are added to the same zone as the bridge for the analogue speakers which are to be replaced. Thereafter, the bridge will be removed from the zone in the software and disconnected by Juno's firm.

4.3 Scenario Analysis

In order to identify problems we carefully analysed the scenarios and the different installation flows. The analysis was made by reading the scenarios and commenting on different actions, tools and flows with respect to the prerequisites of the personas. The identified problems resulted in a set of requirements for an assisting identification tool. The requirements are presented in section 4.4.

4.3.1 Installation Phases and Limitations

Six main installation phases were identified in the installation scenarios. Tables 4.1 to 4.4 display the phases, the order of the phases and a set of requirements for each phase. There is one table for each scenario. The phases include: *planning, mounting, testing, setting names, checking names* and *configuring zones.* In the *planning* phase the projector decides how many devices are needed and where they are to be placed. The *mounting* phase includes the physical mounting of speakers only. *Testing* is making sure the devices are not faulty and the network connection to the devices is working. The *setting names* phase includes assigning the physical speakers nice names, which then may be used to identify them on the network. *Checking names* include making sure the devices are named correctly. *Configuring zones* includes grouping the speakers by room or physical spacing for the nearby speakers to play the same music and announce the same messages. i indicates the order of the phases.

The requirements include:

- *L/S* (laptop/smartphone) - is any stationary or hand held computer required to perform the phase?
- *Blueprint* - is a blueprint required to perform the phase?
- *On Site* - must the phase be performed on site?
- *Network* - does the phase require network connection?
- *Ladder* - does the phase require a ladder?

The main challenge of this thesis, to map the identity of physical devices to nice names or to map an identity to a particular position on a map, may be performed just before or after the *mounting* phase based on the workflow of the project. The mapping may be performed by the projector or the fitter. Who performs what is determined by the workflow. Each phase may not be obligatory or possible for each installation process. The *testing* step is an example of an affirming step which is desirable but not possible if the network connection is not working. As presented in the tables, the order of the steps may vary slightly resulting in different workflows.

Tables 4.1 to 4.4 reveal a high set of workflow demands for the installation to be successful. A future tool should aim to minimise such requirements in the phases of installations. Therefore, low need for computers on site, blueprints, on site actions, functioning networks and ladders would be optimal.

Table 4.1: Prerequisites for scenario one.

i	Phases	L/S	Blueprint	On Site	Network	Ladder
1	Planning	yes	no	yes	yes	no
2	Mounting	yes	no	yes	no	yes
3	Testing	no	no	yes	yes	yes
4	Setting Names	yes	no	yes	yes	no
-	Checking Names	-	-	-	-	-
5	Configuring zones	no	no	yes	yes	no

Table 4.2: Prerequisites for scenario two.

i	Phases	L/S	Blueprint	On Site	Network	Ladder
1	Planning	yes	yes	no	yes	no
3	Mounting	no	yes	yes	no	yes
-	Testing	-	-	-	-	-
2	Setting Names	yes	yes	no	no	no
5	Checking Names	yes	yes	yes	yes	no
4	Configuring zones	yes	yes	no	yes	no

Table 4.3: Prerequisites for scenario three.

i	Phases	L/S	Blueprint	On Site	Network	Ladder
1	Planning	yes	yes	no	yes	no
2	Mounting	no	yes	yes	no	yes
3	Testing	yes	no	yes	yes	no
4	Setting Names	yes	yes	no	yes	yes
-	Checking Names	-	-	-	-	-
5	Configuring zones	yes	yes	no	yes	no

4.3.2 Installation Problems and Inefficiencies

The scenarios were also analysed to identify specific problems or inefficiencies which can occur during the installation process. Further prerequisites and limitations of different sites and constellations were also investigated. The available

Table 4.4: Prerequisites for scenario four.

i	Phases	L/S	Blueprint	On Site	Network	Ladder
1	Planning	yes	yes	no	no	no
2	Mounting	no	yes	yes	no	yes
3	Testing	yes	yes	yes	yes	no
4	Setting Names	yes	yes	no	yes	no
-	Checking Names	-	-	-	-	-
5	Configuring zones	yes	yes	no	yes	no

equipment of different actors were taken into account when establishing relevant requirements.

In the first scenario the projector Eva uses her phone to take a photo of the evacuation plan in order to remember the floor plan. She also takes photos of possible positions in which the devices can be mounted. It is a clever way of documenting the site when there is no blueprint available, however it is not a very sophisticated or durable solution for larger sites. Also, her phone is placed in a waterproof case which makes it harder to interact with. Her way of identifying devices, playing test tunes and listening for them, works for the specific case, given the small shop, but would quickly become extremely ineffective on a bigger site with a larger amount of devices. Further, the installation is performed after the shop has closed which means no customers will be present. Thus, the working environment is quiet and calm. This also affects how effective it is to use sound for identification as noise increases difficulty to hear the different speakers.

The installations process in the second scenario works well given the circumstances, but if the installation had not been scheduled during a holiday it would have been hard for Herman and his colleagues to configure the devices on site. Due to the large amount of devices it is optimistic to assume they could have performed the configuration at the office instead. Another troublesome action is how every device has to be connected to a computer by cable in order to be assigned a nice name. To name the devices before mounting also appears to be very ineffective since the fitters would have to search for the correct devices among all of the close to 100 devices. Any good sorting system or logistic flow would ease the process but is likely to require a lot of coordination and appears unrealistic on a bigger site with more people involved.

In the third scenario several different parts are involved in the installation process and a simple misunderstanding makes the process a lot more complicated than planned. However, the suggested solution for identifying devices was not very effective in the first place and is obviously quite fragile. Since several fitters are involved, they would need one blueprint for each fitter. If they were to take a note of the MAC address on the blueprint the projector Göran would have to go through all of the blueprints to retrieve all the addresses. The solution is also sensitive to incorrectly written numbers and bad handwriting. Further, Göran and his colleague don't have access to a ladder and had to rely on the possibility to borrow one. In this scenario Göran and his colleague were able to listen to the devices in order to check if they had found the correct one, but since the site is under construction they most likely should have worn earmuffs. Had they used earmuffs, their method would have been useless. They also have to carry a laptop which potentially could be ungainly on a site under construction when there is no existing furniture to place it on. The fitter, Ingrid, has reduced sight and must wear earmuffs and visor, so in this case assigning her further tasks involving for example listening would not be possible. Also, she doesn't have a work phone.

In the forth scenario Axis Site Designer is not used for the planing phase. Further, the involved parts don't speak the same language which can potentially make the installation processes troublesome. In this case it is not possible to use sound to identify devices due to surrounding volume and acoustics. The identification takes place during the mounting, which makes the configuration phase efficient. However, the same problems with the large amount of blueprints as in scenario three arises. What happens if a blueprint is lost? It is a quite fragile solution. In this case a possibility to identify Audio Bridges is also needed. The projector, Juno, has a hearing impairment, which also limits the possible ways for him to identify devices. Hamid, the fitter, usually wears gloves which makes it hard for him to for example interact with a tiny phone.

As a summary, several potential problems have been addressed in the scenarios. The problems arise during different phases and are experienced by different actors. An assisting identification tool should aim to maximise efficient workflows and must be designed to work for people with different prerequisites and varying knowledge of IT.

4.4 Identification Tool Requirements

Based on the analysis of the scenarios, we defined requirements for an assisting identification tool. The requirements can be found in table 4.5. The requirements were graded *high* (H), *medium* (M) or *low* (L) based on importance.

Table 4.5: Requirements for an assisting identification tool.

Requirement	H	M	L
Must not include writing by hand	X		
Must be easy to communicate	X		
Must not require physical maps		X	
Must work even if the user wears earmuffs or visor	X		
Must work even if the user wears gloves		X	
Must not require a phone			X
Must not require that the projector uses ASD	X		
Must be possible to use with different languages	X		
Must support identification of audio bridges		X	
Must support phone placed in waterproof case	X		
Must be possible to use with impaired sight or hearing		X	
Must include effective device mapping	X		
Must not depend on a quiet environment	X		
Must support varying knowledge of IT	X		
Must support varying demographic parameters		X	
Must support wireless pre-naming			X
Must not require pre-naming	X		
Must not require IT infrastructure	X		
Must not require a blueprint	X		
Must not require a ladder	X		
Must support identification in buildings with high ceilings	X		

Chapter 5

Conceptual Design

This chapter describes the conceptual design phase, starting with two brainstorming sessions and the outcome of these. The chapter further presents flowcharts and storyboards for how an identification tool could be used based on the ideas from the brainstorming. Lastly it contains a rough evaluation of the explored solutions.

5.1 Brainstorming

After the identification of potential problems and requirements, two brainstorming sessions were held to start exploring and articulating solutions. Brainstorming is a technique for generating and refining ideas [49, pp. 373]. Our two brainstorming sessions were one hour each and during the sessions we tried out a number of different brainstorming techniques. The solutions proposed during the first session were sorted into categories using an affinity diagram, which is a method for sorting ideas into groups. The method consists of sorting notes based on shared affinity rather then predefined categories [52, ch. 3]. The affinity diagram we constructed can be seen in figure 5.1.

Our affinity diagram consists of the four categories *concept*, *transmission technologies*, *product form* and *prerequisites. Concept* refers to different approaches for solving the problem, including suggestions for who should do the identification and during which installation phase. *Transmission technologies* present different ways of moving information from A to B, e.g. from a device to a user or from a device to another device depending on which concept it is applied to. *Product form* suggests different ways of presenting information and *prerequisites* are factors which have to be taken into account when designing the identification tool. Sections 5.1.1 to 5.1.4 describe the content of the four categories in detail.

To avoid limiting the number of ideas too early we kept all proposed solutions from the brainstorming and challenged ourselves to think big by randomly choosing one idea from each category and construct a complete solution incorporating all of the ideas. During the second brainstorming session we focused on worst case scenarios and tried to imagine how different solutions would apply to these.

In the next step we narrowed down the number of solutions by removing the

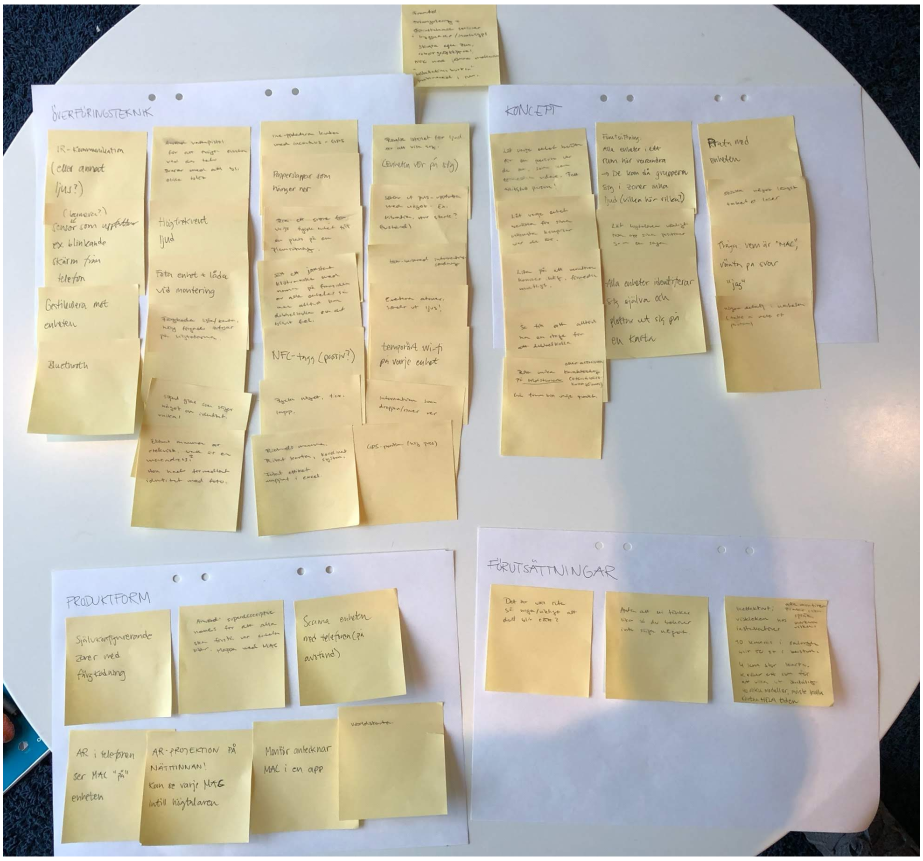


Figure 5.1: Affinity diagram constructed after the first brainstorming session.

ones too absurd or obviously ineffective. The remaining solutions were further categorised using mind maps and lists.

5.1.1 Concept

After quickly creating solutions based on randomly selected ideas from each category we got new ideas about how to approach the identification problem. After discussions we narrowed down the concept ideas to three key concepts which present three different approaches on how to solve the identification problem. These were:

1. The devices are identified during mounting.
2. After the mounting, a person physically is on site and
   (a) walks to each device and asks for its identity.
   (b) walks freely among all devices to auto detect them.
3. After the mounting, each device tells its identity to someone in its vicinity. The outcome of this would be a self discovery network.

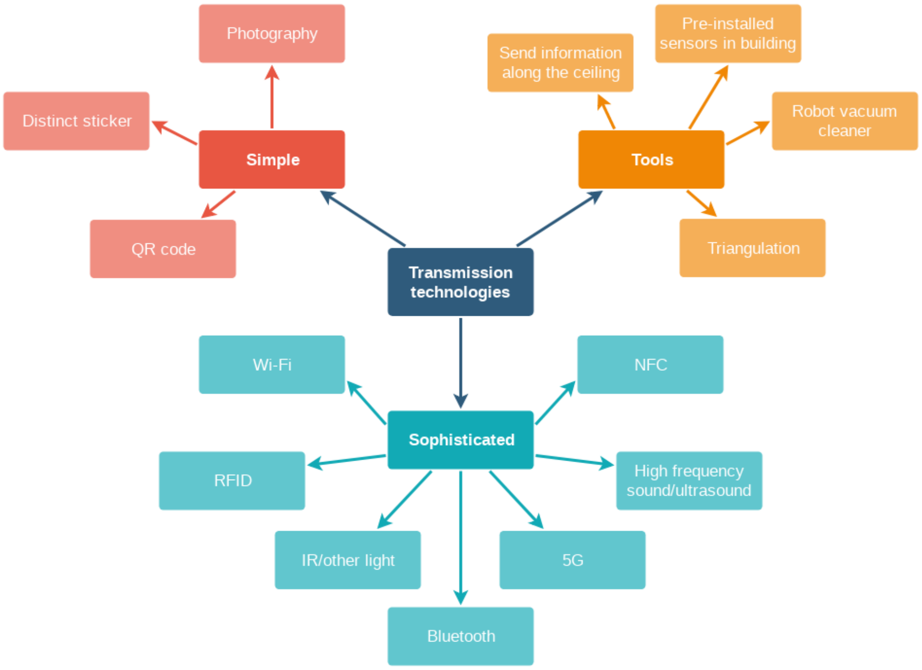


Figure 5.2: Mind map of the transmission technologies, divided into three categories.

5.1.2 Transmission Technologies

All three key concepts could be used with different transmission technologies. The technologies discussed during the brainstorming is presented in a mind map in figure 5.2. They are parted into the three sub-categories *simple*, *sophisticated* and *tools*.

The *simple* technologies consists of methods which do not require advanced technical abilities of the user, but instead they become quite troublesome or inefficient to use. For example, photography refers to the method of taking a photo of the device where its MAC address is visible and a photo of where the device is mounted. The details of the photography process can be altered in different ways, but the outcome is a solution demanding high workload on both the person taking the photos and the person going through the photos. The distinct sticker solution includes marking the devices with stickers which in a clear manner displays their identities. The stickers would have to be visible even if the ceiling is very high and with no obvious advantage apart from its low cost the sticker solution was concluded not to be very efficient.

The *sophisticated* technologies solve the transmission problem in more efficient but also more technically demanding ways and are mainly a set of digital and wireless transmission technologies.

