University of Bergen

Department of Information Science and Media Studies

Master Thesis

FireTracker:
Using beacons and indoor positioning to enhance firefighter's training exercise scenarios

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Author: Edvard Pires Bjørgen
Supervisor: Barbara Wasson
Co-supervisor: Jo Dugstad Wake

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"There’s a time and place for everything, but not now"

Oak, 1998

Abstract

This master thesis presents the FireTracker Indoor Positioning System (FireTracker) for tracking movement of firefighters in cold smoke diving exercises. The research presented in this thesis is a part of the iComPAss project (Inquire Competence for better Practice and Assessment), a collaboration between NORCE (Norwegian Research Center) and the University of Bergen. The research went through design and development that included testing and feedback from Sotra Fire and Rescue Service (SFRS). Much of the development in this thesis was done with a co-student.

This Design Science research project engaged four iterations of design, development and testing. The result, FireTracker, comprised of a mobile application, a web application, and a back-end server. With the use of Bluetooth beacons, the system was able to create visualizations based on firefighter movements in an exercise building.

The two first iterations ended with a test of the system, followed by an interview. The prototype was tested with the SFRS in these iterations. The third iteration ended with a heuristic evaluation with four IT-students. The feedback given from these tests was used to further improve the prototype.

In the final evaluation, the prototype was field trialled with the SFRS in a live exercise. The system was tested multiple times in several sessions. After the test, the firefighters involved in the testing were interviewed and given questionnaires to assess their opinions of the system.

The results presented in this research are based on the analysis of the data collected in the evaluation of the final prototype.

Acknowledgment

I would like to thank my girlfriend Vivian for being an incredible moral support during the research. This thesis would’ve been a lot harder to finish without her.

Also, I would like to thank my supervisors Barbara Wasson, and Jo Wake for their help and support, and valuable feedback on the thesis.

Lastly I would like to thanks the guys in my office space, room 642, "Big D-ata Boys", for motivation, huge distractions, and giving me great ideas and input on the thesis.

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Glossary

ABL Android Beacon Library

API Application Programming Interface

BLE Bluetooth Low Energy

DOM Document Object Model

GPS Global Positioning System

HTTP Hyper Text Transfer Protocol

HVL Western Norway University of Applied Sciences

iComPAss Inquire Competence for Better Practice and Assessment

JSON JavaScript Object Notation

IPS Indoor Positioning System

LA Learning analytics

MMLA Multi modal learning analytics

REST Representational State Transfer

RFID Radio Frequency Identification

SDK Software Development Kit

SFRS Sotra Fire and Rescue Service

SLATE Centre for the Science of Learning & Technology

UI User Interface

UX User Experience

Chapter 1

Introduction

In modern society, the need to adapt, learn and continously develop skills is changing and highly necessary. For society to function properly it needs a competent workforce that stays on top of new challenges and can easily adapt to new ones. A key element in maintaining workforce competency is the quality of training and educating; on which there has to be a continuous focus. This also introduces several challenges. One of these challenges is to maintain an overview of needs, competence, and development of these, so that decision-makers can make informed decisions about learning and teaching (Netteland et al., 2017).

The research presented in this thesis is a part of the iComPAss project (Inquire Competence for better Practice and Assessment), a collaboration between NORCE (Norwegian Research Center)[1] and the University of Bergen. The project's goal is to investigate how to support data-driven decision-making by individuals, instructors, and leadership, and also aims to develop a unique approach to planning and monitoring professional competence development. The iComPAss project is focused on two professional disciplines that want to raise the quality of their education and training. The first is a Masters program for Organization and Management (Health and Welfare line) at Western Norway University of Applied Sciences, campus Sogndal, and the second is Sotra Fire and Rescue Service (SFRS)[2] (Netteland et al., 2017). This research focuses on the latter.

Firefighter education in Norway consists of three parts: An internal course at the fire department; a web-based course; and, a basic course offered by the Norwegian Fire Academy (NBSK). The practical training and education is provided by the individual fire departments and only after passing this can candidates take the courses at NBSK. The fire department is responsible for the different practical routines and ensuring that the firefighter meet both physical and mental standard needed to do their work properly (Ministry of Education and Research, 2017). SFRS personnel engage in a

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[1] Previously UniResearch

[2] Changed to Ågotnes Fire and Rescue Service in late 2018

wide range of tasks, from giving courses and informing about fire safety, to the rescue and protection of property and people during fires, smoke outbreaks, and accidents. In order for the individual firefighter to have an overview of the required skills, SFRS needs to maintain an overview of competence skills needed by the firefighters, teams, and the brigade as a whole. It is necessary for the team leader to make daily decisions about their team, for the organisation leadership to both ensure that they meet all the national rules and regulations, and to carry out strategic development (Netteland et al., 2017).

SFRS expressed interest in having a system that can track firefighter performance in one of the skills they train, smoke diving. More specifically a system that can extract positioning data from the firefighters in-door position at the training site, so that their movements and actions can be reviewed at a later stage, enabling the instructor to give more relevant feedback, and enable the firefighters to reflect upon their own decisions during the training exercise.

This research aims to investigate how to extract learning data from a specific learning exercise scenario, more specifically in-door positioning data. The focus is on how the data can presented to facilitate their decision-making. The visualizations can be used by the instructors to give the firefighters better feedback on their training performance.

1.1 Motivation

The motivation behind this research is that there currently does not exist a tool for indoor tracking for firefighter's movements. Another motivating factor is the exploration of an application for Bluetooth beacons, whether they can be used to create and extract data from an exercise scenario.

1.2 Collaboration with co-student

This research was done in collaboration with a co-student, Fredrik Vonheim Heimsæter. This thesis represents the individual research that I have done. Together we developed the FireTracker system, which consists of a front-end application, a mobile application and a back-end, see figure 1.1.

Figure 1.1: Components of the FireTracker system

The development described in this thesis is focused on the development of the fron-end application and the mobile application. The mobile application was developed together, while I was responsible for developing the front-end application. Fredrik developed the back-end.

1.3 Research orientation

The goal of this research is to see what data it is possible to retrieve from a smoke-diving training, and to see how these data can be used to support data-driven decision-making about the training of firefighters. This has further been formulated into a more specific research question:

How can an indoor positioning application be developed to support instructors and firefighters in smoke diving training exercise?

with the following sub-questions:

- *Which indoor position data are of most value to the instructors and smoke diving in training?*
- *How can these data be created and extracted?*
- *How can the indoor position data be visualized, to make them most pedagogically valuable?*

To answer these questions the research first looked at the current learning situation at SFRS, identified the kind of routines they have, how the actual training exercise is performed, what the firefighters are supposed to learn, and how the instructor guides and gives feedback to firefighters. The next step was to implement an indoor positioning system that can extract data from either one or several specific exercise scenarios.

Tracking the positions of the firefighters will produce new data about their movements that can be reviewed at a later time by both the instructor and the individual firefighter, and can be used to improve assessment of performance, and feedback during training.

1.4 Organization of the thesis

This thesis is organized into 11 chapter. Chapter 2 presents the the theory and related works, within the field the field of learning analytics and indoor positioning systems. The research methodology is introduced in chapter 3, where the research, development, and data collection methods used in the research are explained. Chapter 4 explains the exploration of the problem space, and technologies used in the research and how they were used. Chapters 5 to 8 documents development iterations, with data collection, analysis and prototype design and development. These chapters are followed by an analysis of the evaluation of the prototypes. Chapter 10 discusses the techniques used in the research and evaluation results of the research. The final chapter summarizes the results, limitiations, and suggests future research.

Chapter 2

Literature Overview

This chapters presents the research fields in which this research is situated in, identifying relevant topics and research.

2.1 Learning analytics

Learning analytics (LA) can be described as the process of using learning data to understand learning behaviour and processes of learning. This can provide further insight into education practices. Siemens and Gasevic (2012) describes learning analytics as the "measurements, collection", analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs." (p.1-2). An important aspect of LA in this research is data collection.

Passive and active data registration

Passive and active data registration are two different approaches of logging data. The passive approach is described as automatically logging data without the user's involvement. Whereas in an active approach, the user has to actively register and log the data (Kalnikaite et al., 2010). Log data is one of the most common types of data used for LA (Misiejuk and Wasson, 2017). According to Kalnikaite et al. (2010) automatic data registration "eliminates the burdens of users having to decide whether a particular incident is worth capturing, as well as the need to manually prepare and operate capture device. One of the advantages is that no important moment gets missed, and users aren't taken 'out of the moment'." (Kalnikaite et al., 2010, p.2045).

2.1.1 Multimodal Learning Analytics

Multimodal learning analytics (MMLA) combines multiple modes of data from a learning situation in order to understand learning. By having data from several data sources in a learning situation, it can be used to analyze the student learning in complex learning environments (Worsley et al., 2016). Worsley et al. (2016) defines MMLA as: "Multimodal learning analytics (MMLA) sits at the intersection of three ideas: Multimodal teaching and learning, multimodal data, and computer-supported analysis. At its essence, MMLA utilizes and triangulates among non-traditional as well as traditional forms of data in order to characterize or model student learning in complex learning environments." (p.1346).

2.2 Related topics

This section describes the topics related to this research.

2.2.1 GPS - Global Positioning System

A widely used technology for positioning is the Global Positioning System (GPS). GPS uses satellite signals to determine position. The satellite network is made up of 24 solar-powered satellites orbiting around the planet. The satellites send a signal, which contains a time stamp, and the orbital positions of all the satellites in the network, including its own, to the device with the GPS chip, which then calculates its own relative position. GPS has become a well known technology, and there are GPS receivers in almost every smart device.

GPS is also used for giving context-based information. Apps and software utilize this to tailor the user-experience based on the whereabouts of the user. Services such as Facebook and Snapchat utilizes this kind of data to provide the user with information that can be of interest to them. Snapchat, for instance, can present the user with customized image filters with the name of the area or ad campaigns based on the location.

GPS significantly loses signal strength when used indoors, making exact positioning of its user very difficult (Zandbergen and Barbeau, 2011). There is also the issue of GPS's range accuracy; for mobile phones this is estimated to be around 10 meters, which for is not optimal for pinpointing an indoor location. While GPS can determine the elevation of the user above sea level, it cannot determine the relative elevation of the user, i.e. it's not possible for GPS to determine on which floor of the building the user is located (Zandbergen and Barbeau, 2011). However, a study by Diggelen (2002) showed that using assisted GPS (A-GPS) and massively parallel correlation could provide data for determining the indoor position of a user. The median accuracy they achieved in a shopping mall, was 17 meters, which could be used to determine in which store the user was located (Diggelen, 2002).

2.2.2 IPS - Indoor Positioning System

Indoor Positioning System (IPS) is defined as a network of devices that is able to locate objects and people in an indoor environment (Yalamanchili and Babu, 2015). It can be used to display these on a map of an indoor environment, or utilize a device to perform context-sensitive actions, such as display information or notify the user of a mobile device when entering a store.

Figure 2.1: Illustrative image of GPS view and IPS view

In contrast to GPS, IPS does not have a set of standard technologies. IPS can consist of one or several technologies working together. Some of these technologies are reviewed below.

Wi-fi access points

In an IPS that utilizes Wi-Fi access points (AP) the signal strength of the received radio frequency (RF) is the key element. The receiver estimates the incoming signal to calculate the possible position of the user. The signals are sent out by the several Wi-Fi AP's located in the indoor area. The receiver could be a smartphone, with Wi-fi activated, that also has a piece of software that monitors and records the signal strengths of the AP in its vicinity (Liu and Yang, 2011).

Radio frequency Identification (RFID)

RFID are small chips with an integrated circuit for data-storing and and an antenna for receiving and transmitting signal. The data can be read by an RFID-reader, which is a device that emits radio waves. The data storage on each RFID chip, also called tags, are usually small in size, but enough to contain at least an ID for it to be uniquely identified. There exists at least three different types of RFID-chips all of them with different range:

- Passive
- Semi passive
- Active

The passive tag requires no battery-power and utilizes radio energy received from the reader. The semi-passive tag contains a battery, not to generate an RFID response, but to power other electronics such as a thermal sensor and data storing (Jedermann and Lang, 2007). An active tag contains a battery and periodically transmits its data to any receiver in the vicinity.

Achieving indoor positioning using Bluetooth beacons

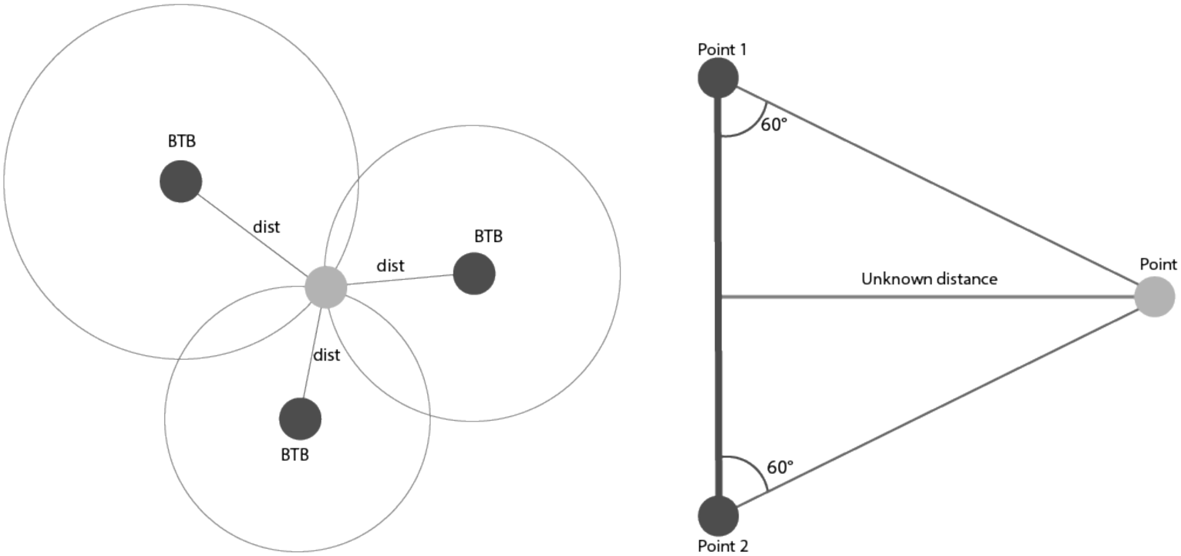
There exist several approaches of how to achieve an indoor position. Usually, beacons are used as anchors and placed around the area of where the IPS is to be implemented. Depending on how accurate the IPS is to be, beacons could be distributed by having one beacon per room or multiple beacons per room.

With one beacon per room the device can determine which of the beacons sent out the strongest signal and decide that it is located in that room. This information can then be further used to visualize the user's location onto a map. Even though walls and other objects provide a significant decay to the signal strength, there is still a possibility that devices outside the room can perceive the wrong beacon as the closest one (Oosterlinck et al., 2017).

With multiple beacons, the estimation of the users' position has a different approach.

Trilateration is a trigonometric approach for tracking mobile objects by utilizing the concept of triangles. It requires at least three beacons to pinpoint a position. By calculating the distance of the user to each of the three beacons.

In figure 2.2a the calculated distance to the Bluetooth-beacons (BTB) is the radius of the circle, the intersection of the three circles can then be determined to be the position of the user (Chawathe, 2008). This is a an approach that is used by GPS, but can also be adapted for use in an implementation of IPS, as the concepts involved are very alike (Subhan et al., 2011). The accuracy of when to use trilateration is quite dependent on the environment, and the received signal. By using mathematical



(a) Trilateration (b) Triangulation

Figure 2.2: illustrations of trilateration and triangulation

filtering techniques, the accuracy can be improved, and minimize the variance of the estimation error (Kotanen et al., 2003).

Triangulation has many similarities to trilateration (see figure 2.2b), but in this approach the angles of the received signals are the ones that are being calculated, not the distance. For IPS that utilizes radio frequency as it’s primary positioning solution this is not feasible. Bluetooth-signals, for example, does not give out any indication of which angle it has (Chawathe, 2008).

2.3 Similar work

This section presents summaries of relevant studies for this research. This section presents similar research and compare them to the IPS developed in this research.

2.3.1 Learning Analytics for Sensor-Based Adaptive Learning (LISA)

Fortenbacher et al. (2017) sought to improve learner support through the use of sensor data. Their idea was to bring together learner-centric learning analytic methods with the use of sensor data that indicated the state of the learner. By developing a wearable sensor device they attempted to extract data from the user to see if they could determine their current emotional state. They used electro-dermal activity (EDA) sensors and electro-cardiogram (ECG) sensors, which provided physiological data of the user. This data was then used to determine the current emotional state of the learner, which they presented to the learner while they were doing the pre-defined activities. The idea was that the learner would use the processed information from the device to self-regulate themselves in, for example, a stressful activity.

LISA has many similarities to the research described in this thesis. It aimed to give the its users feedback in real-time, which allowed them to react and change their actions immediately. In this research, on the other hand, tracks firefighters during an exercise and then, in retrospect, enables the visualization of their movements. This enables instructors and firefighters to review their movements retrospectively and receive feedback after the exercise.

2.3.2 CoenoFire: Monitoring Performance Indicators of Firefighters in Real-world Missions using Smartphones

CoenoFire is a smartphone based sensing system that was developed for monitoring temporal and behavioral performance in firefighter missions (Feese et al., 2013). The aim was to use this data for comparing the generated performance metrics of a firefighter team with other participating firefighter teams. With the use of the smartphone embedded sensors, they sampled the data, stored it on the phone and transmitted it via Wi-Fi for real-time monitoring. The data they collected was the activity, intensity, and variability of the firefighters movement, and their speech activity. They also monitored temporal metrics, such as first above ground, where they determined who was the first to enter a situation using a turntable ladder. The last measurement was arrival on-site.

CoenoFire was quite similar to this research. They used a smartphone to collect data from both real-life incidents and exercises. These data were sorted and analyzed afterwards. They visualized the real-world data to show how the data could support mission feedback. They used a wide array of data sources, such as sound, acceleration and oriental, barometer, GPS, and network radios, from the smartphone. The research also focused on extracting data from several different smartphone sensors. Another similar aspect is that their goal is to use these data retrospectively for learning purposes.

2.3.3 Bluetooth tracking of humans in an indoor environment: An application to shopping mall visits

Oosterlinck et al. (2017) performed research where they tracked people's indoor movement in a shopping mall. The main goal was to study Bluetooth's applicability for indoor positioning and how it could be used as a method for marketing purposes. Their findings were that it is possible to find spatio-temporal behavior of the individuals in the mall, and that the data collected can in fact be useful, as it reveals the movement patterns of the mall customers.

To track people in the shopping mall, they developed a Bluetooth scanner that scanned all Bluetooth devices in its vicinity. The resulting data set was then analyzed and by comparing time stamps and MAC-addresses, the Bluetooth radio's unique address, they were able to visualize the customers movements in the mall. There are many similar aspects between this study and the research in this thesis. Such as the placing of the placing of beacon transmitters around to find the spatio-temporal behavior of the firefighter and how it could be used to visualize their movements.

2.3.4 Summary

This chapter has explained the relevant research fields, concepts, and technology relevant for learning analytics and positioning system. There are several studies that have carried out similar work to this research, but have focused on different aspects of the resulting data.

Chapter 3

Methodology and methods

Design Science Research is the methodology chosen for this research. In this chapter it will be thoroughly explained and justified. Afterwards the various methods used will be presented, including the design and development methods, the methods of data gathering, and how the data will be analyzed.

3.1 Design Science

Design Science is a widely used methodology in research where the aim is to design and develop Information Systems (IS) and IT applications.

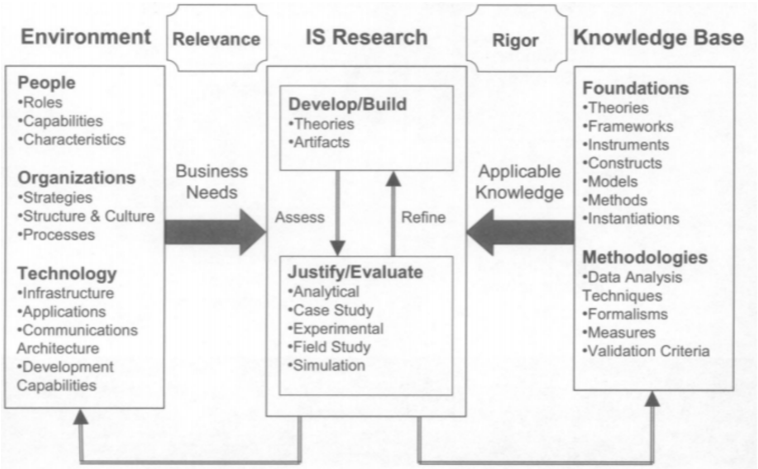


Figure 3.1: Design Science Research model (Hevner et al., 2004, p.80)

Figure 3.1 shows Hevner et al. (2004)'s Design Science Research model. The three main concepts of the method are *relevance*, *rigor*, and *design*.