The *tools* category do not present stand-alone transmission solutions, but rather different approaches for the transmission. For example, using RFID together with a robot vacuum cleaner could make the identification fully automated while using only RFID would require a person to physically walk around.

5.1.3 Product Form

The product forms can be combined with different transmission technologies and concepts. The product forms do not provide solutions for the identification problem, but are rather ideas for useful features. That includes ways of presenting information and platforms for presenting information in an identification tool. The product forms are:

Portable devices positioned in different locations - by using portable devices which can be moved around on the site, a user can identify devices in, say a room at a time. The portable devices communicate with the mounted devices in order to determine their locations and identities.

Colour coded maps - the identification tool uses colour coded maps in order to facilitate navigation trough e.g. different zones.

Super-descriptive names - the devices are given names describing their location in detail, to ease the management process once they are identified.

Smartphone application - the tool is implemented as a smartphone application.

World map - the tool has support for displaying multiple sites in different locations in order to facilitate world-wide management.

Live feedback map - a map with all planned and mounted devices that indicates the status of the devices as well as providing live updates if any device is moved to another location.

AR - the tool uses AR to recognise and identify rooms.

5.1.4 Prerequisites

Three main factors which could affect the efficiency of the installation process were found during the brainstorming. These were language barriers, the installers understanding of MAC addresses and the need for device level identification. We concluded that the tool must support different languages, that we can not rely on every user knowing what a MAC address is and finally we questioned the need for always identifying each device individually. For some sites, it may be enough to determine the zone for each device. This opens up for an identification tool only identifying zones which potentially could provide a more efficient workflow compared to identifying all devices.

Based on these prerequisites, we further concluded that a product form including super-descriptive names would not be suitable since it doesn't provide support for different languages. Imagine a global company with centralised device management located in Germany; super-descriptive names for devices mounted on a site in Spain would not be much use for a German speaker if they were in Spanish. Due to this, a solution including maps would be desirable compared to a solution based on precise naming.

5.2 Flowcharts

Based on the overall result from the brainstorming and the data gathering we created flowcharts for how interaction with an assisting installation application could be performed. The flowcharts were designed with the proposed technologies in mind, however they were designed to be somewhat flexible regarding

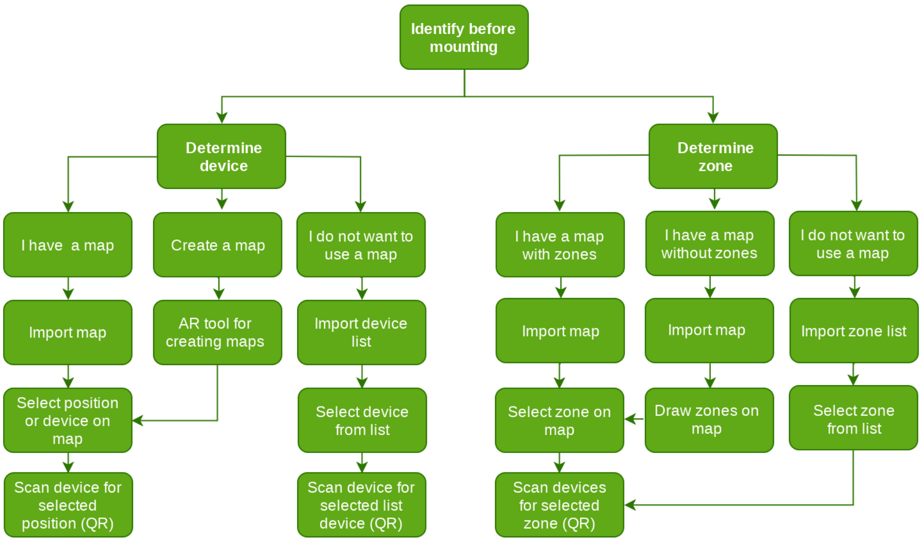


Figure 5.3: Suggested flows for the *identification before mounting* case.

transmission technologies and not to be dependent on specific graphical user interfaces. A product based on the flowchart can potentially run on a smartphone or a tablet. The service must be portable and available on site to be valuable. The two flowcharts are presented in figure 5.3 and 5.4. The flowcharts presented represent a goal oriented strategy rather than an actor oriented strategy. The term *map* in the figures refers to a digital map which can be loaded into the product. In the case where the user prefers the installation to be made with a physical map only, the *I do not want to use a map* option is suitable. The phrases in the flowchart are describing actions only and are not proposed button names or label texts for the interface of the application.

The first flowchart presented in figure 5.3 displays a workflow in which the fitter is scanning a device, mapping it to a specific nice name or position or zone in which the device will be mounted. This is done just before mounting the device in the ceiling or on the wall. Such a solution could use a QR scanner or a bar code scanner in order to scan a code containing information about the MAC address of the device. The QR code or bar code is most likely printed on stickers which are placed on the device itself rather than the box of the device as the fitter mounting the device might not unbox the device.

The second flowchart presented in figure 5.4 presents workflows in which the device is first mounted in the ceiling or onto the wall before being identified. In this case, the identification is most likely to be made by a projector. The first case of *identification after mounting* is determining devices individually by selecting them one by one on a map or in a list. The selected device is linked to the physical device spatially closest to the fitter. The second case of *identification after mounting* is determining several devices at once. The principle is the same as for the individual case, however a map is required as the projector is instructed to walk around the room in a certain direction to detect the physical devices in the same order as the map will register them. This solution does not require precise indoor navigation but relies on correct

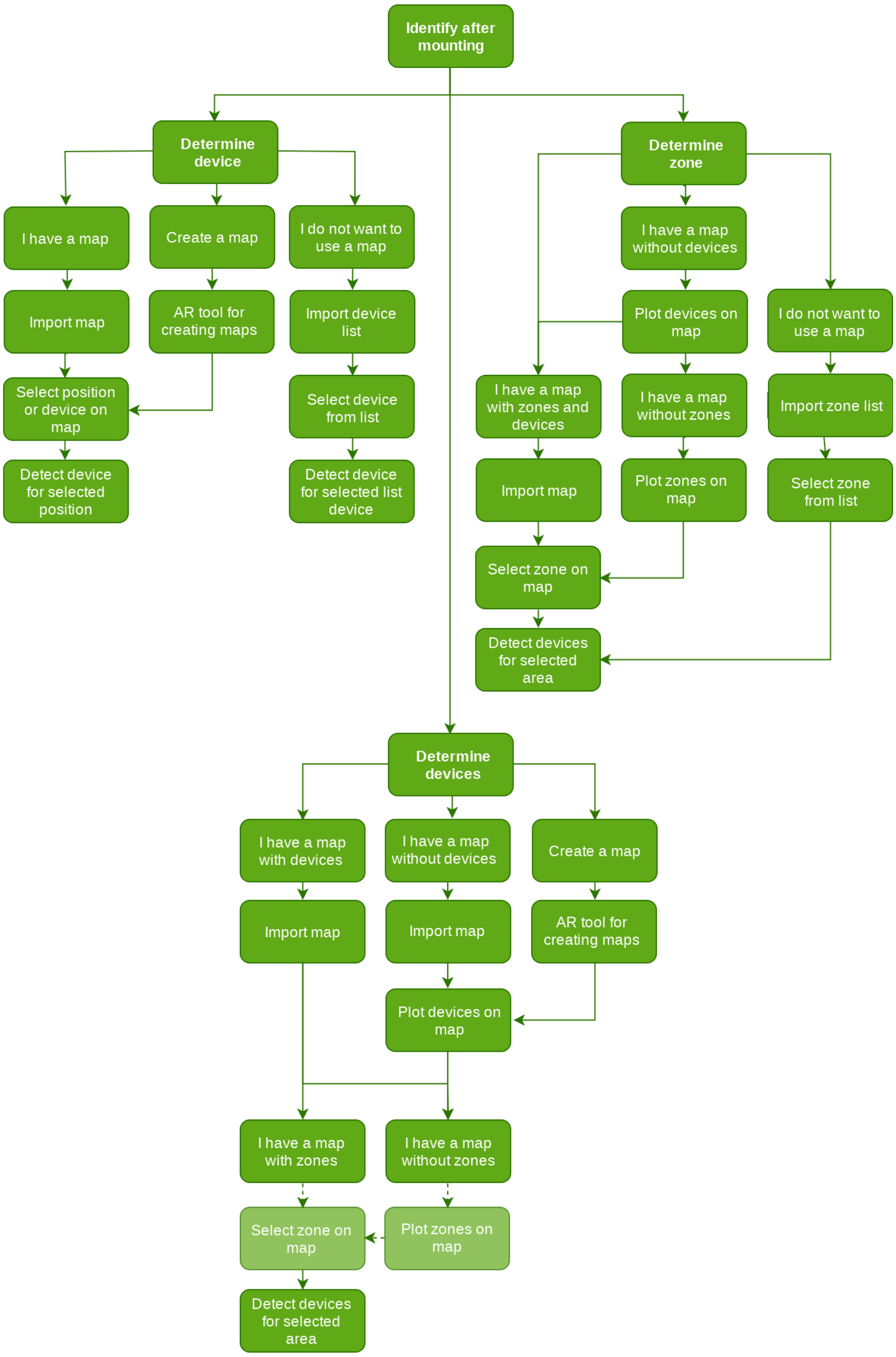


Figure 5.4: Suggested flows for the *identification after mounting* case.

movement of the projector. The third case for *identification after mounting* is similar to the second case, however no specific route is required besides a route covering all the devices in a zone and no devices out of the selected zone. The feedback for the user will be number of detected devices only but no position for the detected devices. In the case of identifying several devices at once, limiting the identification to one zone is optional. The optional steps are illustrated in a lighter colour in figure 5.4. If no zone is selected, all devices on the map will be included in the identification.

All of the workflows which include creating a map are labeled *AR tool for creating maps*, meaning they are using the camera of the device running the identification tool to create an accurate map of the room's floor plan. Such a solution is only a suggestion, but one which was investigated lightly during the brainstorming phase, thus suitable to consider for the actual tool or prototype. The usability of such a solution would have to be further investigated.

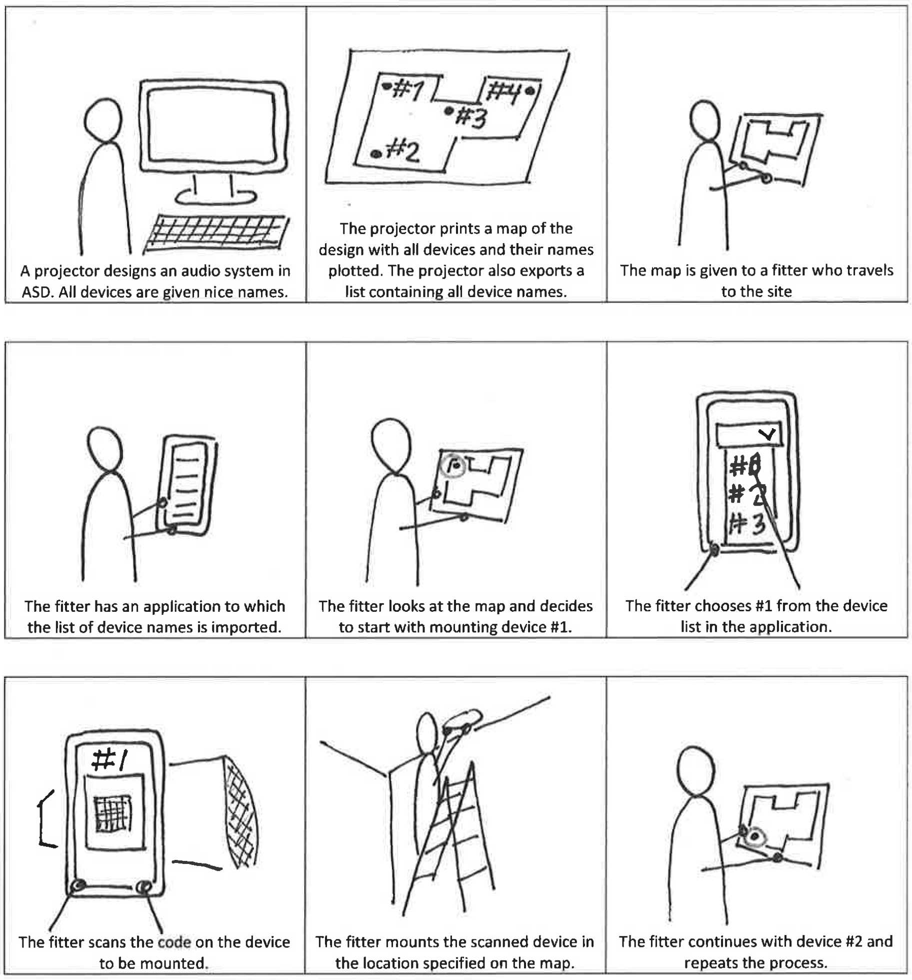
5.3 Storyboards

The flowcharts provide high abstraction descriptions of different installation flows. To bring down the level of abstraction of the proposed installation processes we created storyboards. A storyboard is similar to a scenario since it also demonstrates a user situation, however it evokes more emotion using sketches along with text. The purpose of a storyboard is to show how a user performs a task [49, pp. 393].

We chose one flow from the *identification before mounting* chart and one from the *identification after mounting* chart. The storyboards also take into account the different actors which are involved during installation. The purpose of the storyboards was to get a more concrete understanding of how an identification tool could be used and what functions it could include. We decided to work with the flows that differed the most, in order to illustrate solutions for a broad range of scenarios. In both cases we have chosen the ones where individual devices are determined and not only zones since determining zones is just a simplified case of determining devices. In the *identify after mounting* case, two flows for identification of individual devices exist of which we have chosen to focus on the one involving identification of multiple devices at the same time. This is motivated by being the most relevant scenario to investigate as it is the most efficient one.

The first storyboard can be seen in figure 5.5. It demonstrates the installation process in the *identification before mounting* case, when individual devices are to be determined and no map is used. This flow can be seen in figure 5.3.

The second storyboard can be seen in figure 5.6 and demonstrates the installation process in the *identification after mounting* case. Here, multiple devices are to be individually identified and a map without zones is created on site. The devices are thereafter plotted and at a later stage identified. This flow can be seen in figure 5.4.



A projector designs an audio system in ASD. All devices are given nice names.

The projector prints a map of the design with all devices and their names plotted. The projector also exports a list containing all device names.

The map is given to a fitter who travels to the site

The fitter has an application to which the list of device names is imported.

The fitter looks at the map and decides to start with mounting device #1.

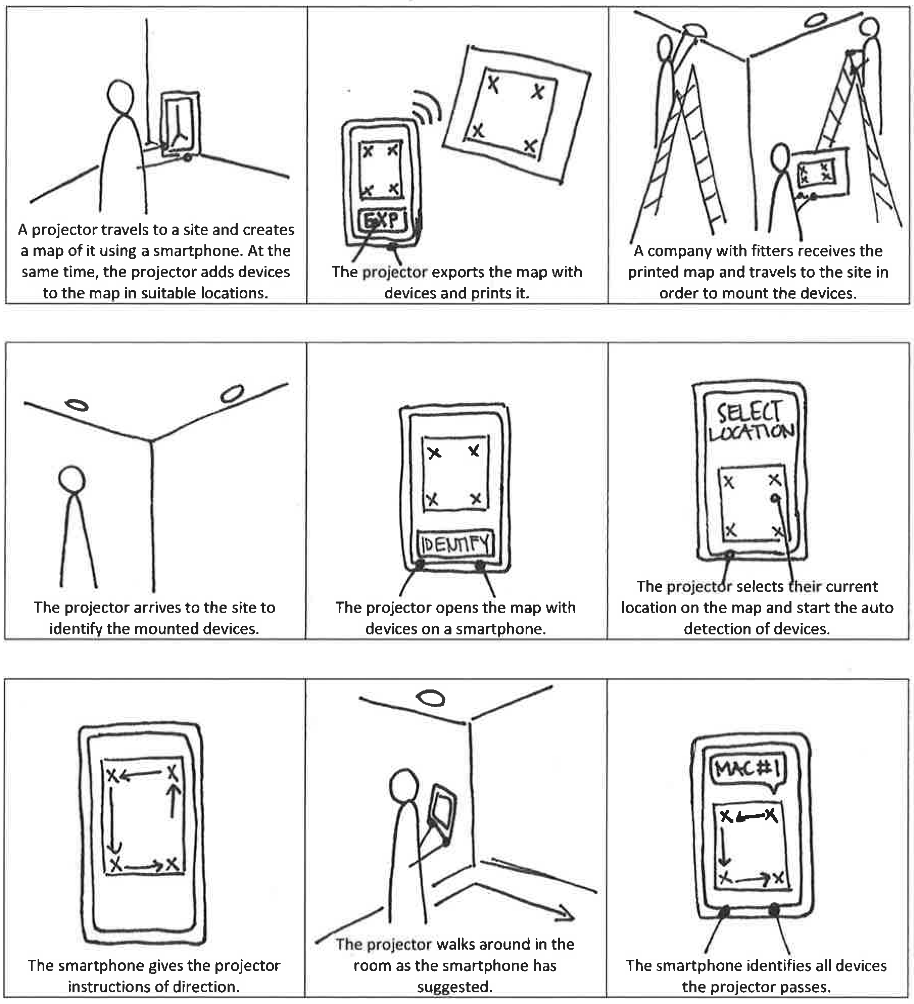
The fitter chooses #1 from the device list in the application.