Relevance is achieved by taking business needs and issues into consideration, while *rigor* is established by taking knowledge from research and science in to the design. Together, these two concepts are applied to the *design* (Hevner et al., 2004).

According to Hevner et al. (2004), design is both a process, a set of activities, and a product or an artifact. Further, March and Smith (1995) define two design processes, *build* and *evaluate* that are produced when using the Design Science research method. The *build process* is a sequence of activities that results in a product or an artifact. The *evaluate process* is where the artifact is evaluated to provide feedback and a better understanding of the state of the artifact, and how it relates to further understanding the problem. These processes are usually repeated iteratively, until the final artifact has achieved its goal (Hevner et al., 2004).

The *environment* defines the problem space of the design. (see figure 3.1) It is composed of the people, organization and their existing or planned technologies. These are explored in order to facilitate the development of an artifact and add to the knowledge base (Hevner et al., 2004).

The *knowledge base* can be defined as where the foundation and methodologies can be explored. It is made up of previous, well-established theories, artifacts, and research developed or used by researchers. To achieve rigor the researcher has to apply existing foundations in the design/build phase, and methodologies in the evaluate phase (Hevner et al., 2004).

Hevner et al. (2004) write that design science is inherently a problem solving process. They have therefore drawn up seven guidelines to aid researchers when using design science as a research methodology, see table 3.1.

These guidelines are used to reflect on this research. This can be seen in chapter 10.

Table 3.1: Guidelines for the Design Science Research (Hevner et al., 2004, p.83)

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

3.1.1 Artifacts

An artifact is something that is manmade, an element created to to solve a class of problems. Hevner et al. (2004) define several types of artifacts (p.79):

1. *Constructs:* Provides the language; concepts and vocabulary that are used in the related domain, so that the problem and solutions can be communicated. Examples of these construct can be entities, data flows, of objects.
2. *Models:* It utilizes a combination of the existing constructs to represent a real world scenario for aiding in problem understanding and solution development.
3. *Methods:* When the problems of the research has been found, methods can provide guidance in how to produce the models and set up the process stages.
4. *Instantiations:* Can be seen as a working system or a demonstration that is an implementation of the constructs, models and the methods. This artifact can be

used in e.g. real-world scenarios to learn about the user's behavior towards the software.

In this research the main artifact is a web application that visualizes the firefighter's movement in a cold smoke diving excercise.

3.1.2 Process

Figure 3.1 illustrates the development and evaluation process for this research. The development will take place as a series of four iterations, followed by a evaluation of the final prototype. This can be seen in figure 3.2.

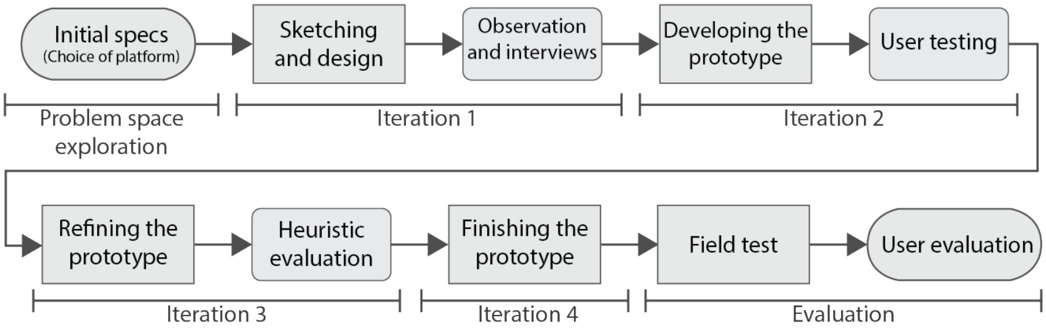


Figure 3.2: Overview of the development and evaluation process

The following sections describe the methods involved in understanding the problem space, the development of the prototype, the formative data collection and the final summative evaluation.

3.2 Understanding the Problem Space and Conceptual Model

The problem space can be seen as the understanding of the current problem of a topic, and how it is going to be improved or changed (Rogers et al., 2007). Rogers et al. (2007) has defined a framework with a set of core question to aid in defining the problem space (p.39):

- Are there problems with an existing product or user experience? If so, what are they?
- Why do you think there are problems?
- How do you think your proposed design ideas might overcome these?

- If you have not identified any problems and instead are designing for a new user experience, how do you think your proposed design support, change or current ways of doing things?

In addition to this framework, Rogers et al. (2007) also suggest to make assumptions and underlying claims about the problem, e.g. by claiming that all users want to stand while using watching TV. By defending and supporting these claims, it will help highlighting the faults in the design idea. This process usually involves identifying problematic activities and working out how these can be improved or supported by a different set of functions. The process can also be more speculative in terms of thinking of what to design for a user experience that currently does not exist.

To understand the problem space in this research, a set of explicit assumptions of the usability and user experience were made and defended to see if they were viable or not, also firefighter trainings were observed and interviews were carried out.

3.2.1 Conceptual model

A conceptual model an abstract outlining of the activities a product or system can do and what concepts are needed to understand how to interact with it (Rogers et al., 2007). Johnson and Henderson (2002) describes it as a "a high-level description of how a system is organized and operates" (p.26). According to (Rogers et al., 2007) the core components of conceptual models are (p.40-41):

- Metaphors and analogies that convey to people how to understand what a product is for and how to use it for an activity (e.g. browsing, bookmarking).
- The concepts that people are exposed to through the product, including the task-domain objects they create and manipulate, their attributes, and the operations that can be performed on them (e.g. saving, revisiting, organizing).
- The relationships between those concepts (e.g. whether one object contains another, the relative importance of actions to others, and whether an object is part of another).
- The mappings between the concepts and the user experience the product is designed to support or invoke (e.g. one can revisit through looking at a list of visited sites, most frequently visited, or saved websites).

In this research, a concept model was outlined based on the problem space and these core components.

3.2.2 Initial specification

The initial specifications will be exploring ideas and technologies for creating and visualizing indoor position data.

3.3 Development

This section describes the methods used in the development process. The development process for the artifacts was an iterative process. An iterative process, with testing at the end of each iteration, allows for assessing the state of the prototype and external input on the prototype.

3.3.1 Prototyping

A prototype is an early first version of a product. Its purpose is to gain understanding of how it can be used to modify the analysis and design models and to create a revised prototype (Oates, 2005). The prototype is built iteratively and modified until a satisfactory implementation is built where it meets the requirements it was set out to fulfill. There are two types of prototypes: *low-fidelity* and *high-fidelity*.

Low-fidelity prototypes are simplifed representations of the final product. It does not provide the same functionality, but is a quick and cheap way to show the functions or a set of the functions and receive feedback on these. It is usually developed using paper sketches or other rudimentary materials, allowing it to make changes easily as it is cost effective and quick to develop.

High-fidelity offers more functionality and is more like a final product. It provides an interactive design and more functionality than a low-fidelity prototype. The intention is to provide a user experience that resembles the final product.

In this research an iterative process will be followed where succesive prototypes are evaluated before revisions are made. The development will test from a set of requirements, and evolve through a low-fidelity and into a functional, high-fidelity prototype.

3.3.2 The interaction design lifecycle

In the interaction design lifecycle there are four activities: *Establishing requirements*, *Designing alternatives*, *Prototyping*, and *Evaluating*. Figure 3.3 illustrates the relationship between the activities.

Establishing requirements for the functions and the user interface (UI) and user experience (UX), designing alternatives that meets the established requirements, prototype these alternative designs so that they can be tested and assessed, and evaluate the prototypes to see what of the functionality and the UI/UX meets the requirements. If not, a new cycle is started and the requirements needs to be reestablished based on the feedback from the last iteration's evaluation (Rogers et al., 2007).

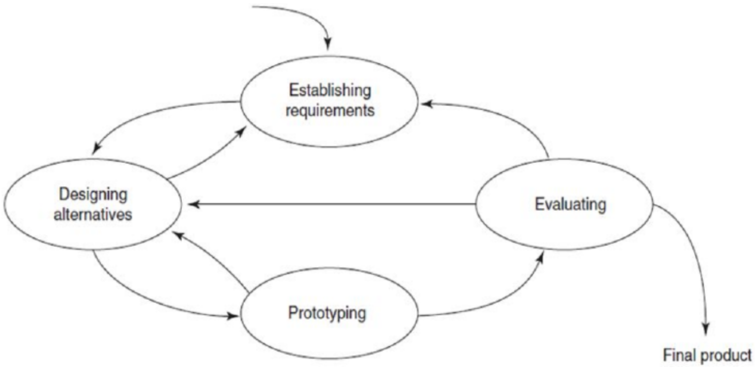


Figure 3.3: Interaction design lifecycle (Rogers et al., 2007, p.332)

This research used these four activities seen in figure 3.3. First the problem space was explored and analyzed, the initial, technical requirements were established. Then the design and development were done through several iterations of developing and testing, as illustrated in figure 3.2. The first iteration began with sketching and designing a low-fidelity prototype with the specifications from the problem space exploration. The prototype was then shown and tested with SFRS. Iteration two started with the actual implementation of the IPS and ended with a new user test with SFRS. The results from this test was used to set new requirements in the third iteration. The protoype was redesigned and was evaluated using Nielsen's heuristics. In the fourth iteration, the most severe issues from the heuristic evaluation were corrected. After this iteration, a final summative evaluation was done to conclude the research. Each of these iterations will be described in later chapters.

3.4 Formative Data Gathering

Formative data gathering in an iterative development cycle is used to verify that the components of the prototype meet the needs and requirements of the user. It is used to find out whether a component of the artifact works or not. According to Nickerson and Landauer (1997) evaluation should take place troughout the entire development to achieve a guided evolution of an artifact.

In the development iteration cycles, the two first iterations ended with a user test with SFRS, followed by a semi-structured interview. The third iteration ended with a heuristic evaluation in order to test the prototype with IT-experts.

3.4.1 Observation

According to Oates (2005) observation is a data generation method that can be used almost within any type of research. It often involves looking, but it can also involve other senses such as; hearing, smelling, touching, and tasting (Oates, 2005). Oates (2005) says there is one important distinction in using observation as a data generation method, and that is between "overt" and "covert" research. *Covert* research is when the subjects are being studied without their knowledge. The advantage here is that the subject’s behavior will be natural and not affected by knowing that they are participating in a study. In an *overt* research, the observations are carried out with the subjects knowing that they are being studied. The advantages here are that the subjects are able to give their consent to being studied, making the research more ethical. Also the researchers are able to freely ask the subjects questions involving the study.

In this research, overt observations of the firefighter’s exercises were carried out. Notes were taken of the important and relevant moments of the observations.

3.4.2 Semi-structured interviews

Qualitative data analysis involves abstracting from the research data, the verbal, visual or aural themes and patterns that might be important to the research topic (Oates, 2005). A technique used to attain qualitative data in this research is a semi-structured interview.

Semi-structured interviews combine both open and close-ended questions. The interviewer has a list of the themes to be covered and questions to be asked. The openness of the interviews allows the interviewee to answer more freely and get more details on the issues. This also applies to the interviewer; while having a pre-planned structure it’s also possible to change the order of the questions, introduce new issues that is not on the interview agenda (Oates, 2005).

To understand and assess the firefighters suggestions, expectations, and opinions, interviews were carried out during the problem space exploration and the development iteration cycles.

3.4.3 Expert Evaluation using Nielsens Heuristics

Heuristic evaluation is a usability inspection method developed by Nielsen and others (Nielsen and Molich, 1990). This inspection method is performed by experts where they follow a set of usability principles called heuristics. Rogers et al. (2007) states that it is also possible to develop one's own heuristics that are more suited to the application itself, as the Nielsen's heuristics may not always be applicable to the application's context. With the help of these heuristics the experts evaluate the user-interface design, taking elements such as navigation structure, menu, dialog boxes and other elements, into consideration. Nielsen's heuristics can be seen in table 3.2.

Table 3.2: Questions in the SUS questionnaire (Usability.gov, 2018)

No.	Heuristic
1.	Visibility of system status.
2.	Match between system and the real world
3.	User control and freedom
4.	Consistency and standards
5.	Error prevention
6.	Recognition rather than recall
7.	Flexibility and efficiency of use
8.	Aesthetic and minimalist design
9.	Help users recognize, diagnose, and recover from errors
10.	Help and documentation

A full description of each heuristic can be found in Appendix A.

At the end of the third iteration a heuristic evaluation is used to evaluate the prototype.

3.5 Summative Data Gathering

Summative data gathering is the evaluation of a project. In this research it represents the final evaluation of the prototype. The summative evaluation of this research consisted of two parts: A field test with SFRS, where they used the IPS in an smoke diving exercise, and semi-structured interviews followed with the SUS questionnaire.

3.5.1 Field Trial

Field trials, also called field studies, aim to evaluate the subjects in natural settings. They are primarily used to identify oppurtunities for new technology, establish the requirements for a new design, and facilitate the introduction of new technology, or inform delpoyment of existing technology in new contexts. Typical methods in field studies are observation, interviews, focus groups and interaction logging (Rogers et al., 2007).

In this research, a field trial of the final prototype was arranged. During the field trial the exercise was observed, semi-structured interviews were carried out, and questionnaires were used.

3.5.2 System Usability Scale

The System Usability Scale (SUS) is a usability scale formed as a questionnaire that is small and simple, and created in manner to easier assess the usability of a product (Brooke, 2013). It consists of ten questions with five responses that range from *Strongly disagree* to *Strongly agree* (Usability.gov, 2018).

According to Brooke (2013) the objectives of SUS are:

- To provide us with a measure of people's subjective perceptions of the usability of a system
- To allow us to do so in the very short time available to us during an evaluation session.

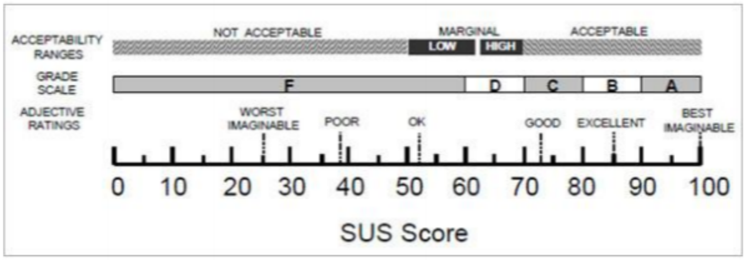


Figure 3.4: System Usability Scale Score (Brooke, 2013, p.36)

The scoring system ranges from 0 to 100, making users of it interpreting it as a percentage ranking scale. SUS score should be not be interpreted in this manner (Brooke, 2013). Figure 3.4 shows the values of the score and its acceptability ranges. A score over 68 is defined as an acceptable score for a product (Brooke, 2013). The SUS questions can be seen in Appendix B.

3.6 Summary

This chapter has introduced the Design Science Research methodology. Other more specific methods for development, data gathering and analyzing, such as prototyping, semi-structured interviews, heuristic evaluation, and System Usability Scale has also been described.

Chapter 4

Problem Space Exploration

This chapter describes the understanding and the exploration of the problem space. It also introduces and explains the chosen technologies, how they were used, and why they were chosen.

4.1 Initial requirements

After an initial meeting with SFRS, the requirements were clear: They wanted a system where they could see the firefighter's movements inside an exercise building. To further understanding the problem space, a set of assumptions and claims were made, regardless of whether they were technically feasible or not. In addition to the requirements from SFRS, these claims and assumptions were based on the relevant topics and research reviewed in chapter 2.

Claim 1: The firefighters wants to see the movements in real-time.

By having the firefighter's movements tracked in real-time, the instructors would be able to see where in the building the firefighters are during the exercise. This could enable them to give orders or guidance during the actual exercise. However, by having the system act in this way it would require high reliability and stability. The instructor has to be certain that the movements shown in the system actually correspond with the firefighter's actual movement. This would require a great amount of testing, equipment and time.

Claim 2: The firefighters wants a system that requires little effort to use

A system used for tracking movement would have to include both hardware and software elements. There has to be a transmitter that transmits a signal received by another device. For the system to be be useful for the firefighters the complete set-up of both the hardware and software must be easy to understand for all parties involved, meaning both the smoke divers and instructors. This means that the hardware must either be similar to other equipment they use, or simple to use. The software should be user-friendly and make use of concepts already known to the firefighters, such terms related to firefighters, and design concepts.

4.2 Conceptual model

In order to devise a conceptual model, a relationship between the hardware and the software had to be established first.

Figure 4.1: Flowchart of the initial concept model

Figure 4.1 shows how a transmitter sends a signal that is picked up by a receiving device, the device then sends the received data to the system. The transmitters are placed around the area, while the firefighters have the receiving units mounted on them. The receivers then gathers the signal data while the firefighter is moving around the area. The signal data is then sent to the system.

In the system, exercises were conceptualized as "sessions". The session represented all the data and information an exercise had.

4.2.1 Choice of technology

In order to further develop the conceptual model, the technologies of both the hardware and the software had to be chosen. This section presents the technologies that were used, and the setup of the system, which will from here on be referred to as "FireTracker".

The hardware of FireTracker consists of devices that can transmit radio signals, and devices for receiving these signals. The chosen transmitting devices were Bluetooth LE Beacons. The reason for this is that they are relatively cheap products, and battery-driven beacons are versatile in terms of placing. Also, the Bluetooth-technology is a well supported technology.

Smartphones were selected as the receiving devices for the Bluetooth Beacons. The reason for this was because smartphones already had existing technologies for receiving radio signals, such as Bluetooth signals. It also had Internet capabilities, making it possible to wirelessly upload the signal data from the device itself onto a server. Another factor was the mobility, it can easily be mounted on the firefighters.

The last hardware is the where the signal data was visualized. While not explicitly shown in figure 4.1, the data had to be available on a device that is able to show the firefighters the viusalized data from the tracking.

To utilize the capabilities of the smartphone as a signal receiver, an application was developed. Android was chosen as the operating system (OS) platform. It is an OS designed for mobile devices. The main reason for developing the application for Android was that it helped shorten the development time due to previous experience in developing Android applications. Another reason was access to multiple, viable Android devices, as there had to be one device per member of the smoke diver team. By personally owning several Android devices, these could accommodate this requirement.

The alternative to the Android was to develop a cross-platform application. While this would certainly be the most optimal as the application would be compatible for both Android and Apple's iOS, however, this would have been time consuming and taken focus from the design and development of the functionalities in the application.

The visualizations was presented through a web application. The web application was built using React.js (see section 4.4.4), a JavaScript library. There exist multiple libraries that could have been used that also offer equal functionality. The primary reason for choosing React.js was that it is a popular and well-documented library (Medium.com, 2017), and it allows for the use of asynchronous data fetching functions already implemented in JavaScript that are also supported by a vast majority of the most common internet browsers (Mozilla, 2018).

To store the data from the mobile application, calculate the positions, and store the data for visualization, a server was needed. The web server is hosted on a Linux virtual host, and the chosen framework was GinGonic, an HTTP framework (see section 4.4.3). The reason for choosing the GinGonic framework was previous experience with it. this helped cut down development time.

Figure 4.2 shows the FireTracker flow of data, and the relation between the hardware and the software. The right side of the figure shows the software components of the FireTracker system. The mobile application is technically also a part of the system. The Bluetooth signal data received from the beacons are recorded by the mobile device. The application then stores this data and sends it to the server. When the server receives the raw signal data, it uses an algorithm to determine and generate locations. The location data can then be requested at any time by a web application. The web application then visualizes the data.

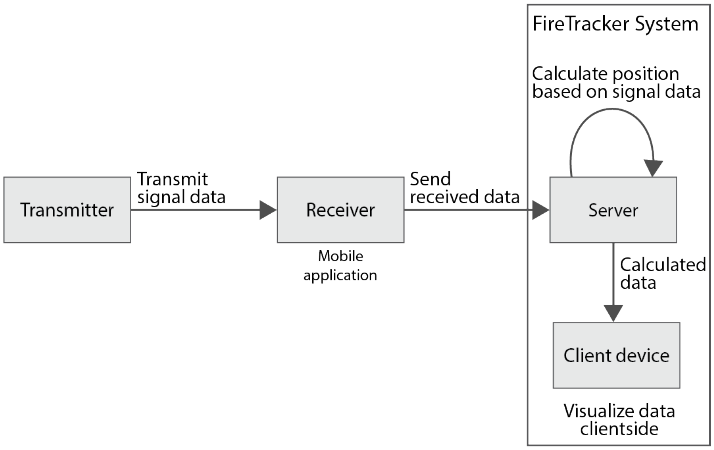


Figure 4.2: Flowchart of the high-level concept model with technologies

4.3 Technologies of the hardware

This section describes the hardware of the FireTracker system.