The fitter scans the code on the device to be mounted.

The fitter mounts the scanned device in the location specified on the map.

The fitter continues with device #2 and repeats the process.

Figure 5.5: Installation process for the *identification before mounting* case.



A projector travels to a site and creates a map of it using a smartphone. At the same time, the projector adds devices to the map in suitable locations.

The projector exports the map with devices and prints it.

A company with fitters receives the printed map and travels to the site in order to mount the devices.

The projector arrives to the site to identify the mounted devices.

The projector opens the map with devices on a smartphone.

The projector selects their current location on the map and start the auto detection of devices.

The smartphone gives the projector instructions of direction.

The projector walks around in the room as the smartphone has suggested.

The smartphone identifies all devices the projector passes.

Figure 5.6: Installation process for the *identification after mounting* case.

5.4 Concept Evaluation

All of the *simple* solutions, except for the QR code, presented in the mind map of transmission technologies to be seen in figure 5.2, were abandoned for the prototyping phase due to inefficiency of use and lack of scalability for larger projects. The concept of a fully automated self-discovery network was also abandoned as such a solution would be highly dependent of circumstantial parameters and would most likely not be flexible and easy to use in a smartphone application without extensive on-site testing. The idea of portable assisting devices for locating network devices was abandoned due to additional workload, additional training for use, cost of equipment and risk for troublesome transport. We also decided not to evaluate the world map due to limited project time and due to limited relevance for the presented problem. The flows in the storyboards were prioritised for the prototyping phase in order to maximise the quality of the prototypes. The remaining workflows in the flowcharts were given a lower priority as they do not include any additional features of prominent value.

Chapter 6

LoFi Prototyping and Technology Evaluation

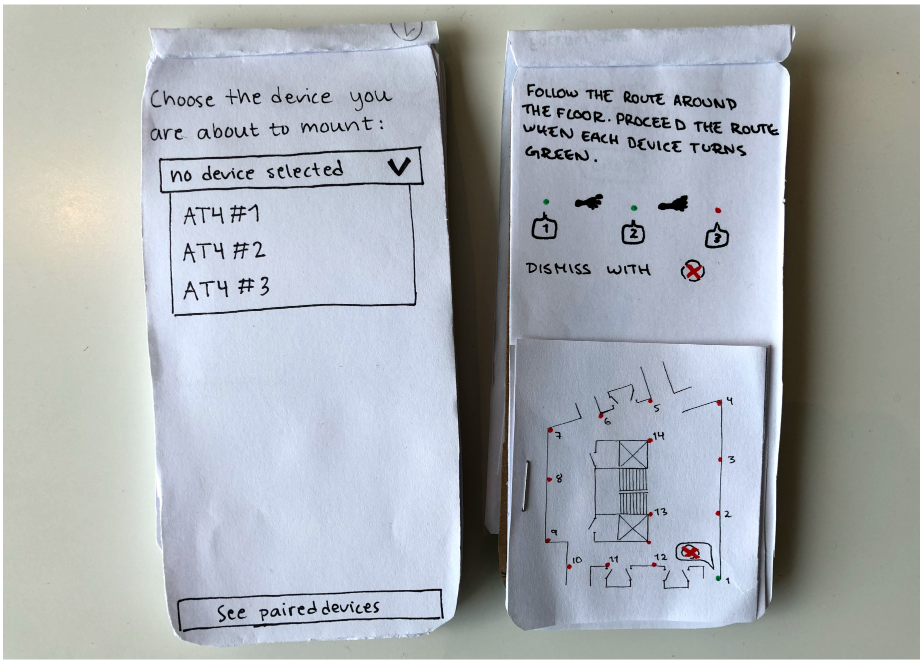
This chapter describes the LoFi prototyping phase in which two LoFi prototypes based on the outcome of the conceptual design phase were produced. The chapter also covers an exploratory test held with the purpose to evaluate the LoFi prototypes. Further, different transmission technologies suitable for the identification tool are evaluated.

6.1 Prototyping

In order to evaluate the identification part of the flows illustrated in our storyboards from the conceptual design phase, we created two simple prototypes. A prototype [49] is anything which demonstrates a design in an interactive way. The level of interaction can vary greatly between different prototypes. A prototype can be a simple sketch or a more advanced product similar to the final product. Prototypes are often categorised in low fidelity (LoFi) and high fidelity (HiFi), where LoFi prototypes are very simple, cheap and often constructed in materials such as paper. LoFi prototypes are a great way of exploring different design ideas. HiFi prototypes looks more like the final product and can be very useful for testing functionality and technical solutions [49, pp. 390–396].

The purpose of our prototypes was to demonstrate how the different identification processes would be performed using an identification tool running on a smartphone. We chose to create LoFi paper prototypes focusing on the identification only with no further functionality. When creating the prototypes we decided not to pay too much attention to the graphical user interface (GUI), the navigation or the conceptual model, but rather the flow of events involved in the identification processes. The prototypes were very simple and incorporated only the basic features necessary for identification. This is because we wanted to be able to evaluate the flow of events only and not the design of a potential GUI.

The created prototypes were designed to support the installation flows presented in the storyboards which can be found in figure 5.5 and 5.6. The prototypes were named A and B, where A supported the *identification before mounting* case and B supported the *identification after mounting* case. The prototypes



Choose the device you are about to mount:

FOLLOW THE ROUTE AROUND THE FLOOR. PROCEED THE ROUTE WHEN EACH DEVICE TURNS GREEN.

Figure 6.1: The A prototype (left) and the B prototype (right).

can be seen in figure 6.1, where the sketch to the left is the A prototype and the sketch to the right is the B prototype. As a complement to the A prototype we also constructed a physical paper map, since the A prototype did not contain a digital map. The map can be seen in figure 6.2a.

While creating the B prototype we realised that our initial idea about the application giving the user instructions of the order in which the devices should be identified, as demonstrated in figure 5.6, would not be possible. This is because we can not rely on the user having access to a smart map. Rather it should be possible to upload a static image, supporting the scenario described in section 4.2.1, where the projector Eva uses a photo of the evacuation plan to design an audio system. Without a smart map the application can't know about walls or other obstacles, probably leading to a badly planned route. Thus, the user of the B prototype instead has to input the desired route manually.

6.2 Exploratory Test

When the prototypes were finished we designed an exploratory test, which is a test method with the main purpose of exploring early design concepts [50, pp. 29]. The test consisted of two parts, testing one installation flow each. The test parts were named part A and part B where part A was testing the A prototype and part B was testing the B prototype. The test was held with two participants, both engineering students ,23 and 24 years old. They had a background within interaction design with experience of interacting with paper prototypes, however they did not have any knowledge about Axis or Axis products.

Part A consisted of the task *mount three devices according to the provided*

(a) Material used for part A of the test.

(b) Participant performing part A of the test.

Figure 6.2: Pictures of materials and participant from part A of the test.

map. Identify the devices as they are mounted using the provided LoFi prototype. The participants were provided with a map of the floor plan where the test took place. They were also given the A prototype. The map and the prototype can be seen in figure 6.2a.

Part B consisted of the task *pair MAC addresses of the previously mounted physical devices to the devices plotted on the map in the smartphone identification tool.* The participants were provided with the B prototype, in which a map of the floor plan where the test took place was included.

During the test, one participant started with part A and the other with part B. Thereafter they switched parts. The main purpose of this was to minimise the risk of biased results caused by learning. While performing the test the participants were asked to use the think-aloud protocol, that is verbalising thoughts, actions and feelings during completion of a task [52, ch. 87]. After the test cases during which the prototypes were used, a semi-structured interview was held. During the interview both participants were present and a couple of predetermined questions regarding the different parts of the test were asked. The interview went on for an hour. A detailed description of the test can be found in appendix B.

The test results are presented below. Section 6.2.1 presents observations made during the test and sections 6.2.2 to 6.2.6 present the outcome of the interview which followed the test. Figure 6.2a and 6.2b shows the material used during part A and one of the participants performing part A of the test.

6.2.1 Observations

For part A, both participants failed to carefully observe the map. Also, they did not clearly understand what happened during the pairing. For part B, both participants were keen to visit the exact position of all spots plotted on the map in the application, however finding the starting point for the route required some focus.

6.2.2 Part A Interview

The notations on the paper map were a bit confusing as both the product number and the individual IDs weakly differed between bridges and speakers. Insufficient technical insights in the product line affected the level of confusion as well. The installation flow was easy, but one participant found it troublesome to understand when to mount the devices in the instruction flow. One participant did not understand that the list of devices was a drop-down menu.

In the case of a big installation site, the participants though paper maps would be inefficient to carry and the absence of feedback would make it hard to know what devices have been mounted. Scrolling through the list to find if the devices were already mounted was not considered a good way to do it. They also found it troublesome that they could not scan for confirming but only pairing. They felt it might be confusing to determine or remember where they were located had the site been bigger.

The participants were asked how they thought they would have performed the task without the application. They answered they thought they would have looked for an ID sticker on the device. They thought they would perceive the application as a checklist for installation rather than a tool for identifying devices had they been presented the application in a real life case. Further, the participants thought it was quite easy to identify with the role of a fitter.

6.2.3 Part A Analysis and Improvements

Adding instructions of when to mount the device would be a solution for the problem of understanding when to mount a device. It might also help avoiding the risk of having a fitter scanning all of the devices at once before mounting them. The signifier for showing that the list of devices is a drop-down menu must be changed to be more clear.

Introducing the opportunity to scan for confirming if a device was paired would increase the confident of the test participants. Another solution would be to discard nice name and instead plot devices on digital maps with indications of configured and mounted devices, such as in part B of the test. This was considered a good solution by the test participants.

As the participants thought the IDs were already present on the devices and the application was merely a checklist, it became clear the participants did not fully understand what happened during the task. Hence, the installation flow requires a clearer conceptual model than what was provided by the prototype. To what extent the participants lack of understanding of the task was due to the participants inexperience of the products was not clear. However, it proved to be very important to emphasise the importance of doing the identification, which in part A was the scanning. Further, it must be very clear what bar code or QR code to scan, since several different codes could be present on the devices. The fitter should not need to have extensive knowledge about bar codes or QR codes.

While the participants did not find it hard to identify with being a fitter, there is a substantial difference between their experiences and knowledge of engineering students and the experience and knowledge of a fitter. While engineering students are more likely to have a deeper understanding of network configuration than fitters, fitters are aware of real case circumstances which may affect the mounting process.

6.2.4 Part B Interview

Both participants though the instructions were clear, however during the test they did not read the instructions carefully which affected both participants performance negatively. Also, the first screen, were the route was to be determined, was linguistically confusing.

Insufficient feedback was mentioned as a problem by one of the participants. Both participants would have wanted feedback from both the application and the speakers and not only the application as in the test.

The participants did not feel confused navigating using the map in the application due to the simple test conditions, however they thought they easily might be for a bigger site. They also thought it would be inconvenient to select a route beforehand for a big site with a high number of devices.

As a whole, the participants did consider the process to be intuitive. Both participants appreciated the identification flow and emphasised the automation and low effort.

6.2.5 Part B Analysis and Improvement

Due to the nature of a LoFi prototype, the low level of feedback might have affected the participants' understanding of the procedure negatively. One of the participant had a much easier time performing the task a second time. Feedback from the speakers was considered a good feature for a future identification tool. Such feedback would ensure the right device was paired with the map.

An indicator where the user is positioned would increase the confidence of the participants had the site been bigger. The test participants however thought an indicator of direction only would be valuable as well.

6.2.6 Part A vs. Part B

The participants agreed that part A of the test required a higher level of attention than part B as there were fewer tasks connected to part B. Both participants perceived part B to be more efficient. They also perceived part A more of a checklist for mounting devices and part B more focused on configuration. The participants thought both applications were equally hard. Both participants felt more confident solving their second test even though one participant began with part A and the other participant began with part B.

As an improvement for both prototypes, the participants suggested feedback if one was to connect the wrong device model to the wrong position. If installing the wrong device model in the wrong position is a problem for actual fitters is unknown.

6.3 Technology Evaluation

After the tests we changed focus from the installation flow and the user experience to research of different transmission technologies which could be used for the identification tool. We started with the technologies discussed during

Table 6.1: Pros and cons for different transmission technologies.

Technologies	Pros	Cons
RFID	low cost, no power requirement	requires additional receiver equipment
BLE	low cost, can run on battery	low accuracy
WiFi		low accuracy, high power consumption
5G	high accuracy	not deployed
AR	maps distances, maps rooms	does not solve the identification problem
Camera Scanner	easy to use, low cost	short distance only
Infrared	low multipath	requires additional receiver equipment
Visible Light	stays within room, high accuracy	short distance
Ultrasound	stays within room, no disturbance, high accuracy	requires additional receiver equipment
Audible Sound	requires no additional transmitter equipment, low cost, can be encoded into background music	noise disturbance

the brainstorming but as the process went ahead and we discovered new possibilities, we expanded our research to involve other technologies as well. The researched transmission technologies are described in section 2.1.

Based on the presented prototypes and the outcome of the technical research we evaluated the technologies. The result is presented in table 6.1.

The technologies most suitable for an identification tool were concluded to be camera scanners, audible sound and BLE beacons. Camera scanners are only favourable for short ranges, but would be a good technology to use for the *identification before mounting* flow in the A prototype. Audible sound and BLE beacons can be used for the *identification after mounting* flow in prototype B. The following paragraphs motivate why these are the most suitable technologies.

An RFID based solution would require UHF RFID tags on all speakers since the RFID tags which use lower frequencies do not support the long range requirement. The big advantage of an RFID system is that passive tags are cheap and do not need power sources, opening up for a system functioning even without power or network. However, an UHF RFID system would require an external reader, thus it can not be deployed on a smartphone.

BLE beacons are low cost with low power consumption. They can operate on battery, opening up for a system functioning even without power or network as for the RFID case. Techniques such as iBeacon and Eddystone make BLE beacons easy to utilise in applications. The main drawback of BLE is the relatively low accuracy.

WiFi is generally a suitable technology for an indoor positioning system due the fact that WiFi infrastructure already exists in many buildings. For our case however, where network infrastructure can not be assumed it is not very suitable. A WiFi solution would require high power consuming WiFi modules on every speaker, probably both expensive and not able to operate on reasonable sized batteries. WiFi does have better accuracy than BLE beacons but also comes with more drawbacks. Both WiFi and BLE beacons require configuration of the path loss model for good accuracy, which would be extensive and time consuming to do for each installations site.

5G is not commercially deployed at the time of writing this thesis, making it a difficult technology to implement. It does however provide high accuracy and has great potential providing positioning services in the future.

AR is a cheap technology since it can be deployed on a smartphone but it is not an actual technology for transmission and therefore it does not solve the identification problem. It can however be a useful tool for creating maps or determine distances to speakers since it can collect useful information about an environment. Camera scanners for bar codes or QR codes are also cheap technologies as one can run them on a smartphone. Camera scanners can be used for interpretation of information but is only suitable to use before mounting as it is neither desirable nor efficient to place big stickers visibly on speakers.

Infrared does not suffer from multipath problems but requires external receivers since smartphones are usually not equipped with infrared receivers. Visible light has the advantages of not being affected by surrounding electromagnetic waves and not passing through walls. However visible light only has a range of about 300 cm, making it unsuitable for our scenarios.

Ultrasound provides high accuracy and does not penetrate through walls, making it a suitable candidate for our identification tool. Further the signal can not be perceived by the human ear which also suits our scenarios since it would not interfere with daily business or be disturbing for users. However an ultrasound solution would require the speakers to be equipped with ultrasound transmitters since the ultrasound spectrum is out of the speaker's frequency domain, see section 1.5.1. Further, smartphones cannot act as ultrasound receivers. Therefore the tool would need to be complemented with an external receiver.

Audible sound could be implemented using the existing hardware of the speakers making it a very good candidate. Further it has a high accuracy, however there is a risk for it to be disturbing for users since they most likely will hear it.

Chapter 7

User Interface Design and Bluetooth Evaluation

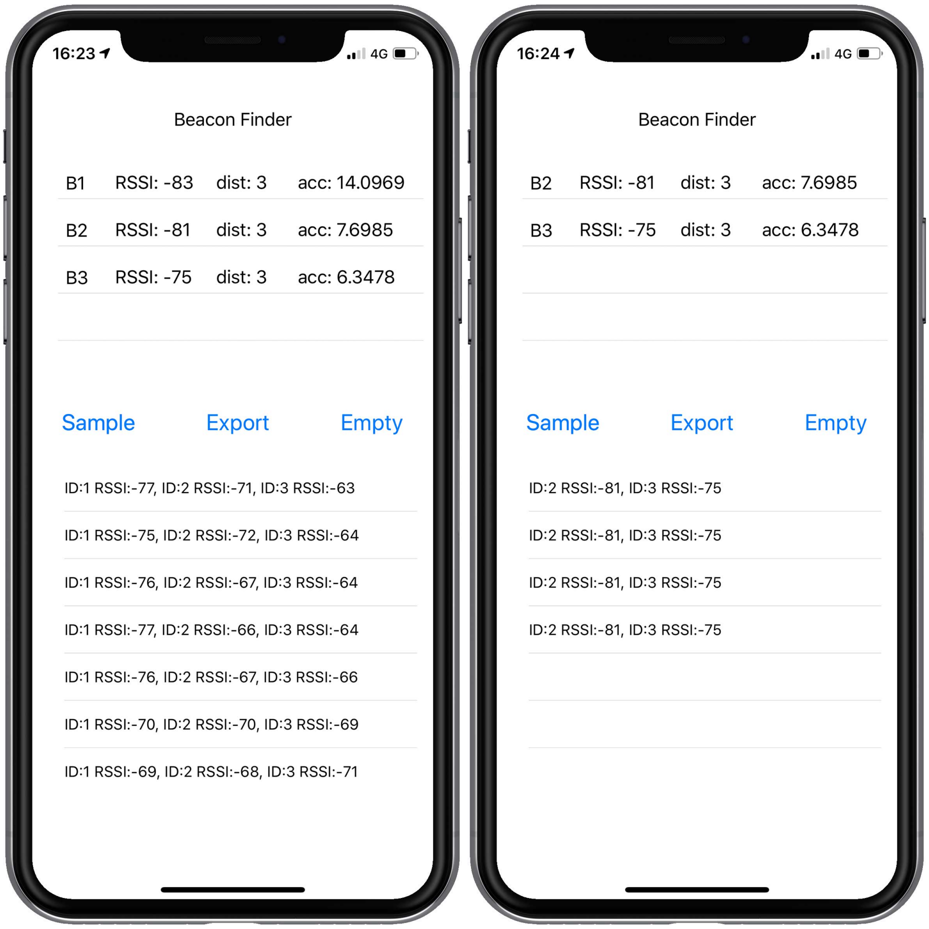
This chapter describes the process of implementing and using a test application for collecting and evaluating BLE performance data. The chapter further presents the result and an analysis of the collected BLE data. The chapter also describes the features of the identification tool and motivates the design of the identification tool GUI.

7.1 Development of Test Application

After the theoretical evaluation of the different technologies and the exploratory test, we decided to proceed with implementing a tool for the *identification after mounting* case using BLE beacons. The reason for choosing the *identification after mounting* case was partly because we thought it to be the most challenging case for us to work with and partly because we saw the most value in creating a tool for that case. Identifying after mounting would put the workload on the system integrator rather than the fitter which decreases the risk for errors due to miscommunication between the system integrator and the fitter. Also, the system integrator's technical understanding of the system is likely to be higher than the fitter's. Due to the disadvantage of disturbing users with audible sound we decided to try to use BLE beacons.

We started to develop a test application to determine how well the BLE technology would work in practice. The application was developed for iOS using Xcode and its purpose was to examine the performance of the technology during different test cases. The application does not support any of our presented installation flows and was developed only for evaluating the BLE technology.

The main features of the test application include receiving identification data from the beacons via BLE signals and to display the RSSI values of the BLE signals. In theory, the lowest RSSI value represents the closest beacon. Hence, one would be able to receive the identification of one particular beacon by being spatially closest to that beacon. The test application scans for beacons nearby using Apple's iBeacon protocol and prints their names in a list with their corresponding RSSI values. Screens from the test application is presented in figure 7.1.



Beacon Finder

```
B1   RSSI: -83   dist: 3   acc: 14.0969
B2   RSSI: -81   dist: 3   acc: 7.6985
B3   RSSI: -75   dist: 3   acc: 6.3478
```

```
ID:1 RSSI:-77, ID:2 RSSI:-71, ID:3 RSSI:-63
ID:1 RSSI:-75, ID:2 RSSI:-72, ID:3 RSSI:-64
ID:1 RSSI:-76, ID:2 RSSI:-67, ID:3 RSSI:-64
ID:1 RSSI:-77, ID:2 RSSI:-66, ID:3 RSSI:-64
ID:1 RSSI:-76, ID:2 RSSI:-67, ID:3 RSSI:-66
ID:1 RSSI:-70, ID:2 RSSI:-70, ID:3 RSSI:-69
ID:1 RSSI:-69, ID:2 RSSI:-68, ID:3 RSSI:-71
```

Beacon Finder

```
B2   RSSI: -81   dist: 3   acc: 7.6985
B3   RSSI: -75   dist: 3   acc: 6.3478
```

```
ID:2 RSSI:-81, ID:3 RSSI:-75
ID:2 RSSI:-81, ID:3 RSSI:-75
ID:2 RSSI:-81, ID:3 RSSI:-75
ID:2 RSSI:-81, ID:3 RSSI:-75
```

Figure 7.1: Beacon test application with three detected beacons (left) and two detected beacons (right). Both screens show sampled data in the bottom table.

By clicking the *Sample* button, one takes a sample of the RSSI values for beacons within range each second for a total of five seconds. The sample values are presented in a second list. Five samples per click on the *Sample* button was chosen as it was considered a good balance between short sample time and good accuracy. By clicking the *Export* button, the measurements may be exported to a file which one can interpret in any preferred spreadsheet service. The exportable data includes raw RSSI values, Kalman filtered RSSI values and estimated distances, based on the log-distance path loss model. The low accuracy of the log-distance path loss model was not considered a problem as all distances will only be evaluated relatively to each other as well as to themselves in different sample positions and not as absolute values. The distance estimation was applied to the raw RSSI values and to the Kalman filtered RSSI values.

7.2 BLE Beacon Performance

Several tests of different ceiling heights and beacon positions were lightly evaluated in an iterative manner. Most of the tests were made while the test application gained additional features and transmission power as well as advertising rates of the BLE signals were adjusted. However two tests were performed using the latest version of the test application, thus being comparable. The tests differed only by height of ceiling and the devices to be identified were placed in a horizontal line three meters apart. One test was performed with the ceiling height of two and a half meters above the floor and another test was performed with the ceiling height of four and a half meters above the floor. Images of the test setting for the ceiling height of four and a half meters can be seen in figure 7.2.

The two tests were just performed one time each and in one setting due to a narrow available time frame and do therefore not guarantee similar test results if performed again, however the results do resemble previously performed tests. The tests were carried out by us and did not involve any users, since it was not a usability test but rather a technology performance test. During the tests we used the test application to collect data. The collected data was then imported to Google Sheets where it was analysed using diagrams which increased the visibility of trends and patterns. The results from the two tests are presented in figure 7.3 and 7.4.

For both tests the beacons were passed by in the order beacon one, beacon two and lastly beacon three. Also, for both tests samples one to five contains values from measuring position one, samples six to ten contains values for measuring position two and samples 11 to 15 contains values for measuring position three.

The dotted lines in figure 7.3 represents the unfiltered data while the solid lines represent data on which a simple Kalman filter has been applied. For both figures, the Y-axis has been converted from RSSI (dBm) to distance (meter).

Figure 7.3 shows the result of the first test with a ceiling height of two and a half meters and a distance between smartphone and BLE beacon of a little over one meter. The result is desirable as sample one to five present the shortest distance for beacon one, sample six to ten present the shortest distance to beacon two and sample 11 to 15 present the shortest distance for beacon three. This test has proved to be the least challenging test regarding the accuracy of the

Figure 7.2: The test setting for the BLE beacon performance test carried out with a ceiling height of four and a half meters.

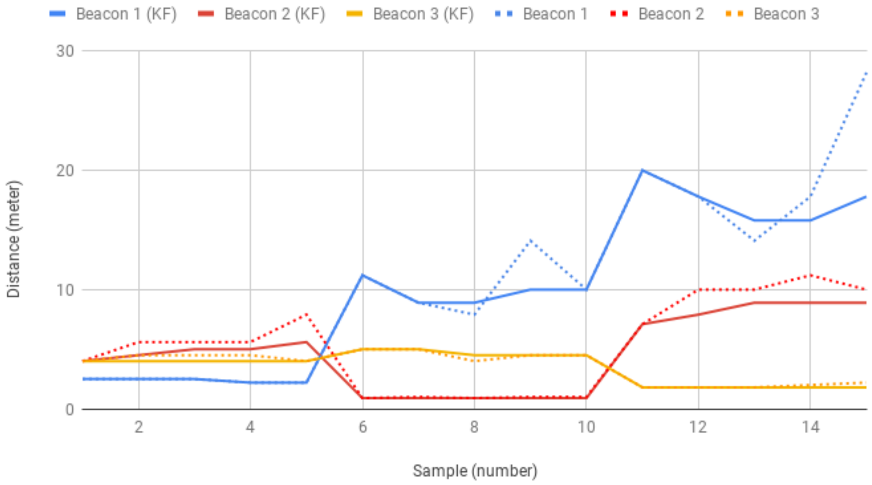


Figure 7.3: Distance estimation between the transmitting beacons and the smartphone receiver for data collected with the test application at a ceiling height of two and a half meters.

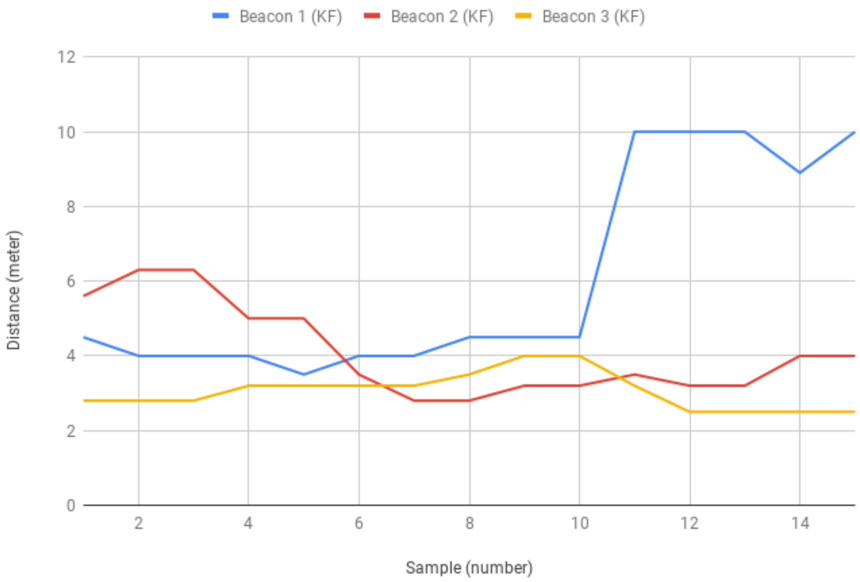


Figure 7.4: Distance estimation between the transmitting beacons and the smartphone receiver for data collected with the test application at a ceiling height of four and a half meters.

BLE beacons.

Figure 7.4 shows the result of the second test with a ceiling height of four and a half meters and a distance between smartphone and BLE beacon of a little over three meter. As for the test result presented in figure 7.3, the first five samples in figure 7.4 present the calculated distances when the receiver, that is the smartphone, is closest to beacon one, sample six to ten present the calculated distances when the receiver is closest to beacon two and the last five samples present the estimated distances when the receiver is closest to beacon three. One can tell that the beacon with the shortest estimated distance does not resemble the beacon with the shortest actual distance in all measuring positions. However, for each beacon, the shortest estimated distance over time occurs in the position which has the shortest actual distance. Thus, one has to collect all samples before determining the closest beacon in each position.

7.3 Identification Tool GUI

In parallel with the test application development and evaluation we started to work on the GUI of the identification tool. Since we decided to work with the *identification after mounting* case, the implemented flow is that from the storyboard in figure 5.6. However, during the technology evaluation it became clear that in order for BLE to work for higher ceilings, the estimation of which beacon is the closest can't be done until all beacons have been measured so that the collected RSSI values can be analysed over time. This lead to a change in the identification flow; from each device being identified at the same time it is passed by to the identification taking place once all devices have been passed.

We further concluded that the identification tool can be separated into two parts:

1. The creation of the site map and adding of devices.
2. The identification.

In the storyboard in figure 5.6, the creation and the identification are not performed immediately after one another since the fitters arrive to do the mounting in between the creation of the site map and the identification. Thus, it makes sense to divide the functionality this way. Due to lack of time, we took the decision to only focus on the identification.

As a reference for the HiFi prototyping we created LoFi sketches of the identification tool GUI for the *identification after mounting* case, illustrating the flow through the application together with different menus, options and navigation. Unlike the previously presented LoFi prototypes, these sketches display a more in-detail GUI with labels and features to be used in the final prototype. Our focus was to design a good conceptual model with the help of design principles and metaphors. We also considered different cognitive processes.

To evaluate our LoFi sketch before implementing the HiFi prototype we held an evaluation session together with the UX Lead of a mobile application team at Axis. During the session we performed a heuristic evaluation [52] of the LoFi sketch. A heuristic evaluation is performed without actual users, often within the development team. The purpose is to detect and fix usability problems before conducting a usability test. The evaluation is an inspection of an interface against agreed-upon usability best practises [52, ch. 46].

The UX Lead who participated during the evaluation works with UX design of iOS applications and has previously worked with other applications developed by Axis. The person has met projectors and fitters and has participated during installations.

The evaluation gave us valuable input on what iOS components we could use to make users feel familiar in the GUI. We further discussed signifiers and constraints in the application.

Sections 7.3.1 and 7.3.2 describe the features of the GUI and motivates the design of the GUI, respectively.

7.3.1 Features

The core features takes off from a *start* screen listing the user's sites. This could be different locations where the user administrates devices. In order to start the identification the user selects the desired site in the list. The user receives onboarding instructions on how to perform the identification and is then forwarded to the *identification* screen containing a map of the site with plotted devices. The *identification* screen can be seen to the left in figure 7.5.