4.3.1 Bluetooth

Bluetooth is a short-range wireless technology that is widely included in many electronic devices, such as laptops and mobile devices. It enables devices to communicate with one another, allowing them to share data, images, voice and music among other things. For this two-way communication to happen, both of the devices must pair with each other. This means that the devices have to accept each other requests to connect (Bluetooth Special Interest Group, 2017b). When a Bluetooth network is established, it creates an ad-hoc network, called piconets. In these piconets there is one device that takes the role of master, and other devices takes the role as slaves (Bluetooth Special Interest Group, 2017a).

Bluetooth Low Energy

Bluetooth Low Energy (BLE) is a distinctive feature of the Bluetooth 4.0 specification. Its key features are less power-consumption than earlier standards. According to a study performed by the MDPI, in BLE, there exists a trade-off between energy consumption, piconet size, and latency (Gomez et al., 2012).

The BLE standard allows for a beaconing, or advertising mode, meaning that it can send out short, unrequested messages in it's vicinity. With an external device, these messages can then be used to detect proximity to the BLE device based on the Received Signal Strength Indication (RSSI) (Faragher and Harle, 2014). The RSSI is used to measure radio signal strength. RSSI is a signal strength percentage, the higher the

RSSI number is, the stronger the signal. It is a relative measurement defined mostly by each and own chip manufacturer, which means that the RSSI is different for different radio circuits (Gao, Vincent, 2015). Another factor that can affect the RSSI are objects between the receiver and the transmitter. For instance if a person is between the receiver and the transmitter, it can create a significant drop in signal strength, which could complicate the range estimation of the device (Faragher and Harle, 2014).

iBeacon

iBeacon is a wireless BLE protocol developed by Apple and was released in 2013. It is BLE-based and it broadcasts the beacons information periodically, where another terminal device, e.g. a smartphone, receives the information and is then able to process the information. The information the beacon sends out is described in Table 4.1.

Table 4.1: iBeacon data specification

Data	Description
iBeacon Protocol Prefix	Indicating that the iBeacon protocol is in use
iBeacon UUID	Unique identifier of the installed beacon
Major Code	Major value
Minor Code	Minor value
Tx Power	Signal strength

To identify the iBeacon, the terminal device receives the Universally Unique Identifier (UUID), along with the Major and Minor values. The UUID is usually used to identify the actual beacon, the type and make. Major is used to define a subset of beacons within a larger group, for example,m beacons in a certain such as a building floor. The minor value can then be used to identify the specific beacon, within that subset. The Tx power value is used to calculate the distance from the beacon. The value stored here is the RSSI measured at 1 meter from the beacon.

4.3.2 Android Beacon Library

The Android Beacon Library (ABL) is an API that allows Android devices to interact with Bluetooth beacons. It is an open source project developed and maintained by Radius Networks (Radius Networks, 2018). The library allows the device to monitor and range beacons in the vicinity. The component that enables this is the BeaconManager class. The class can be configured to monitor beacons in the background by using the MonitorNotifier class, or it can actively range beacons by using the RangeNotifier class.

When monitoring beacons the application is passively listening to beacon signals. This runs as a background service in Android, meaning that the application doesn't have to be active in the foreground to detect beacons. Beacons are grouped in regions, where a region can consist of one or many beacons. When the application detects a beacon belonging to a region, it sets itself to be in that region. When the application enters or leaves a region, it triggers a didEnterMethod or a didExitRegion.

Ranging beacons is when the application is continously searching for nearby beacons. In this case the application must be in the foreground. The application is set to fire the listener in short intervals, the minimum in ABL being 1.1 times per second. This is also consumes more of the device's power, meaning that the battery of the device will drain more quickly. When detecting beacons in the region, it receives an array of data from the beacons, including the identificators, such as the UUID, major and minor. It also receives the RSSI of the signal.

In the FireTracker mobile application, the library is used in ranging mode. The application continously scans for beacons and stores the data received from beacon into the devices local storage.

4.4 Technologies of the software

A large part of the FireTracker system is web based. It consists of both a server and a web application.

4.4.1 REST API

REpresentational State Transfer (REST) is an architectural style for designing systems with constraints and properties based on HTTP. With a REST API, developers can perform request and receive responses through HTTP. REST APIs are typically language independent, meaning that it can be written in several different languages. The REST API is an interface for clients to access underlying systems, for example a database. The client can be a web or a mobile application among other things. It also allows them to write data into the database. The functions are exposed as URI's, where the client has to send a request to the REST API. The data sent to the API has to be sent with an HTTP request methods. The method defines what the REST API does with the data. There exist several request methods, for example, the GET method is primarily used to tell the API to send the data located at the URI as a response to the request. Another method is the POST request. Which is used to generate new data, for instance, in a database. The clients sends a body of data along in the request, when the REST API receives the request it can process this data further. Typically it stores the data as an entry in a database. The format the data is stored is usually in XML, HTML or JSON.

The FireTracker web application allows the user to create and open sessions. Session is defined as a closed events where the data from the tracking is stored. The storing and retrieving of the session data is possible through the REST API that has been developed with the GinGonic framework (see section 4.4.3).

JSON

JavaScript Object Notation (JSON) is an open-standard file format. It is a schemaless, text-based representation of structured data. It is based on key-value pairs and ordered list. It is originally derived from JavaScript, as it has the same format and structure as JavaScript objects. It is also very commonly used as the format for exchanging data between clients and servers (JSON.org, 2018). JSON stores data in objects. It can be processed as text, but it is also possible to convert it directly into objects using dedicated libraries available in the different languages.

The data served through the REST API is stored in JSON, and is used both in the mobile application and the web application. The mobile application stores the tracked data as a JSON file locally on the device and uploads it to the server for calculations. The web application retrieves the calculated data from the server for display.

4.4.2 Golang

Golang is a statically typed programming language. It enables developers to write terse, concise, simple and highly concurrent and scalable programs. It has recently gained traction as a language to build scalable web services (Golang.org, 2018).

4.4.3 GinGonic

GinGonic is a highly extensible framework for writing HTTP server in Golang. It enables developers to write an easy and simple web server to provide a REST API. It enables specifying routes and HTTP-request and responses to which the HTTP server can respond (Martinez-Almeida, 2018).

4.4.4 React.js

React.js is a JavaScript library for building and developing user interfaces. One of its main features is its component-based structure. The UI elements are built as components that can manage their own states seperately. The components can be put into other components, enabling the composition of more complex UI elements. Another key feature of React is the virtual document object model (DOM). When React renders its code, it internally builds a DOM and when a change happens in a component, for instance the component changes its state, React is able to compute the difference in the component, and the DOM of the component without reloading the entire displayed DOM.

4.5 Alternative technologies

During the development process other technologies were considered for positioning, including Pozyx and Estimote.

4.5.1 Pozyx

Pozyx is a hardware solution that provides indoor positioning and motion data. By using ultra wideband radio signals it is able to give a position of 5-10 cm of accuracy. For three dimensional localization the system requires at least four modules. One of the modules is used for tracking an individual or an object, while the others act as anchors. The anchors are fixed modules placed around the area. These modules then use trilateration to achieve position of the tracked module (Pozyx, 2018).

There are two main reasons for why Pozyx wasn't chosen. The first is that all of the modules require a constant power source as it doesn't have a dedicated battery. While it would have been possible to connect custom batteries for the modules, the size of the batteries would negatively affect the usability of the system. The modules would still have to be mounted on the firefighter, and with the added battery pack it would most likely have to be placed on another location on the firefighter, which could have affected the firefighters performance, due to the added size and weight of the battery.

The second problem was that the system is not wireless. The collected data on the tracked module is stored on the device itself and it is not possible to transfer wirelessly to a computer. This is also something that would have negatively affected the usability of the system in terms of ease of use. The fact that FireTracker does not require any physical connection to another devices makes it easier to deploy and faster to start using.

4.5.2 Estimote SDK

The Estimote Android SDK is a development kit for developing software to be used with Estimote's own BLE beacons. The SDK allows devices to authenticate themselves with the beacons and send contextual notifications, among other things. It also offers indoor positioning. Like Pozyx SDK, it requires four beacons to act as anchors and one device placed on the tracked individual or object. (Estimote, 2018)

The reason this SDK wasn't used was that the Estimote SDK doesn't support beacons from other vendors. Beacons used with Estimote SDK have to be added to their own

Estimote Cloud dashboard, and this only applies to Estimotes own beacons.

4.6 Summary

This chapter explained the process of exploring the problem space. This consisted of setting the initial requirements of the FireTracker system, outlining a high-level conceptual model and presenting the technologies the system is up of. Table 4.2 shows the different hardware and software components chosen for the FireTracker system.

Table 4.2: Components of the FireTracker system

Hardware	**Software**
Bluetooth LE Beacons	FireTracker Mobile Application
Mobile receiving device	Firetracker Web Application
Client device	Back-end server API

Chapter 5

First iteration - Sketching and design

This chapter provides and accounts for the design process that led to first prototype. It describes what choices were made and how they affected the initial design and development decisions.

5.1 Designing the prototype

To start designing the first prototype, a preliminary design had to be established and an assessment of the smoke diver exercise was carried out. The purpose of the prototype was to have an initial design that could be shown to, and tested by SFRS.

5.1.1 Initial design

The initial design is based on the technical aspects explored in chapter 4. It was already established that smartphone devices were going to be used as receivers of the BLE signals, and that the data should be visualized on a web application. The initial system requirements at this point were simple: A mobile application capable of tracking signal data on the receiver device and sending the data to a server, a back-end service for calculating the raw data and serving these data through an API, and a web application for visualizing the processed data.

Mobile application

The mobile application was the first to be designed. The user-interaction with the application had to be kept simple as it only had one function. To gain an overview of the interactions in the application, a flow chart was created, see figure 5.1. In the mobile application the user is able to create a session, input the name and the user of the session. When these data are confirmed the user is able to start the session.

The application then records the surrounding BLE signals until the user stops the recording. When stopped, the session ends and the application starts to upload the recorded data to the server.