The user walks to the nearest device and taps it on the map in the application. The application tells the user to wait while it collects RSSI values and when the collection is finished, the user proceeds to the next device and the process is repeated until all devices have been measured. The user presses the *Estimate identities* button and the application calculates to most likely identities of the measured devices given the collected RSSI values.

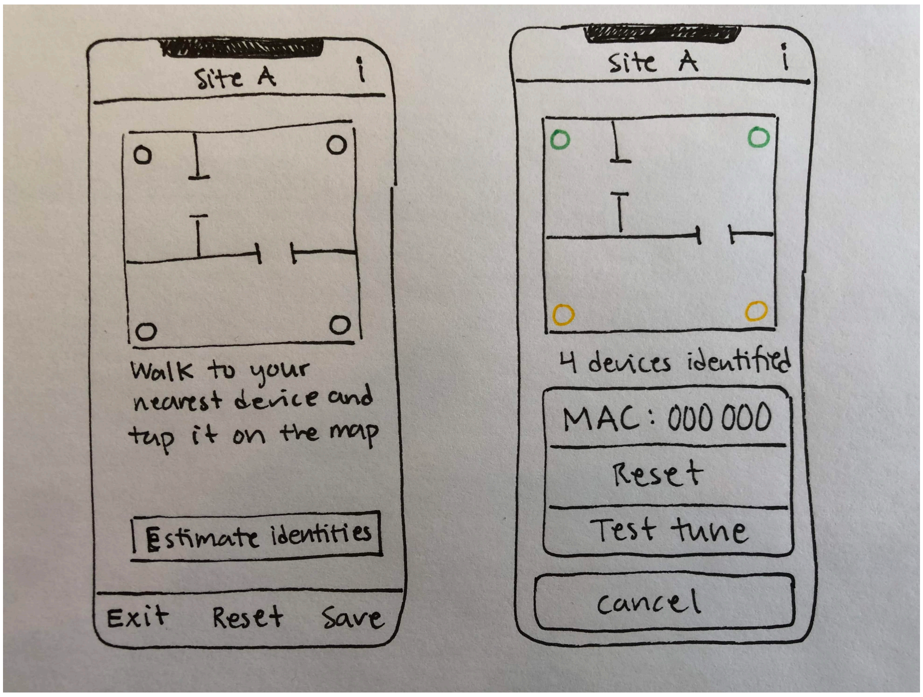


Figure 7.5: The *identification* screen with instructions and buttons (left) and the *result* screen with colour coded devices and an action sheet appearing after a device is pressed (right).

The user is presented with the result of the estimation on the *result* screen. The user can now tap the different devices to display an action sheet with possible actions for the selected device. The action sheet displays the MAC address, a resetting action and provides the possibility to play a test tune on the device. The *result* screen where a device has been pressed and the action sheet is open can be seen to the right in figure 7.5.

The *identification* and *result* screens further comes with a set of buttons, all present in figure 7.5. The functionalities of the buttons are described below.

Exit - the user can exit the *identification* or *result* screen and return to the *start* screen. If the user has not saved the latest collected data the user will be asked to save but also has the option to delete collected data.

Save - the user can save all collected data.

Reset - the user can reset and delete all collected data. The user is presented with an alert asking if they are sure about deleting the data.

Estimate identities - the user can start the estimation of the measured devices. If all devices on the site have not been measured the user is asked if they want to estimate anyway.

i - the user can get help and information about the application at any time during usage. The onboarding instructions can be accessed from this menu.

Further, it will be possible to tap measured and estimated devices to get actions related to that specific device.

During the evaluation of the beacon performance we realised that in some cases it will not be possible to determine the identity of a device with 100% certainty. The GUI of the tool must take this into account when presenting the estimated result since it otherwise would give the user unclear signals about the accuracy of the result. We therefore decided to use colours to mark the probability of an estimated identity. In the *result* screen, devices with high probability of correct identity are green while devices with lower certainty are yellow. This is illustrated to the right in figure 7.5.

7.3.2 Design Motivations

In order to facilitate the attention process we prioritised which information was the most relevant for the GUI. The amount of buttons is as low as possible without limiting the necessary actions. Texts and instructions are kept short and precise with the most important words highlighted.

For the identification process to be performed correctly the tool demands the user to act in the correct way. The user must get easy-to-follow instructions in order to conduct the identification and the procedure must not get to complicated to perform or to remember. The user will get onboarding instructions on how to perform the identification when the identification process is started, but to support the memory process the application will also provide instructions during usage. Thus, the user should not have to remember the entire procedure but will from start have an overall understanding of the system. To further support the memory process we have worked with iOS standard GUI components, labels and icons familiar for users. Menus and navigation are placed consistently and does not change depending on where in the installation process the user is. The use of easy onboarding instructions further facilitates the learning process and clear, familiar components grouped by function eases the perception process. One such group of functions is the bottom bar with the *Exit*, *Reset* and

Save buttons which can be seen to the left in figure 7.5.

To make use of standard iOS components, descriptive labels, informative feedback and clear instructions we hope to create an easy and intuitive application. By providing the user just the amount of feedback required to perform the task correctly and to avoid unnecessarily complicated terms, we hope to provide a simple conceptual model that makes sense to the user. Our work with cognitive processes and design principles will hopefully also enhance the connection between the conceptual and the mental model of the application.

The following sections further describes our toughts about *affordances*, *signifiers*, *constraints*, *mappings* and *feedback* in the application.

Affordances and signifiers

To mediate the different affordances of the buttons and actions in the application, we have used standard iOS components as signifiers. Since the signifiers are standard iOS components they will hopefully guide the user to the right actions as they are previously known to the user. In the cases where the possible actions are of a more diffuse character, for example when the user is to run the estimation of the device identities, we have worked with labels and precise words in order to signify what the actions do.

Constraints

Our work with constraints mainly consisted of making sure that actions only can be carried out if the application is in the correct state. For example it will not be possible to estimate devices if no devices have been measured: in this state the user cannot press the *Estimate identities* button. A challenge we encountered was how to constrain the user to stand still while the application measures RSSI values. One way of solving this could be to use the accelerometer of the smartphone to detect movement of the user during the measurement. Too much movement may trigger an alert asking the user to stand still. Such feature would act as a physical constraint which increases the possibility of accurate measurements. However we can only prevent the user from not moving, not from measuring in the wrong position.

Mappings

Mapping is of great importance in the application since the functionality relies on the user to correctly identify their spatial position in relation to the map. If a user fails to understand what parts of the map corresponds to what parts of the spatial room, the device identification will not work. It is therefore very important that the map in the application is clear and representative for the physical site. Since we want to support uploading of maps we can not control the condition of the map, however we have focused on making the representation of devices clear and visible so that a user easily will understand where devices are placed and in this way we hope to facilitate the mapping process.

Feedback

Regarding feedback we considered the feedback during the measurement of RSSI values to be the most important. This is a very crucial step in the identification process and the user needs to understand that the system is collecting data and therefore the user cannot move from the current location before all necessary measurements are taken. To achieve this, the application must provide a progress indicator mediating data collection. We also decided that the application needs to provide some kind of tactile feedback like vibrations when the measurement is done so that an experienced user must not look at the screen all the time, since this might be tiresome while identifying a large amount of devices.

Further it is desirable that the user gets feedback from the speaker being identified, as proposed during the exploratory test described in chapter 6. However, since the BLE technology demands that all devices are measured before they could be identified, this is not possible for our proposed implementation.

Chapter 8

HiFi Prototyping and Usability Testing

This chapter presents the work with the HiFi prototype of the identification tool. The chapter includes a description of the prototype and covers a usability test held with the purpose to evaluate the prototype. Lastly, some improvements based on the outcome of the test are suggested.

8.1 Prototyping

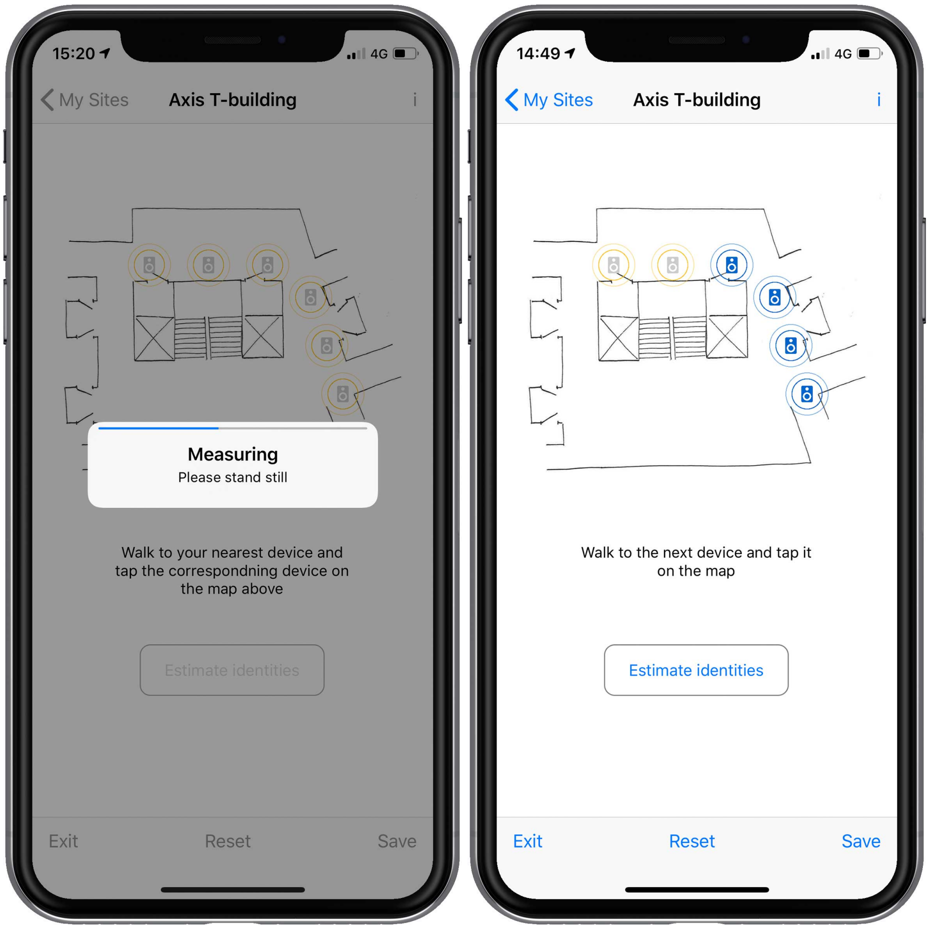
With the help of the LoFi sketches presented in chapter 7 we started to develop a HiFi prototype in Xcode. The HiFi prototype implementation was performed in an iterative manner where we started with the core features and successively moved on by extending the prototype into a more interactive product. Much of the code from the test application described in chapter 7 could be reused as the BLE beacon logic in the HiFi prototype works the same as in the test application.

Screens from the HiFi prototype of the identification tool can be seen in figure 8.1 and figure 8.2.

The dots or circles representing devices in the LoFi sketches in figure 7.5 were replaced with Axis speaker icons in order to limit risk of confusion for the user. This also makes it possible to use different icons for different device types which may help the user to navigate in the room.

The usage of colours was also more extensive in the implemented prototype compared to the sketches in figure 7.5. The new colours were the following:

- **Grey speakers with a yellow circle**, the default colour of the Axis speaker icon, represents unmeasured devices.
- **Blue speakers** represent measured devices.
- **Red speakers** represent estimated devices which couldn't be identified.
- **Orange speakers** represent estimated devices identified with limited probability.
- **Green speakers** represents estimated devices identified with high probability.

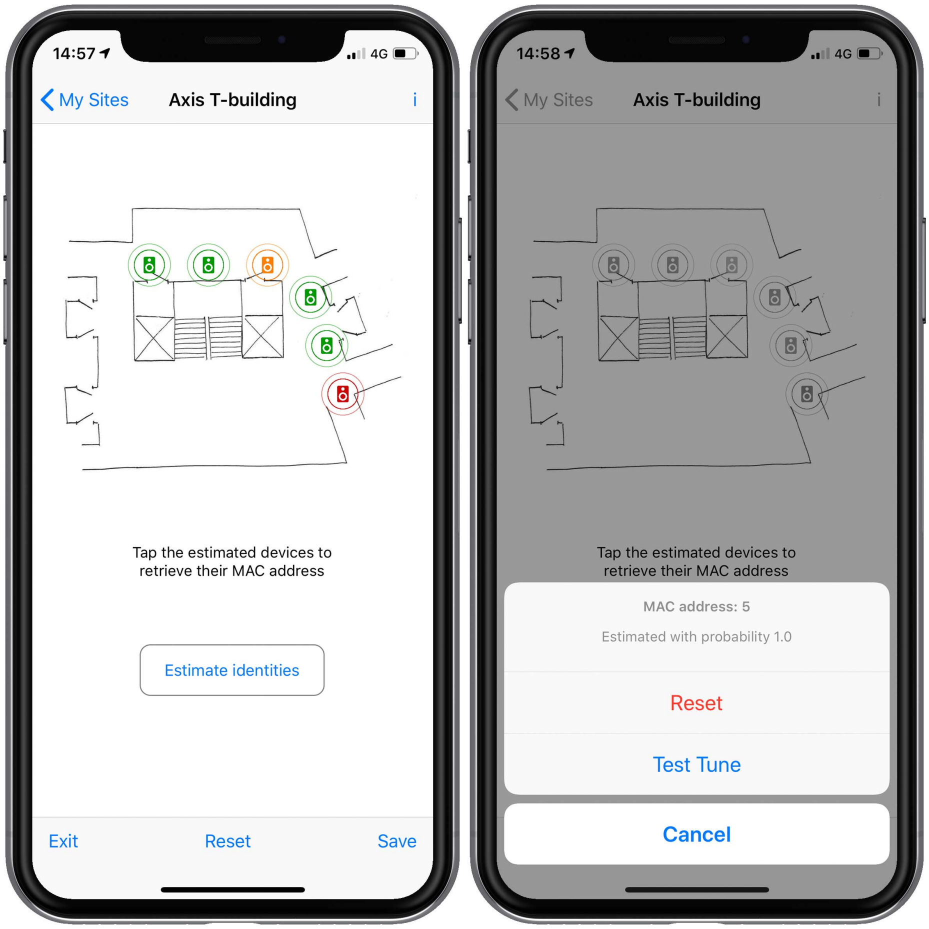


Measuring
Please stand still

Walk to your nearest device and tap the correspondning device on the map above

Walk to the next device and tap it on the map

Figure 8.1: Identification tool prototype measuring in first position (left) and prototype with four performed measureents (right).



Tap the estimated devices to retrieve their MAC address

Tap the estimated devices to retrieve their MAC address

MAC address: 5

Estimated with probability 1.0

Figure 8.2: Identification tool prototype after estimation (left) and prototype after estimation with one device selected (right).

The new colours can be seen in figures 8.1 and 8.2. The colour for estimated devices with limited probability was changed from yellow to orange since yellow had a very bad visibility on the smartphone screen. The decision to use more extensive colours than on the sketches was taken because it became clear during the development that devices which could not be identified could not be green or yellow since this would indicate they were estimated. At the same time, keeping them in the same colour as a measured device would falsely indicate that no estimation attempt had been made. This led to the decision to set the colour of a measured device to blue and to introduce the red colour as the colour of a device with a failed estimation.

In the HiFi prototype, the default iOS return button with the label *My sites* in the top left corner is present. In the final product, this will be removed. Instead, one will be able to return to the start screen, the *My sites* screen, by pressing the *Exit* button. The reason the return button will not be present in the final prototype is because the user is not supposed to be able to return to any screen but the *My sites* screen regardless of potential screens in between. This is to avoid confusion of what has been saved if the user steps back. The return button has not been removed in the prototype because the return button is implemented by default while the *Exit* button has to be implemented manually and because there are currently no screens between the *My sites* screen and the *identification* screen which might cause the confusion.