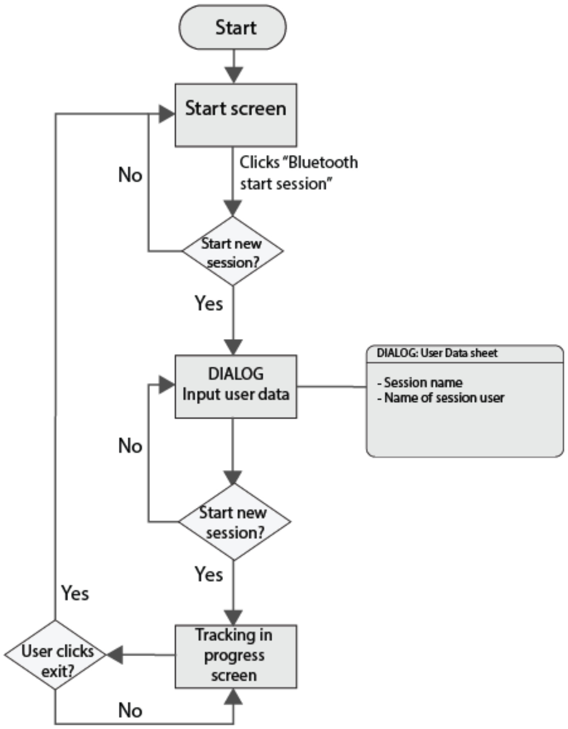


Figure 5.1: Flowchart of the mobile application

The flowchart in figure 5.1 was further expanded into a sketched wireframe made up of screens describing the actual design. Sketching on paper enabled faster and easier changes to the design. The goal of the sketch was to propose a design to cover the bare minimum requirements of the application, and also to quickly iterate over it (see figure 5.2).

The sketches were redesigned into a high-fidelity prototype using Adobe Experience Design, a prototyping tool. This can be seen as a wireframe in figure 5.3. This prototype was interactive, meaning that clicking on the circular points in the figure takes the user to the screen in the arrow's direction.

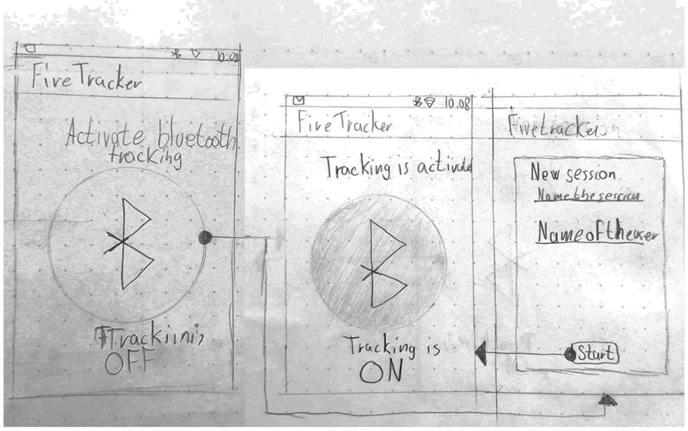


Figure 5.2: Paper sketches of the mobile application's tracking screen

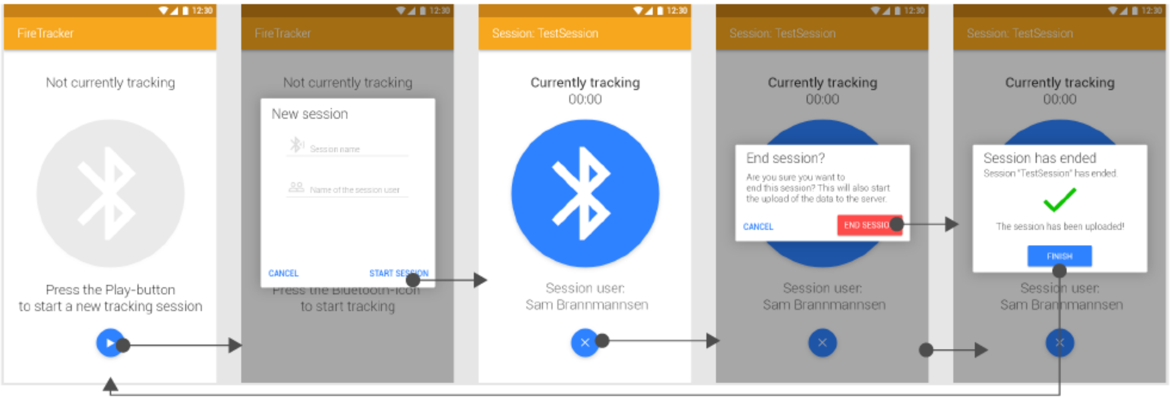
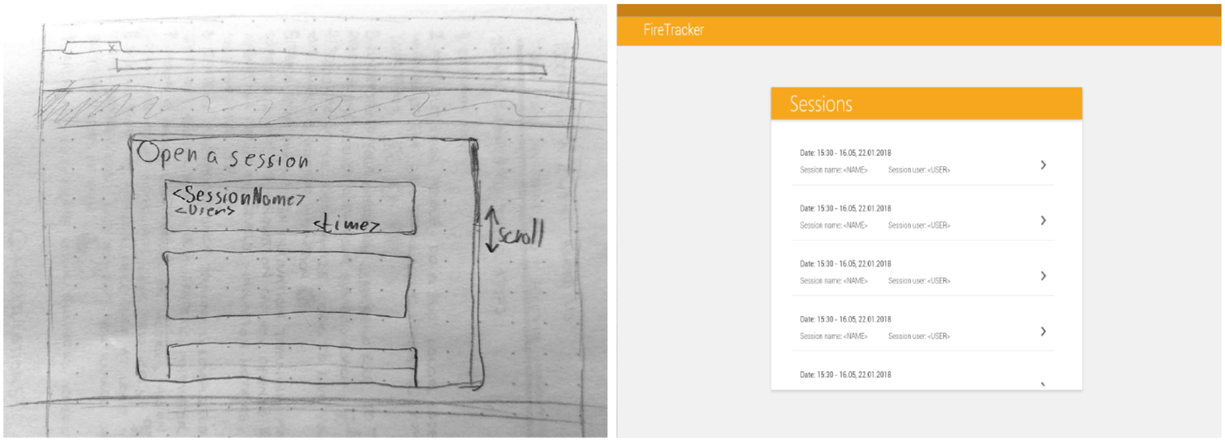


Figure 5.3: Wireframe of the high-fidelity prototype of the mobile application

Web application

The requirement set for the web application was that it should visualize the tracked data. It therefore needed a way for the user to select for which session to see the visualized data and other information about the session.

The web application in this iteration was not particularily complex, it was therefore decided not to design a flow chart of the application's structure. The initial design started first with sketches on paper, see figure 5.4a. Soon after it was turned in to a digital sketch, which in return was worked in to a prototype, see figure 5.4b.



(a) Paper (b) Wireframe

Figure 5.4: From paper to digital sketch

A clickable, high-fidelity prototype was also created for the web application, see figure 5.5. The reason for this was to show the application's structure when tested and to gain an understanding of how it was to be used. In this prototype the user is first presented the list of available sessions and when a session is clicked the user is redirected to a new screen. On this screen the user is presented a map of the area, a button can be clicked to display the data about where the session's user has been. From here the user can choose to exit the session and return to the overview of the sessions.

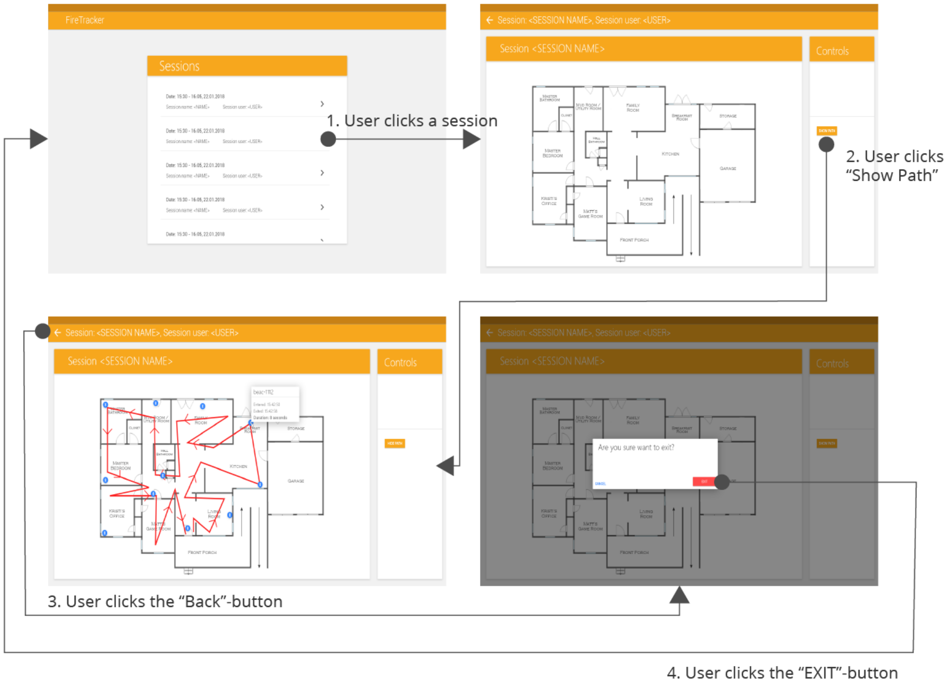


Figure 5.5: Wireframe of the high-fidelity prototype of the mobile application

5.2 Testing of the prototype

To gain a better insight in smoke diver's training it was necessary to a) gain an understanding of what SFRS's current situation was, in terms of the firefighters smoke diving training, b) know their expectations to the visualizations and c) how this should be presented and used in a user-friendly manner.

5.2.1 Interview with the fire department leaders

The evaluation of the first prototype was carried out as a semi-structured interview the training leader and the department leader. The interview guide can be seen in Appendix C. The overall structure of the interview was separated into three parts: The practical aspect of the exercise, the system's visualization, and feedback and evaluation. During the interview a high-fidelity static prototype, with which they could interact, was shown to them. The 20 minute long interview was recorded and transcribed.

Analysis
The questions in table 5.1 were asked to get more knowledge about the actual smoke diving exercise, how it is carried out and what the personnel does.

Table 5.1: Questions about the practical aspect of smoke diving exercise

	Question
1.	Which preparations do the firefighters do before an exercise?
2.	Where can the signal receiver (phone) be placed on the firefighter during the exercise?
3.	How many persons are there on a smoke diving exercise?

Preparations

The firefighters know only that there is going to be a smoke diving exercise. They don't know the location or which building will be used. The reason for this is that the firefighters should not know the building layout. As in real live smoke diving scenarios, the firefighters have little to no knowledge of the building layout. According to the training leader, SFRS tries to find new buildings where the firefighters haven't trained before, but this is not an easy task.

Placement of signal receiver

As the Bluetooth signal strength decreases steadily when it goes through solid objects (Chawathe, 2008), the optimal place for receiver placement would be somewhere where the blocking of the signal could be minimized. The training leader confirmed that the receiver phone could easily be mounted on the firefighter's helmet or oxygen tank.

The smoke diving exercise

While the number of persons participating in a smoke diving exercise varies, the training leader said that usually 7-8 persons are present in an exercise. If all three regional station teams are present there could be as many as 12 persons. There are five people in a team: Team leader, fire engine driver, smoke diver leader, and two smoke divers.

The driver doubles up as the pump controller, which means keeping the fire hoses in line and making sure that the team inside has enough hose length. One of the team members is also the team leader. The team leader coordinates the smoke diving situation together with the on-duty fire chief. The three remaining team members consists of two smoke divers and a smoke diver leader.

The smoke diver leader coordinates the two smoke divers ususally from the main entrance of the building. He or she relays the communications from the smoke divers to the team leader. The two smoke divers are the ones that performs the search in the building.

Analysis

Table 5.2 lists the questions asked about the visualization.

Table 5.2: Questions about the visualizations of the indoor movements

	Question
1.	What kind of information can this type of data give you?
2.	How should this data be presented?

Types of information

When asked what kind of information they could get from the data they answered that it could be used to assess the firefighter's search technique. It can be used to see if the firefighters have covered the entire area in their search and their choice of direction at the beginning of the search. The instructor could see whether the firefighters have missed an area or a room of the building. It was also mentioned that the visualizations could be served as a source for feedback, such as asking the firefighters how and why they missed an area or a room.

Presentation of the data

When asked how the data should be presented, they answered that it would be helpful having the data visualized on top of a floor plan, and also include a more detailed list of each movement to be able to see how long the firefighters were in a room or an area. They were also asked which type of device they would like to see the visualization on and they thought it would be best viewed on a larger screen, and that they are going to have iPads in all the crew vehicles.

Analysis
Table 5.3 lists the questions asked about the feedback and the evaluation.

Table 5.3: Questions about feedback and evaluation

	Question
1.	Could this system have any negative consequences in terms of feedback and evaluation?
1.1	Could this perhaps make the firefighters focus on different elements of the exercise, knowing that their movements being recorded?
2.	Could this give the firefighters better feedback in retrospect?
3.	Could this system or the data be used in further training of the firefighters? - If yes, how?

Consequences of feedback, evaluation, and focus

When asked if this system would have any negative consequences in terms of feedback and evaluation they responded that they meant the system shouldn't affect the firefighters in a negative manner and that they are so focused on the task at hand that they would not have time to think about the system recording their movements.

Bettering feedback

The interviewees meant that the feedback given to firefighters based on the visualizations would be more thorough. In addition, the firefighter would have the possibility to see where and how he or she has searched through the building.

Usage of of the data in further training

Not everyone is able to perform a smoke dive under the exercise, due to time limitations and the role which they have been assigned. The department leader thought that this could be used to show the movements of the team inside the building on a large screen to facilitate a joint review afterwards. The instructors could then show and give feedback to both firefighters who participated in the exercise and to those who where not able to attend or did not have arole in the smoke diving.

Summary of the interview

The interview gave substantial insight into how the exercise is usually performed. The feedback on the wireframe prototype was that FireTracker would give them clear insight into the system's functionality, and the visualizations would provide a basis for better evaluations and feedback.

5.3 New Requirements

Based on the feedback on the interview, some new requirements were outlined for the next iteration:

- The system should be able to visualize the movements on a floor plan of the exercise buildings.
- The system should be able to handle tracking of multiple firefighters in an exercise.
- The system should give detailed information about the tracked movements of the firefighter.
- The system should be able to be present all relevant session information and data in its entirety.

Chapter 6

Second iteration - Development

This chapter describes the second iteration, the development of a functional prototype.

6.1 Prototype

The initial development of the prototype started with creating the Android application. This application is where the raw Bluetooth-data are generated, and was a good starting point for further determining the data specifications. The development of the web application and web server began when the Android application was able to gather data from surrounding BLE beacons.

The scope of the development of the prototype was added to in this iteration. In the design prototype described in chapter 5, the user had to create the session in the Android application. Based on the feedback received from the interviews in chapter 5, this was changed into having the exercise sessions created in the web application, making the web application into a management tool for the instructors. By having the instructors managing and creating the exercise sessions in the web application, the interaction with the system from the smoke diver's perspective is limited to the mobile device only.

This prototype also includes tracking of sensory data such as gyroscopical data and number of steps taken. In the summary of chapter 5 one of the requirements set was that the system should give detailed information about the tracked movements of the firefighter. By tracking the actual movement data using the sensors on the smartphone, in addition to the signals from the BLE beacons, returned more information about the movements of the firefighter.

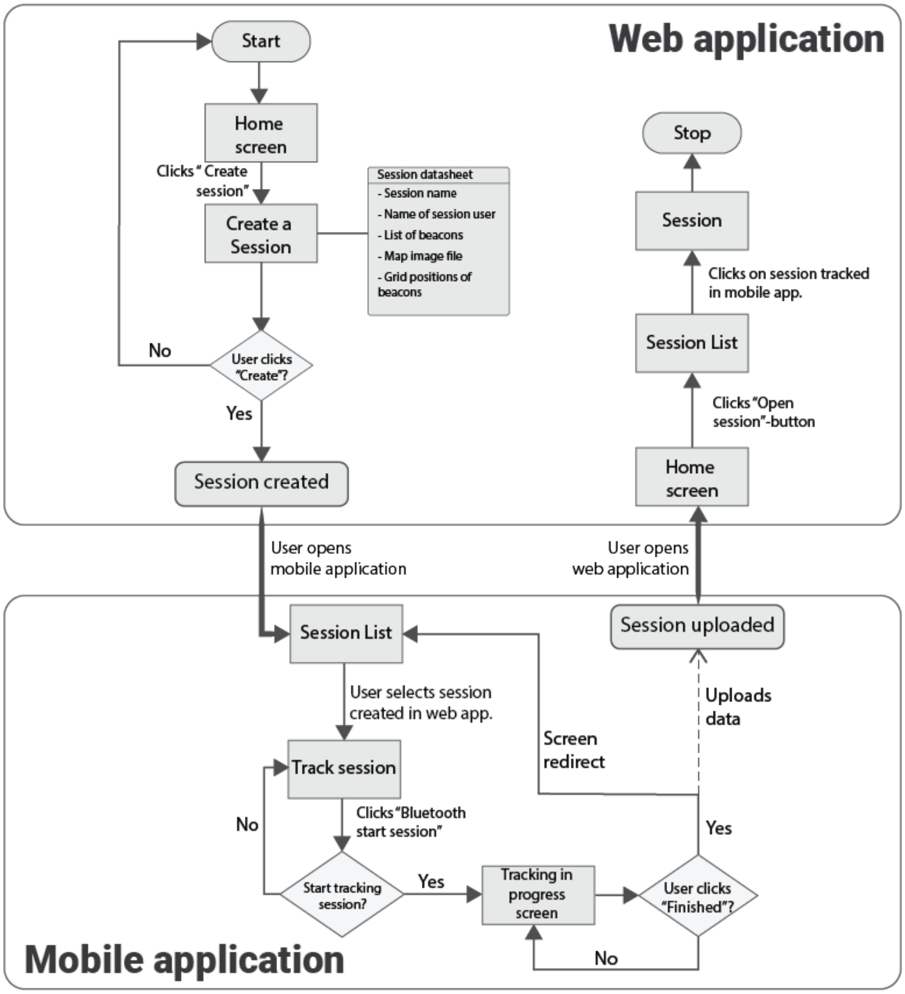


Figure 6.1: Flowchart of the functional prototype

The major change was that the creation of the session was moved from the Android application into the web application. The information space needed for adding the session data and details was greater than what a mobile screen could provide.

One of the requirements outlined in the summary of chapter 5 states that the system should be able to visualize the movements on a floor plan of the exercise buildings. The sketches of the application did not include ways to let the user upload a map for the session and allow them to input the position of the beacons on the map. This was then added into the web application.

Based on this, a new flowchart of the application was outlined, see figure 6.1.

6.1.1 Android application

The development of the Android application started with the wireframe designed in chapter 5, see figure 5.3.

Select a session
Session name: igjen, listefyll
Session user: android
Session name: listefyll android
Session user: android
Session name: må fylle listen i androidappen 1
Session user: android
Session name: Radnom tem
Session user: TEsieman
Session name: Test
Session user: Fredrik

Not currently tracking
00:00
Press the Play-button
to start a tracking session

Currently tracking
ACCEL CHANGED: X -.04| Y -.52| Z -.85
Session user:
Fredrik

Not currently tracking
00:00
Session has ended
Session Test has ended.
Uploading session...
Press the Play-button
to start a tracking session

(a) Session list (b) Tracking activity (c) Active tracking (d) Session uploading

Figure 6.2: Screenshots of the Android application

Figure 6.2 represents the Android application and its different states. Figure 6.2a is the session list. This is the first screen presented when opening the application. This list contains the sessions created in the web application. When a session is clicked, the application redirects the user to the tracking activity. When the tracking state is activated, the application registers BLE signal data from its surroundings. This state is shown in figure 6.2a. When the user has finished tracking the session, the stop button at the bottom can be clicked, see figure 6.2c. When clicked it prompts the user with a question of whether they want to the end the session. If yes it starts uploading the session data to the web server. Figure 6.2d shows the uploading screen.

Sensors

In addition to using the Bluetooth module to collect signal data from the BLE, the use of the accelerometer and gyroscope was also added. This allowed for detecting change of velocity and the device's angular position. The accelerometer was used to detect and estimate the number of steps taken by the device holder. By comparing the number of steps taken in a time interval, it was possible to determine whether the device holder was moving or standing still.