A few features have not been implemented in the prototype. These include the *Exit* and *Save* buttons, the movement detection using accelerometer, the onboarding screens, the information (i) button and the highlighting of important words. The *Exit* and *Save* buttons were not implemented as they do not impact the application's core feature. The accelerometer functionality ensuring that a user is standing still while measuring was not prioritised as the impact of the feature is unknown. Further, it was not considered a core feature necessary in order to evaluate the application. Onboarding was considered important for the final product, however it was not prioritised for the prototype as available time was limited. We also considered it interesting to see how well users would perform in a usability test without such assistance. The information button was not implemented for the same reason as the onboarding. Lastly the prototype does not contain any highlighted important words since the highlighting was mainly intended for the onboarding.

8.2 Usability Test

In order to evaluate the prototype we designed a usability test and wrote 10 research questions which the tests were to answer. Those were:

1. Can the participant successfully estimate the identities of all devices?
2. Can the participant effectively reset the measurement of one or several devices?
3. Does the participant understand the different functions of the buttons in the GUI?
4. Does the participant understand the meaning of the different colours of the audio icons in the GUI?
5. Does the participant understand that the audio icons are interactive during all stages of the identification process?

Figure 8.3: Image illustrating a user standing under a BLE beacon taking a measurement, as performed in the usability test.

6. Does the participant consider the RSSI measuring time reasonable?
7. Does the participant find it hard to localise their position in the room relative to the map in the application?
8. Does the participant consider the interaction with the application satisfactory?
9. Does the participant consider the complexity of the application reasonable considering the complexity of the task?
10. Is the participant overall satisfied with the application?

The test itself consisted of four steps. The participants were to do the following:

1. Fill out a pre-test questionnaire.
2. Perform two tasks.
3. Fill out a System Usability Scale (SUS) questionnaire [53].
4. Answer post-test interview questions.

The **pre-test questionnaire** was used to collect general data about the participants such as age, gender, educational background and occupation.

During the **two tasks** the participants behaviour were observed. The participants were given case descriptions to perform the tasks. Task one was *estimate the identities of all devices* and task two was *redo one measurement*. The test was performed using an iPhone X. Further six BLE beacons were placed close to the ceiling along the walls and images of Axis cabinet speakers were hanging in front of the beacons to represent speakers. Figure 8.3 displays a user standing in front of a speaker image, using the application.

In the **post-test interview**, 12 questions were asked to the participants. The purpose of the questions was to gain the participants subjective view of the prototype in contrast to the observation of the tasks. The participants were for example asked if they considered the functionality of the buttons clear, if they considered the task troublesome or if they considered the application unnecessary complex. All questions can be found in appendix C.

The **SUS questionnaire** consisted of predefinied statements graded on a five level Likert scale, covering several usability aspects [53]. A SUS result is calculated as a score ranging from 0 to 100 according to a predefined algorithm. The SUS score may not be interpreted as percentage but must be evaluated in relation to the percentile rating of the system in relation to other systems. The average score has been found to be 68 while 82 or higher is reached by roughly 10% of all systems. This is the level where one may recommend the system to others. 85% of all systems reaches higher scores than around 50. Scores below this level are considered unacceptable [54].

The test was held at Axis and the participants were people working at Axis but without knowledge about this thesis project. The participants were recommended through a student coordinator at Axis, who gave us their contact information. They were selected to cover different ages, genders and departments at Axis. In total, five persons performed the test.

The test material consisted of a detailed test plan written according to the guidelines in [50, pp. 65–91], a manuscript to be read to the test participants ensuring everyone got the same information about the test and the two questionnaires. The detailed test material can be found in appendix C.

To ensure that the test material fulfilled the intended purpose and to minimise uncertainties regarding wordings we held a pilot test before conducting the actual tests. The pilot test was held in the same way as the actual tests: with pre- and post-test questionnaires, manuscript and with a post-test interview. One person participated in the pilot test and no test material was changed based on the outcome of the pilot test.

Sections 8.2.1 and 8.2.2 describe the outcome of the usability test and in section 8.2.3, the results are analysed and improvements are suggested.

8.2.1 Participant Characteristics

The participant characteristics derived from the pre-test questionnaire are:

- number of participants: 5,
- number of male participants: 3,
- number of female participants: 2,
- age range: 22 to 31.

All participants had an ongoing, finished or unfinished higher education within the fields of electronics, computer science, information technology or mechanics. The highest finished educational level of the participants is presented in table 8.1.

All participants but one worked at the New Business department at Axis, however none of them worked in the same team or with the same tasks. The professions of the participants varied a lot and included two developers, one mech lead, one tech lead and one product specialist. The participants' experience of camera and speaker installations are presented in table 8.2.

Table 8.1: Educational level of the participants in the usability test.

	Elementary	Upper Secondary	Bachelor	Master	Ph.D.	Other
Amount		2	1	2		

Table 8.2: Number of participants with experience from installation of audio devices, camera devices and audio or camera devices.

	Participation audio installation	Participation camera installation	Participation any installation
Amount	3	2	4

The iPhone usage experience of the participants is presented in table 8.3.

Table 8.3: iPhone usage of the participants.

	Never	Sometimes	Often	Very often
Amount	2	1		2

8.2.2 Test Results

This section presents the observations, post-test interview answers and SUS responses from the usability tests. The collected data is presented as answers to the research questions constructed for the test.

Can the participant successfully estimate the identities of all devices?

Table 8.4: Task success data and completion time for task one.

Participant	1	2	3	4	5
Task success	Yes	Yes (clues)	Yes	Yes (clues)	Yes
Time	5 min	9 min	7 min	10 min	5 min

Success rate: 100%	Average completion time: 7.2 min

The task success rate and completion time for each participant performing task one is presented in table 8.4. The first participant successfully performed task one, which was estimating the identities of all devices, without assistance. Participant two failed to perform the task correctly without instructions from the test leader. The instructions were to not measure from the middle of the room but to measure in every position on the map. The participant was also recommended to read the instructions in the application. Thereafter, the participant succeeded. The third participant was slightly confused about the expected action flow but succeeded when following the instructions carefully. The fourth participant clicked the first device in the middle of the room but quickly realised they had to go to the selected position. The action order of the participant was thereafter correct, however they measured quite far away from every devices and started the measurement before entering the selected positions on the map. Thus, there were many errors in the estimation and the test leader had to ask them to move closer to the devices. The fifth participant performed the task correctly from the start, however they were confused about the save button and tried to save in every position.

Can the participant effectively reset the measurement of one or several devices?

Table 8.5: Task success data and completion time for task two.

Participant	1	2	3	4	5
Task success	Yes	Yes	Yes	Yes	Yes
Time	2 min	1.5 min	2 min	2 min	1 min

Success rate: 100%	Average completion time: 1.7 min

During task one, all of the participants did reset devices which were not green without any clues from the test leaders to do so. Participant two did accidently reset all the devices through the *Reset* button when they wanted to reset in a single position only and participant four did reset all devices individually by clicking them rather than clicking the *Reset* button when they were to reset all devices. As for task two where the participants were explicitly asked to remeasure a device, everybody succeeded without further clues. The task success rate and completion time for each participant performing task two is presented in table 8.5.

Does the participant understand the different functions of the buttons in the GUI?

As presented in tables 8.4 and 8.5, all participants successfully completed both test tasks. This indicates that the participants understood the GUI and the different functions of the buttons well enough not to fail. However all buttons which are present in the GUI were not needed to complete the tasks. The observations and the post-test interview responses made it clear that some functionality was not very straight forward.

The first participant stated that it was not obvious what the term *identities* referred to on the *Estimate identities* button, however the participant did use the button correctly. Several participants got confused by the fact that the *Estimate identities* button became clickable after one measurement, but when clicking it they were presented with a warning asking if they really wanted to estimate since all devices had not been measured. Some participants would rather have had the button not clickable until all measurements were done.

Some confusion arose regarding the buttons in the bottom bar of the GUI: *Exit*, *Reset* and *Save*. Several participants thought that the *Reset* button should have indicated that it performed a reset of all measured or estimated devices by being labeled *Reset All*. Further, the *Save* button confused the fifth participant who first thought that it should be used to save after each taken measurement. The sane participant did not either see the *i* button due to its low visibility and further stated that it was not clear what *i* meant and that a question mark or the label *Help* would be better. No participant tried using the *Exit* button. Participant four stated that it was unclear what the terms *measured* and *estimated* referred to in this context.

Does the participant understand the meaning of the different colours of the audio icons in the GUI?

The majority of the participants had no problem understanding the meaning of the different colours. Everybody understood the difference between the blue, the green and the red audio icons. However several participants stated that the orange colour representing an uncertain estimation was confusing. They thought that an estimation either fails or succeeds and did not understand what the in-between result meant. The majority of the participants who got confused by the orange colour figured out its meaning by reading the text in the action sheet displaying a devices MAC address, where it is written that several MAC addresses could apply to the device. However, one of the participant who got confused by the orange colour did not understand it at all until it was explained during the post-test interview. The participant then stated that due to impaired sight the small text in the action sheet informing about the uncertain MAC addresses had been very hard to read and therefore missed.

Overall the participants liked the colour coding of the audio icons since it indicated which state a device was in and after an estimation it indicated the result in an intuitive manner.

Does the participant understand that the audio icons are interactive during all stages of the identification process?

During the tests no participant had any problem understanding that they could interact with the audio icons, which became clear from observing them. During the post-test interview the participants were asked if they thought it was clear that they could interact with the icons and all of the participants answered yes to this question. Several participants stated that the yellow circle around the icon of an unmeasured device helped to indicate that it was interactive. Participant one explicitly stated that the different colours of the icons made it clear they were interactive and provided different affordances throughout the identification. Further, during the tests no participants appeared confused by the alternatives in the actions sheet being different depending on the state of the device they selected. However two participants stated during the post-test interview that it was confusing to some degree.

Does the participant consider the RSSI measuring time reasonable?

During the tasks, none of the participants mentioned or complained about the measuring time, however the fourth participant did not stand still during the whole measuring process. When the same participant was asked about the measuring time in the post-test interview they answered that they did not consider the measuring time too long. The participant did however say they did not read the instructions carefully and would have liked a warning when walking. During the interview all participants answered that they did not consider the measuring time too long. Several participants mentioned that the progress bar and the informative alert was the reason they accepted the waiting time as they were provided feedback that something was happening. One participant in particular was commenting on the vibration when the measurement was completed as a very good feature as one does not have to look at the phone all the time.

Does the participant find it hard to localise their position in the room relative to the map in the application?

For task one, participant one navigated the room through physical speakers with the help of the map rather than the other way around causing them to almost select the wrong first device on the map given their position. The third participant required about ten seconds to know where to go in the first place. In the middle of the test the fifth participant quickly hesitated they were in the correct position, however seconds later they continued confidently. Otherwise, none of the participants showed any sign of being confused about their position during the test. No participant performed poorly because of the map. In the post-test interview, none of the participants answered that they found it hard to localise their position relative to the map. One participant answered it might be harder had they not known the layout of the particular floor in advance and another said it was easy as soon as they realised where they were positioned on the map. One participant said they would have liked if they manually could rotate the map in order to make it easier finding their way around.

Does the participant consider the interaction with the application satisfactory?

When being asked if they liked the interaction with the application all of the participants answered yes. All participants also stated that the application felt clean and basic and that it did not contain unnecessary features or buttons. Several participants pointed out that they liked the feedback they got from the application and that the short response time of the actions they performed made the application feel professional and nice to use. The first participant commented on favourable placement of buttons allowing for reaching them using only one hand. The same participant also stated it was good that actions did not demand too many clicks. The participant further tried to enlarge the map by pinching it during the post-test interview, however they did not consider the size of the map too small given the low amount of devices to identify. The fifth participant thought that the text sizes in the action sheet and on the main screen were too small resulting in instructions being hard to read and perceive. The same participant was also a bit unpleased by the fact that they had to perform all the measurements before getting an estimation of each device instead of having the MAC address of a device displayed after a single measurement. Another participant considered it slightly inefficient to remeasure an uncertain or failed estimation by first removing the measurement then pressing it again to measure instead of just pressing a *remeasure* button in the action sheet for the measured or estimated device.

Does the participant consider the complexity of the application reasonable considering the complexity of the task?

In the interview all the participants answered they considered the application lightweight, straight forward and not too complex at all. The low set of features was appreciated by all participants as they also considered the task simple and thought additional features would be redundant.

Is the participant overall satisfied with the application?

Given the SUS scores presented in table 8.6, all but one of the participants seemed to be very satisfied with the application since their computed scores lied above 82, which is reached by roughly 10% of all systems. The score of 50, however, is a very bad score and is considered unacceptable.

A prominent cause of confusion and potentially frustration for several participants was unexpected behaviour in the application during the estimation. When some devices were remeasured and a new estimation was made, other devices which were not remeasured could change colour from green to red. This was interpreted as a bug by several participants and ignored.

Table 8.6: System Usability Scale scores.

Participant	1	2	3	4	5
SUS score	92.5	90	90	50	85

Additional inputs and observations

During the post-test interview with participant two, who required additional instructions in order to perform the task correctly, their attitude towards help features which were not implemented in the prototype were discussed. When being asked about onboarding instructions, they said they would accept about three onboarding screens but not more. The same participant said they do not press information buttons as information buttons usually present very much text.

Further, it can be noted that during all of the tests the participants got incorrect estimations despite performing the tasks correctly. This is interesting since when performing the test ourselves repeatedly, we got correct results and only green speaker icons in the GUI. Because all the participants received incorrect estimations, they were all presented with all different estimated speaker icon colours. The results were caused by technology performing badly and not faulty actions by the users. Despite the low technology performance it was concluded that the performance did not affect the test negatively. Rather, it was a good way of observing how the participants reacted to errors in the application. What the bad performance of the technology might depend on is unknown but it may be due to several persons standing near the beacons, affecting the attenuation of the BLE signals.

8.2.3 Test Result Analysis and Improvements

Given a task success rate of 100% for both task one and task two, one may conclude that the HiFi prototype performed fairly well. However the fact that some participants required clues from the test leader in order to complete the tasks indicated that improvements were needed. The SUS scores further indicated a positive attitude towards the prototype from all participants but one. We have not been able to identify any factor which may have impacted the single low SUS score apart from the fact that the participant giving the low score of 50 was the only one who had never participated during installation of either audio or cameras. Since only five persons participated in the test there is no statistically significance in the SUS score result [54], however it gives a indication of the system usability. The variety of participants was not as large as we would have wished for seen to factors such as age range and fields of education but the difference in professions between the participants was acceptable. We did not notice any difference in performance between participants based on their previous iPhone experience.

The following sections present an analysis of the test results from a usability perspective considering the *usefulness*, *efficiency*, *effectiveness*, *satisfaction*, *learnability* and *accessibility* of the prototype. These terms are further described in chapter 3. The sections also suggest improvements of the prototype based on the analysis.

Usefulness

Usefulness refers to whether the product allows the user to fulfil their goals or not [50, pp. 3–5]. During the test, all participants were able to fulfil the tasks they were given, however with various amount of help from the test leader. This indicates that the prototype is useful to some degree. However, the help provided from the test leader needs to be incorporated in the application. Alternatively the application has to be more intuitive and self explanatory to eliminate the need for this help. The SUS score implies that the test participants liked the product and would be willing to use it. It should however be noted that the test participants were not real case users as none of them works as a projector or a fitter. More extensive tests in real case scenarios need to be held with real users in order to ensure the usefulness of the product.

Efficiency

Efficiency relates to how quick a user performs a task [50, pp. 3–5]. The time it took for the test participants to complete the different tasks is displayed in tables 8.4 and 8.5. For task one, which is considered the most interesting task since it includes the complete identification flow, the completion time ranged from 5 to 10 minutes. As we do not have any other time data to compare the time to, it is hard to evaluate whether the time consumed is really good or not. In order to improve the evaluation a comparison test in a real case environment would need to be held, measuring the time consumed performing the identification with and without the application. However, given that all participants were to get familiar with the application, perform measurements of six devices, make one or several remeasures as well as estimate the identities of the devices, a time range of 5 to 10 minutes can be considered good.

Effectiveness

Effectiveness concerns the simplicity of which a user completes a task [50, pp. 3–5]. Since all participants successfully completed the test tasks and further did not consider the application to be complex it can be stated that the participants went through the identification with simplicity, which implies that the application is effective. However some features and behaviours in the application caused confusion among the participants.

One feature causing confusion was the *Estimate identities* button becoming clickable after one measurement. This is because it should be possible for a user to only estimate a few number of device. For example if only five out of 35 device identities are of interest it should not be required to estimate all 35 of them. Because of this, the button will remain clickable after one measurement.

Another cause for confusion was the orange colour on an identified device with uncertain probability. In order to avoid this confusion the label in the action sheet which tells the user about the uncertainty has to be more visible. Visibility can be increased by increasing the font size of the text.

Further, some participants became confused when an already estimated device which had not been remeasured changed estimation probability after a new estimation had been performed. This is a result of how the data model is implemented in the application. When making a new estimation with new measurements, all devices will be re-estimated and not only the ones that were remeasured. Thus, since the estimation algorithm computes estimations based on all measurements there is a risk of already computed estimations to change values if the BLE signals fluctuates. An alternative would be that the data model only re-estimates the devices with new measurements, however this could cause even more uncertain estimations if the user remeasures only a few devices. In order to solve the issue the conceptual model of the application needs to be reworked. Due to limited time this has not been investigated further in this thesis work.

The decision that one has to measure all devices before performing the estimation is a decision based on technical limitations rather than a preferred interaction flow. It would be desirable to be able to retrieve the MAC address directly when performing a measurement. However that is not possible considering that the algorithm computing the estimation requires several measurements from different locations, due to the low performance of the BLE beacons.

Another thing which affects the effectiveness is to what extent a user performs the measurement carefully. Accurate estimations require the user to stand still and to be in the right position during a measurement. To keep users from moving while measuring and to make sure users understand they need to be close to the device, we suggest that an alert pops up the first time a user measures a device. The alert should present an instruction image of a person holding a phone near a device and a text asking the user if they are near the device. The alert should also inform the user that they have to stand still while measuring. Further a constraint, based on e.g. accelerometer data, which alerts the user to stand still if they happen to walk while measuring may be helpful.

To further improve the effectiveness an alternative to *Remeasure* should be added to the action sheet for measured devices so that a user must not do both reset and measure in order to remeasure. The *Reset* button in the bottom bar should be renamed *Reset all* to avoid confusion and to prevent users from pressing *Reset* on every device separately when they actually want to reset all. Also, what it means to click the *Save* button needs to be clearer. This might be clarified in the onboarding instructions. Alternatively, the site could be auto saved rather than manually saved to avoid the need to click the *Save* button. In such a case, the *Save* button would be removed. Whether auto save would be clearer or raise confusion must be tested.

Lastly, none of the participants had a hard time navigating using the map. A feature to rotate the map was however requested and should be added to the final product together with a feature of zooming the map by pinching it, which was also requested during one of the post-test interviews. This might enhance effective use of the map.

Satisfaction

Satisfaction concerns a user's perception, feelings and opinions [50, pp. 3–5]. The test results show that the participants seemed overall satisfied with the product. They did for example like the colours, the feedback and the placement of the different buttons. Many liked the clear and basic GUI that did not contain unnecessary features. An important outcome was that none of the participants thought the measuring time was too long, mainly because of the feedback they received from the progress bar.

Learnability

Learnability refers to the ease of learning how to use a product [50, pp. 3–5]. During the test, only two out of five participants needed clues to complete task one, according to table 8.4. This means that three participants successfully learned how to correctly perform the task using only the instruction in the application. This can be considered an acceptable result given the early state of the prototype, indicating that the learnability of the prototype is fair. The goal however is that all users should be able to learn the application without assistance. This implies that the application needs to provide more and better instructions.

To increase the learnability the final product needs to have intuitive and easy-to-follow onboarding instructions. This has already been mentioned in chapter 7. The onboarding should present the installation flow in short and emphasise the importance of standing still and being near a device when measuring. The onboarding should also contain an explanation of the different colours of the audio icons plus make it clear what the terms *measured* and *estimated* refers to. The onboarding slides must not be more than three or four, motivated by the input from one participant who during the post-test interview stated that they never read onboarding instructions unless they are few in amount.

No participant tried to use the *i* button to get help during the tests. This might be due to its low visibility and therefore it should be changed from *i* to *Help.* That would hopefully increase the visibility and would serve as a better signifier.

Accessibility

Accessibility refers to a product's ability to be used despite different prerequisites and disabilities of users [50, pp. 3–5]. During the test, in particular one participant who had impaired sight found it troublesome to read the small instructions text and the small action sheet text. Thus, the application was not very accessible for people with impaired sight. Therefore the text size must be increased. The application does not require the user to listen, which makes it usable for people with hearing impairments. Colour blindness might be an issue as information and signifiers are coded in colour. This has to be investigated further. The application is not dependent on double taps or force sensitive clicks, such as Apple's force touch. However, the application has not been tested with motorically impaired users. Whether the application is accessible for people with other variations is hard to tell since we do not have any test results to refer to.

8.3 Requirements Checklist

We also evaluated the HiFi prototype by using the list of requirements created during the *Establish Requirements* phase as a checklist. These requirements are presented in table 4.5. In the evaluation we went through all the requirements of the list and checked if the prototype fulfilled them or not. Some requirements are mapped to concrete features while other require extensive usability testing in order to be answered confidently. To answer whether some of these requirements were fulfilled or not, the usability test results from section 8.2 were used. The result of the checklist evaluation is presented in table 8.7, where the column *Fulfilled* has four alternatives:

- *Yes* - the requirement has been fulfilled,
- *No* - the requirement has not been fulfilled,
- *Partly* - the requirement has been partly fulfilled,
- *Not tested* - fulfilment of the requirement has not been tested.

In the following paragraphs the requirements which were not tested or not fulfilled are discussed and improvements for those are suggested.

The requirement *must be easy to communicate* was added in order to minimise the risk of communication errors between the system integrator and the fitter if the devices were to be identified by the fitters prior to mounting. As the prototype is implemented for the identification to be made by the system integrator and not the fitter, the importance of the requirement has decreased and thereby the reason to extensively test the requirement.

The requirements regarding earmuffs, visor and gloves are not yet tested, however they need to be tested prior to potential release of the tool. Good actions to support such requirements are increasing the font size in the application as well as introducing zoom support on the map, which allows increasing the size of the device icons and the space between icons.

Must not require a phone is a requirement which was written with the fitter in mind. The projector or system integrator however, is already required to use a stationary, portable or hand held computer in order to perform their duties. Therefore it is not important for a *identification after mounting* tool to fulfil this requirement.

The requirement *must not require that the projector uses ASD* has not been supported as the prototype is in a too early state for such features to be implemented. The intended work flow of the tool does however support the projector

Table 8.7: Result from the requirements checklist evaluation.

Requirement	Importance	Fulfilled
Must not include writing by hand	High	Yes
Must be easy to communicate	High	Partly
Must not require physical maps	Medium	Yes
Must work even if the user wears earmuffs or visor	High	Not tested
Must work even if the user wears gloves	Medium	Not tested
Must not require a phone	Low	No
Must not require that the projector uses ASD	High	No
Must be possible to use with different languages	High	No
Must support identification of audio bridges	Medium	Yes
Must support phone placed in waterproof case	High	Not tested
Must be possible to use with impaired sight or hearing	Medium	Partly
Must include effective device mapping	High	Yes
Must not depend on a quiet environment	High	Yes
Must support varying knowledge of IT	High	Partly
Must support varying demographic parameters	Medium	Partly
Must support wireless pre-naming	Low	No
Must not require pre-naming	High	Yes
Must not require IT infrastructure	High	Yes
Must not require a blueprint	High	Yes
Must not require a ladder	High	Yes
Must support identification in buildings with high ceilings	High	Not tested

to prepare the map and export the identified map into Audio Manager without using ASD. The same goes for the language support requirement which could easily be introduced in the tool.

The requirement *must support phone placed in waterproof case* has not been tested due to the limited time span. However, the use of a waterproof case might not only affect the user's ability to read text on the screen or press certain buttons but also to what extent the device will be able to receive wireless signals. This may not be a critical issue in theory but has to be tested before product release.

Fulfilment of the *must be possible to use with impaired sight or hearing* requirement is set to partly as the service is designed not to rely on hearing and because one participant of the test has impaired sight. Testing for this specific group would be required to confidently call this requirement fulfilled. The same motivation goes for the requirement concerning varying knowledge of IT, where only one participant in the usability test claimed to have limited knowledge of IT.

Different demographic parameters has only partly been tested due to limited possibilities to collect test participants from a wide range of user groups. The aim of the participant selection was to at least collect users working in various fields of IT, which has been fulfilled.

Wireless prenaming refers to giving the devices nice names without connecting them to a computer. This requirement is specific for the case in which one wants to identify the devices prior to mounting, which is not necessary given the work flow for which the prototype is designed. A product form fulfilling the requirement is presented in figure 5.5.

Must support identification in buildings with high ceilings is the requirement which demands the most attention of the not yet investigated ones while requiring the highest amount of work. Limited testing has been made, which is presented in figure 7.4. The figure implies the possibilities of the technology, however a more sophisticated algorithm then the one used in the prototype is needed in order to successfully perform the task for high ceilings with high accuracy.

Chapter 9

Discussion

In this chapter some final thoughts about the tests and the HiFi prototype are presented. It is discussed how the identification tool could be used in a larger context and the chapter ends with a short evaluation of the project.

9.1 Sources of Errors in the Tests

For both of the tests the selection of participants was not as good as we would have wished for. It turned out to be hard getting in contact with fitters and projectors, which is something we had not foreseen. Our intention was to participate during an installation and to talk to fitters and projectors, both during the data gathering process and during the LoFi and HiFi evaluations. We did not get the opportunity to do any of this but we have, to the best of our abilities, made research within Axis in order to get an understanding as broad as possible for the users and the problems they encounter. However we can not be certain that we have identified the most significant problems.

In the test of the LoFi prototypes the participants were students within the same field of education as ourselves and in the test of the HiFi prototype all participants were working at Axis. None of the participants in any of the tests were real case users with experience of installations. Even though some of the participants in the HiFi test had been present during installations, none had worked as a fitter or projector making it hard for them to empathise with the profession. As a result of no real users participating in the tests, it is hard for us to say anything about the usefulness of the identification tool we have developed.

During the test of the HiFi we used images of speakers mounted with tape in the ceiling. This may have affected the test result since the participants could have thought the entire flow was mocked which may have led them to not understand that the paper speakers actually had the functionality of the hidden BLE beacons. Thus, all participants may not have realised the importance of walking close to the speakers.

Another phenomenon worth discussing is the high SUS scores from the participants in the test of the HiFi. It is remarkable how high they were given the low set of implemented features and the limited accuracy of the estimations. One reason for this might be that the participants filled out the SUS questionnaire as if the application had worked correctly. Meaning they filled it out given how they were thinking the application would behave if it had been fully implemented, ignoring bugs or non-existing functionality.

Overall the tests were of great importance for the project and a lot of useful results came out of them, however they were not as extensive as they could have been. As stated in chapter 8, more tests with real case users in real case scenarios must be held if the identification tool is to be further developed.

9.2 Uninvestigated Requirements and Use Cases

The suggested identification tool presented in this thesis must support the case of moving devices into new places. Such a case has not been covered in the scenario section, however this functionality could be integrated into the tool. A suggestion would be to introduce a *remove device* action. In the same manner, a *plot device on map* should be implemented to add the device again. These options should not be included on the *identification* screen of the prototype but favourably be presented on a *modify site* screen which looks similar to the *identification* screen. From a technical perspective, the newly plotted device will require a new measurement unless a device object can be moved instead of removed. The flow of moving a device between maps might however be complicated and has not been considered conceptually. Technically speaking, scanning for a single new device on a map is easy as the speaker would be assigned the single newly received MAC address, which is not already discovered on the map. For several new devices, one would have to scan in every place where speakers have been mounted and perform a new measurement for the newly added devices. Note that this suggestion differs from the implementation where new devices would trigger a new estimation of all devices. Further investigations would be needed to determine what is the most suitable choice for the estimation algorithm.

Displaying a map on a small smartphone screen may be a complicated task given that maps are likely to be static. The possibility to zoom is important, while there has to been some kind of assistance which helps the user to understand which area of the map has been zoomed onto. Splitting the map into several images which cover different floors and zones may also be a possibility where the user can swipe between relevant maps for a site. In the work of this thesis it has been challenging to access real case material, including maps. Therefore, the presented solution is based on our interpretation of what maps might look like. However several types of site maps may not have been considered, thus the solution may not be suitable for some cases. Therefore a version of the application not requiring a map is important. In the map free version, the user must be allowed not to use a map but rather nice names together with a physical map. The version without a map would have a similar design but present a list of nice names instead of a map, allowing the user to select a device element in the list or search for the device if the list is long. Colour coding of devices may remain the same.

The BLE beacon technology has proved to be more challenging to use for a robust solution than expected. All tests showed that as the distance between the smartphone and the devices increases, so does the noise and inaccuracy. Therefore, fairly successful results has been accomplished for low ceiling heights but not for high ceiling heights. However more environmental test data as well as new estimation models would have to be analysed in order to determine if the BLE technology is suitable for the presented case.

Another drawback of the BLE beacon solution is its inability to be combined with devices not supporting BLE identification. In case new speakers are introduced with BLE technology, one has to part BLE speakers from non BLE speakers both when preparing the map and when performing the identification in the application. The non BLE beacon devices simply cannot be identified using the proposed tool.

Also, in the proposed solution there is no feedback from the speakers in case a BLE beacon stops working. Thus, if one device stops broadcasting the complete estimation could be inaccurate without precise feedback to the user about the speaker not working correctly. Potential solutions to come around this, e.g. a self diagnostic features where speakers can announce errors on the network, must be investigated. This would however require a running network connection.

Further, how the BLE beacons are to be powered has not been covered in this thesis. A suggested solution would be to include a battery which is charged when the speaker is connected to power. However, for how long these batteries could power the beacons and for how long they are required to power the beacons in order to carry out the identification must be investigated.

9.3 Market Launch of the Identification Tool

The scope for the thesis has been to investigate and solve the identification problem, resulting in an application only for that purpose. It is however relevant and interesting to investigate how the identification tool could be used in a larger context and which gaps in the current installation process it would fill.

During the work with the thesis we have considered different flows and procedures for how an installation can performed using our developed identification tool. One scenario we consider suitable is the following:

1. A projector uploads a map of the site to be designed into ASD. The quality of the map could range from a picture of an evacuation plan to an advanced blueprint.
2. The projector designs the desired set-up in ASD, this includes amount and placement of devices as well as configurations for the devices.
3. The design, including the map and all devices with associated configurations, is exported from ASD and imported to the identification tool.
4. The devices are mounted.
5. The identification tool is used to identify the devices.
6. The information about the identities is exported to Audio Manager and the pre-made configurations for individual devices can be applied.

In the above described scenario the identification tool is used in step five while the other steps provide the larger context. Given this scenario it would further be possible for a projector or a fitter to perform the identification, depending on who is the most suitable seen to technical skills and provided time. One of the requirements we set up during the *Establish Requirements* phase was that the tool should not demand usage of ASD, see table 4.5. We still consider this an important feature and therefore encourage any future identification tool solutions to include an opportunity to create and modify sites, as described in the storyboard in figure 5.6 as well as in section 9.2.

According to the theory about conceptual and mental models [49, pp. 86–88] it is important to offer *appropriate online help and tutorials* and *context-sensitive guidance providing help at the correct level of experience* in order to better match a conceptual model with the mental model of the user. As of this, we would recommend that Axis provides easy and clear instruction of usage for the identification tool on their website. This could take the form of videos displaying how to perform the identification, or slides with easy-to-follow text instruction supported by descriptive images. This would serve as a complement to the onboarding and instructions provided in the application itself.

In case a BLE solution is to be implemented, additional hardware has to be added to the speakers. If this would be profitable for Axis is affected by how much time the tool would save. In practice, the additional hardware cost per speaker must exceed the cost in installation time saved. Installation time saved would differ greatly between projects and any estimation would require more real case insight than we have had the possibility to gain during the thesis work. Given that the hardware is introduced, that the actual positions of speakers are registered accurately and that there are enough speakers installed, one possibility would be for the additional hardware to serve as an indoor navigation system after the identification. The value of such a system is not known, but could add to the product value. An indoor positioning system where the receiver is placed within the user's device make such a system only active if the user wants to, which make unwanted surveillance technically impossible which is ethically good.

Connecting the speakers to a wired network which has no wireless access points might be used as an argument for security as it complicates break ins. Introducing a wireless BLE module might affect the user's trust to the security, since it seemingly would provide a way to reach the speaker. By using a separate BLE module however, the actual speaker device would remain unreachable through wireless networks. This has to be clearly conveyed to the customers of the system, possibly by making the BLE module physically separate from the rest of the device. To what extent this would affect the user's trust to the security is unknown but should be further investigated.

9.4 Interaction Design Decisions

One of the main challenges encountered during the design of the tool has been to introduce relevant constraints. Above all, introducing a physical constraint demanding the user to stand in the right position during RSSI measuring was hard. Therefore, the prototype supports faulty actions it cannot detect, which means it is possible for a user to measure in the wrong position but still get a seemingly correct result. Thus, the user must know how to perform the task correctly in order to gain a successful result. This might affect the match between the conceptual and the mental model [49, pp. 86–88].

During the exploratory test described in chapter 6, the participants suggested that a live indication of their walking direction when performing the identification could ease the navigation. This could be implemented using the geomagnetic sensor of a smartphone, however due to limited time this was never investigated during the thesis work. To further investigate if such a guide would be valuable could be interesting from an interaction design perspective, since it potentially could enhance the mapping between the spatial room and the map in the application.

Several design decisions have been made according to the official guidelines for iOS application, however, if the tool is to be launched it would have to support more platforms than iOS. For the Android platforms different design components might be used, requiring some redesign of the application. The main parts of the GUI, which is the map and the speaker icons, would however remain the same. The design is overall platform independent and could run on a tablet, a smartphone or as an augmented reality application even though some adjustments would have to be made.

9.5 Project Evaluation

After the finished thesis work it can be stated that we, to some extent, have achieved our defined goal within the allocated time frame. The research questions constructed during the initial phase has acted as a frame for the work and has throughout the project been answered with as high accuracy as possible given the available resources. The time plan written during the initial phase has been revised during the project but all the activities we had planned for have been carried out, only to different extents.

When we decided to work with the BLE technology, the theory had given us higher hopes for good results than we actually achieved in practice. Therefore, the time plan did not include as much time for BLE technology optimisation and evaluation as we would have needed in order to thoroughly answer whether the technology is usable for the intended purpose or not. Also, the time put into investigating the performance of the BLE technology led to us having less time implementing features in the HiFi prototype. However, many components from the BLE test application could later be used in the HiFi prototype which led to us being pleased with how far we got with the prototype after all.

Lastly, as presented in the process section 1.6 the identification tool flow and design has been evaluated separately from the technology. Thus, other technologies such as sound may also support the flow and design of the proposed solution.

9.6 Related Fields and Future Envisions

During our work we have not been able to find any tool similar to the one we have implemented. We have however identified fields in which similar technologies are used. One such field is indoor positioning, from which some of our theory is retrieved. With the growth of IoT, it is likely that other fields will appear where identification of network devices will be of interest, especially for industrial use. Therefore it is of interest to widen the perspective of IoT devices which might be identified by the identification tool. It is also of interest to widen the perspective of contexts in which the identification tool may be integrated. An example of a context which might benefit from effective device mapping and simple identification is a building site of an apartment complex for renting or a new office building where IoT devices are integrated into the building design already at planning stage. For these scenarios, smart and dynamic maps may be used from start. These maps may introduce even more efficient and robust identification flows which may be more automised than the proposed solution.

Chapter 10

Conclusion

In this thesis we have achieved the objectives of gaining a deeper understanding of the installation process, including assisting software, hardware and the needs of actors participating during the audio installation process. Based on the target group and their prerequisites, we have designed and investigated two solutions, more extensively one of them, for improving device identification and ease the installation process.

The more investigated solution was implemented as an iOS iPhone application communicating with Bluetooth Low Energy (BLE) beacons. As the application is a prototype, the amount of features in the tool is limited, however the functionality is sufficient to illustrate the concept. The usability tests showed that the design and flow of the application was considered simple and intuitive, however the BLE technology used for performing the identification needs to be further investigated in order to achieve desirable and reliable results.

The most prominent source of error during the thesis work is the assumptions made about the end users. All research questions related to the fitters have been answered through interviews with Axis employees, making their validity limited. Efforts were made to reach the actual target group but this never became possible.

The thesis has not presented a solution for identification of existing network devices. Rather, it has presented a scalable product concept which may simplify identification of any new device that supports the concept. Further, the proposed tool would reach its full potential first when other software used in the installation process provide features compatible with the tool.

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Appendix A

Interview Questions

- Can you describe the workflow of an installation?
- What are known problems, requirements and requests of system integrators and fitters?
- How much time is available for an installation? How is this time span perceived?
- What does the typical installation site look like regarding size and background noise?
- What assisting tools are available today?
- What equipment is available for system integrators and fitters today?
- What are the options for support and by whom is the support provided? Are there any frequently asked questions?
- What education, instructions and experience do system integrators and fitters have related to Axis products?

Appendix B

LoFi Prototype Test Documents

B.1 Test Plan

This is a test plan for two LoFi prototypes constructed based on the cases described in the storyboards of the product concept in the thesis. The scope includes the identification process only. The test consists of two parts named A and B, where part A includes a physical map and device scanning and part B includes a digital map and automatic device detection based on a route. Part A of the test starts after the system has been designed using ASD and the map has been printed and part B starts after the map has been created and the devices have been mounted.

B.1.1 Objective

The tests are made to evaluate the workflows of the proposed installation processes and not the graphical user interface layout.

B.1.2 Selection of Participants

The test will be carried out with two participants, 23 and 24 years old respectively, both having backgrounds within interaction design. They will be familiar with LoFi interaction and think-aloud methodology.

B.1.3 Equipment

The participants will have access to the following equipment performing part A of the test:

- One paper floor plan with plotted devices
- One LoFi prototype of a smartphone identification tool
- One Axis Cabinet Speaker
- One Axis Audio Bridge

The participants will have access to the following equipment performing part B of the test:

- One LoFi prototype of a smartphone identification tool

B.1.4 Tasks

The tasks for part A and part B of the test are described in tables B.1 and B.2, respectively.

Table B.1: The task for part A of the test.

Task	Subtask
Mount three devices according to the provided map. Identify the devices as they are mounted using the provided LoFi prototype.	1. Select device to start mount 2. Unpack device from box 3. Find the device ID printed on the map 4. Select the corresponding device ID in the list provided in the prototype 5. Scan the QR code on the device using the prototype 6. Mount the device 7. Continue with the next device and repeat steps 2-6

Table B.2: The task for part B of the test.

Task	Subtask
Pair MAC addresses of the physical devices to the previously plotted devices on the map in the smartphone identification tool.	1. Determine a path to walk in the smartphone identification tool by clicking each plotted device one by one in the identification tool. 2. Enter the physical space of each plotted device. Continue the path as each device in the tool turns green. 3. Save the finished map with all paired devices.

B.1.5 Execution

The two parts A and B will be performed by the participants individually. One participant will start with part A and the other with part B and thereafter the participants switch parts. Two test leaders holding one part each will be present. The test will be performed as follows:

- The participants arrive to the test site.
- One test leader will read the background description presented in section 2.1 to one of the participants. The other test leader will read the background description presented in section 2.2 to the other participant
- The participants will perform the part related to the background description presented to them.
- Step two and three will be repeated as the participants switch parts.
- When both participants have finished both parts, the participants and the test leaders will sit down to have a discussion based on the questions presented in section 3.

B.2 Background Description

These are the background descriptions which will be read to the participants before the tests. For both tests, the test leader should also inform the participant that this is a test of a LoFi prototype during development and encourage the participant to think aloud.

B.2.1 Part A Description

You work as a fitter and has been assigned a job at the Axis T-building in Lund. You are about to mount three audio devices according to a map provided by your employer. During the mounting, you also must identify the devices using an installation application running on your work phone. The cabling is already done so all you must do is mount and identify the devices. Here is the map, the phone running the application and the devices.

B.2.2 Part B Description

We are currently standing on a site owned by your customer. You have been hired to install a set of network speakers on this floor. You have previously decided how many devices you want and where you want them to be mounted. You have hired a fitter to mount the devices. Before you can deliver the system, you need to configure the speakers. On this floor, you want each device to have individual settings based on their placement, as your customer is to play softer music closer to the dining tables etc. These settings are available through the web interfaces of the speakers; however, you don't know the speakers' identity in the network beforehand. Devices are identified in the network using their MAC addresses. In order to perform the configuration correctly, you want to map the MAC address of each physical device to the devices on your map. You will be given a phone with the required application only. Your map is in the application.

B.3 Post Test Questionnaire

B.3.1 Questions for Part A

- How did you experience the installation flow? What was hard? What was easy?
- Was there any part of the process feeling unnatural?
- How did the actual installation flow match your expectations?
- To what extent were you able to identify with the role of a fitter?
- To what extend did you understand the purpose of the application?
- To what extent did the experience feel authentic to you?
- How would you approach the task without the assistance of the application?
- Was there any part of the task where you experienced the instructions to be insufficient?
- Did the task demand a high level of attention?
- In the case of mounting a high number of devices, what would you think would demand the highest work load?
- In the case of mounting a high number of devices, is there any way you would have tweaked the workflow to make it more efficient or simple?

B.3.2 Questions for Part B

- Did the interface make you confused? Why? Why not?
- Were any instructions given by the application hard or confusing to understand?
- How did you experience the identification flow?
- How did the actual identification flow match your expectations?
- To what extent did the experience feel authentic to you?
- What kind of feedback would you have desired from a real case system in order to feel confident performing the task correctly?
- How did you experience navigating using only the floor plan in the application?
- Did the time required to perform the task meet your expectations?
- Did the task demand a high level of attention?
- In the case of mounting a high number of devices, what would you expect to be the biggest challenge?

B.3.3 Final Questions

- Did any of the test parts feel easier than the other? Why? Why not?
- Did any of the flows feel more efficient that the other? Why? Why not?
- Did you experience that the different tasks required different skill levels?
- Did you feel like solving the same problem in the different parts of the test?
- Did the second part of the test feel easier to you due to experience from the first part?
- Did the first part affect your expectations of the second part? In what way?

Appendix C

HiFi Prototype Test Documents

C.1 Test Plan

This is a test plan for the test of the HiFi prototype in the master thesis. The test is a usability test for evaluating the prototype and its GUI.

C.1.1 Purpose and Goals

The purpose of the test is to evaluate the implemented HiFi prototype of the Audio Identification Tool in order to identify usability problems which need to be fixed before developing the final product.

C.1.2 Research Questions

The test will focus on the following research questions:

1. Can the participant successfully estimate the identities of all devices?
2. Can the participant effectively reset the measurement of one or several devices?
3. Does the participant understand the different functions of the buttons in the GUI?
4. Does the participant understand the meaning of the different colours of the audio icons in the GUI?
5. Does the participant understand that the audio icons are interactive during all stages of the identification process?
6. Does the participant consider the RSSI measuring time reasonable?
7. Does the participant find it hard to localise their position in the room relative to the map in the application?
8. Does the participant consider the interaction with the application satisfactory?

9. Does the participant consider the complexity of the application reasonable considering the complexity of the task?
10. Is the participant overall satisfied with the application?

C.1.3 Data Collection

Table C.1: Data to be collected for each research question.

Question	Objective/ Quantitative	Objective/ Qualitative	Subjective/ Quantitative	Subjective/ Qualitative
1	Successfully executed, amount of time consumed	Errors, comments from participants		
2	Successfully executed, amount of time consumed	Errors, comments from participants		
3		Errors, comments from participants		Post-test interview
4		Errors, comments from participants		Post-test interview
5		Errors, comments from participants		Post-test interview
6		Observations, comments from participants		Post-test interview
7		Observations, comments from participants		Post-test interview
8				Post-test interview
9				Post-test interview
10			Post-test questionnaire	Post-test interview

C.1.4 Tasks

The two tasks of the test is presented in table C.2.

Table C.2: The test tasks.

Task	Sub-tasks	Successfully executed	Maximum time
Estimate the identities of all devices.	1. Measure RSSI data at a position corresponding to a position on the map in the application. 2. Repeat step 1 until all locations have measurements. 3. Estimate identities.	The participant can show the test moderator the MAC addresses of all devices.	10 minutes.
Redo one measurement.	1. Measure RSSI data at four positions corresponding to positions on the map in the application. 2. Reset the third taken measurement. 3. Measure in the same position again.	The participant resets the third measurement by clicking the device that is to be reset and thereafter the participant takes a new measurement at the same position.	5 minutes.

C.1.5 Execution

The test will take place in an office environment at Axis. The participants will get instructions on site and will fill out a pre-test questionnaire and thereafter they will move on with performing task one and two. When the tasks have been carried out the participants will fill out a post-test questionnaire and a post-test interview will be held.

C.1.6 Selection of Participants

A total of 5 participants will perform the test. These will be selected from within Axis and the goal is to get participants of different age, sex, educational background and from different departments. Further the participants should be used to handle a smartphone, preferably an iPhone.

C.1.7 Equipment

The equipment to be used is:

- An iPhone running the identification tool
- 6 BLE beacons
- 6 pictures of speakers to indicate the speaker's positions

- Observation protocol
- Pre-test questionnaire (on paper)
- Post-test questionnaire (on paper)
- Pencil

C.1.8 Test Moderators

Two moderators will be present during the test. One will act as a test leader explaining the tasks and one will act as observer filling out the observation protocol.

C.1.9 Report Findings

The findings will be summarised and analysed in the master thesis report.

C.2 Pre-test Questionnaire

The pre-test questionnaire consisted of the following questions:

- Age (free text)
- Gender (Male/Female/Other)
- Highest completed degree (Elementary/Upper secondary/Bachelor/Master/Ph.D./Other)
- Educational specialisation (free text)
- At what department at Axis do you work? (free text)
- In which team at Axis do you work? (free text)
- What is your work area? (free text)
- How often do you use an iPhone? (Never/Sometimes/Often/Very often)
- Have you participated during an installation of camera devices? (Yes/No)
- Have you participated during an installation of audio devices? (Yes/No)

C.3 SUS Questionnaire

The SUS questionnaire consists of the following questions:

1. I think that I would like to use this product frequently.
2. I found the product unnecessarily complex.
3. I thought the product was easy to use.
4. I think that I would need the support of a technical person to be able to use this product.

5. I found the various functions in this product were well integrated.
6. I thought there was too much inconsistency in this product.
7. I would imagine that most people would learn to use this product very quickly.
8. I found the product very cumbersome to use.
9. I felt very confident using the product.
10. I needed to learn a lot of things before I could get going with this product.

C.4 Interview Questions

The following questions were asked to the participant during the post-test interview:

1. Do you have any spontaneous thoughts about the product?
2. Did you consider the functionality of the different buttons in the GUI clear?
3. Did you consider the meaning of the different colours of the audio icons clear?
4. Did you consider the different colours of the audio icons meaningful?
5. Did you consider it clear that the audio icons are interactable?
6. Did you consider it confusing that the options of the audio icons changes during usage?
7. Did you consider the time for a measurement too long? Why/why not?
8. Did you consider it hard to navigate using the map in the application?
9. Did you consider the application nice to use?
10. Did you consider the task to be troublesome?
11. Did you consider the application to be unnecessary complex?
12. Was there anything else you though was good or bad?