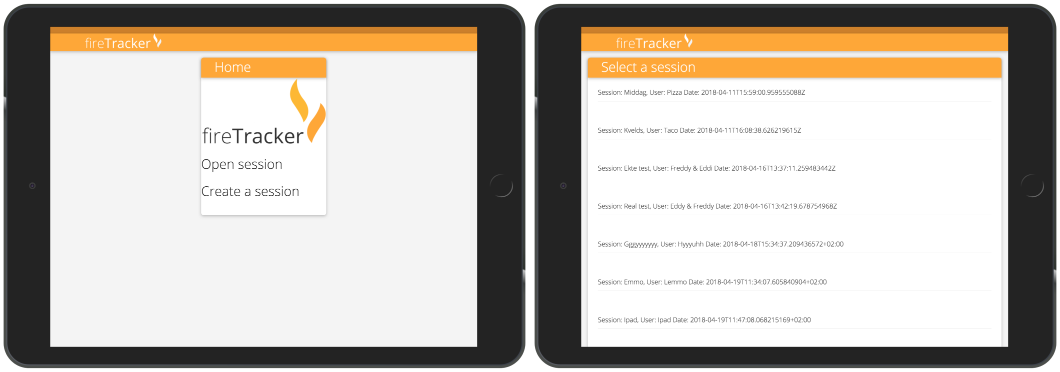
The gyroscope was used to determine the device's relative orientation. At first it was intended to be used as a way of estimating the direction the device holder, but it was discovered that the direction values were relative to the device. Therefore, it was difficult to determine the exact direction, however, by using the same method as with the accelerometer to determine movement, it was possible to compare the time interval with the gyroscope orientation values to see whether the device holder was rotating the device at the given time.

6.1.2 Web application

The web application is based on the designs in chapter 5, see figure 5.5, but has some additions that were not part of the first prototype. The web application is divided into two modules: "Open Session" and "Create Session". The "Open Session" module is where the user can select a session and get a detailed overview of the tracked session. The "Create Session" module allows the user to create a session to be tracked in the Android application.

Open Session module

Figure 6.3a shows the landing page and the following pages of the "Open session" module. The session list in figure 6.3b shows all the finished sessions. When a session is selected, the user is redirected to the session view, shown in figure 6.3c and figure 6.3d.



Select a session

Session: Middag, User: Pizza Date: 2018-04-11T15:59:00.959555088Z

Session: Kvelds, User: Taco Date: 2018-04-11T16:08:38.626219615Z

Session: Ekte test, User: Freddy & Eddi Date: 2018-04-16T13:37:11.259483442Z

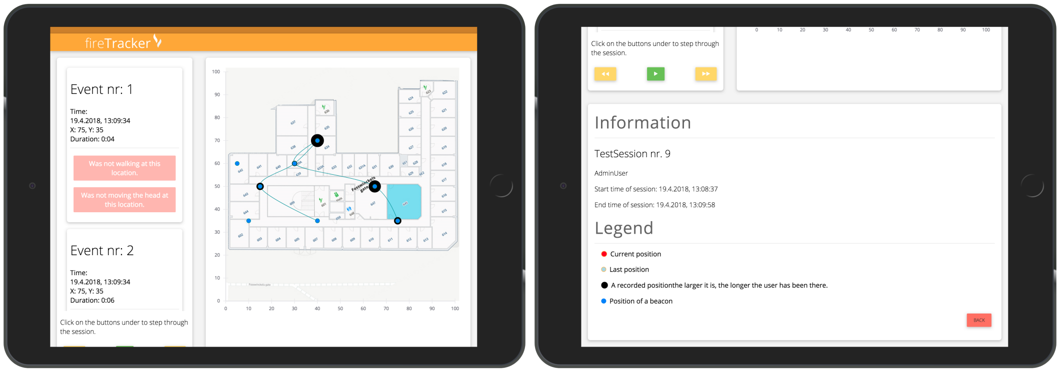
Session: Real test, User: Eddy & Freddy Date: 2018-04-16T13:42:19.678754968Z

Session: Gggyyyyyyy, User: Hyyyuhh Date: 2018-04-18T15:34:37.209436572+02:00

Session: Emmo, User: Lemmo Date: 2018-04-19T11:34:07.605840904+02:00

Session: Ipad, User: Ipad Date: 2018-04-19T11:47:08.068215169+02:00

(a) Landing page (b) List of sessions



Event nr: 1

Time:
19.4.2018, 13:09:34
X: 75, Y: 35
Duration: 0:04

Was not walking at this location.

Was not moving the head at this location.

Event nr: 2

Time:
19.4.2018, 13:09:34
X: 75, Y: 35
Duration: 0:06

Click on the buttons under to step through the session.

Information

TestSession nr. 9

AdminUser

Start time of session: 19.4.2018, 13:08:37

End time of session: 19.4.2018, 13:09:58

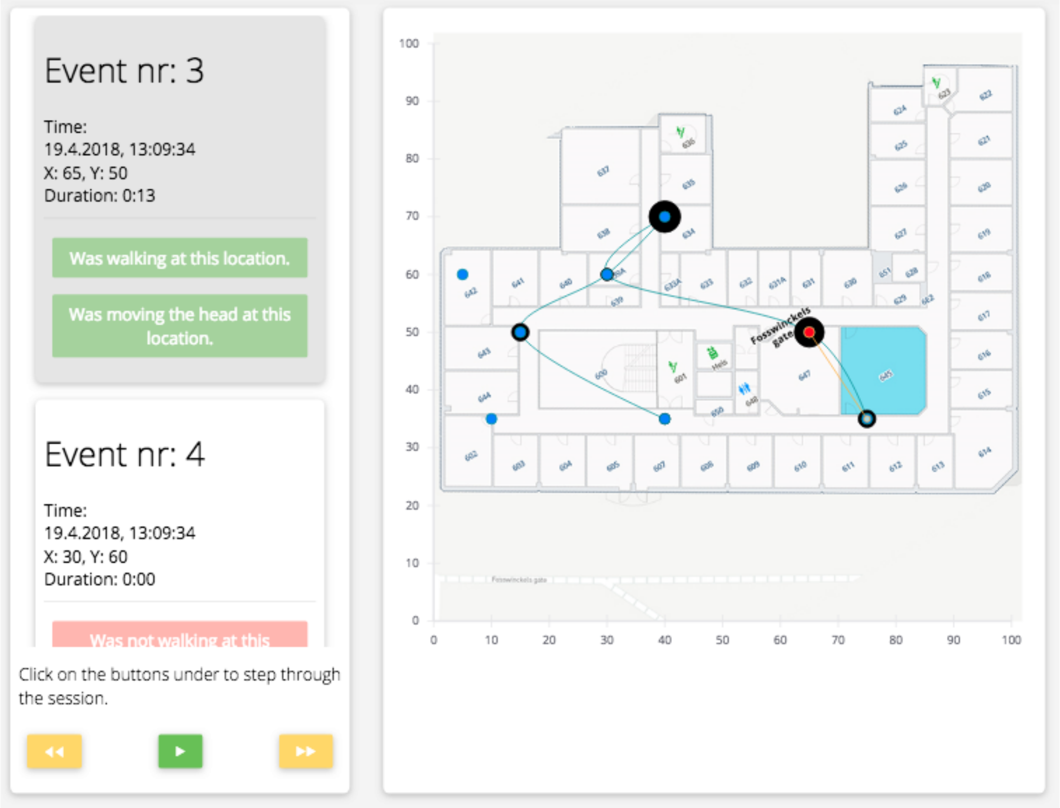
Legend

- 🔴 Current position
- ○ Last position
- ● A recorded positionthe larger it is, the longer the user has been there.
- 🔵 Position of a beacon

(c) Session view 1/2 (d) Session view 2/2

Figure 6.3: Screenshots of the landing page and the pages in the "Open Session" module

The vizualization of the data in this prototype consists of two components, a list of events, which contains the locations and positions of the device holder, and a graph that visualizes these locations on top of an map image file. The list of events, located on the left in figure 6.4, is the main way of interacting with the graph. When a list item is clicked the corresponding coordinates of the clicked event item will be displayed on the graph. Each event in the list contains a timestamp of when the device holder was registered at a location, the actual X and Y coordinates, duration, and how long the device holder stayed at the location. There are also two fields indicating whether the device holder was walking at that location and whether the device was rotating at the location. See figure 6.4 for an example.



Event nr: 3

Time:
19.4.2018, 13:09:34
X: 65, Y: 50
Duration: 0:13

Was walking at this location.

Was moving the head at this location.

Event nr: 4

Time:
19.4.2018, 13:09:34
X: 30, Y: 60
Duration: 0:00

Was not walking at this

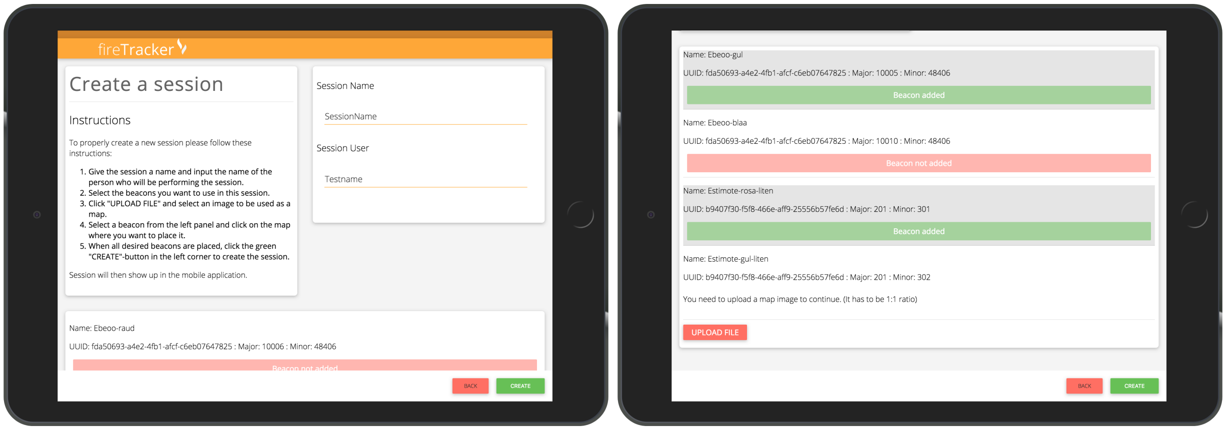
Click on the buttons under to step through the session.

Figure 6.4: Selected location displayed in graph

The red node displays the selected event, while the connected blue node is the previous event. These nodes moves to the position of the selected event. The user has two ways of interacting with the graph. The first is that the user can click on the event element in the list, which updates the graph with the clicked event, the second is using the buttons that can be seen in the bottom left of figure 6.4. These buttons allows the user to either play all of the locations in a sequence or to skip back and forth between the locations. This functionality also updates the graph showing the current location.

Create Session module

The "Create Session" module consists of one page. It's a scrollable page, and can be seen in in figure 6.5a.



Create a session

Instructions

To properly create a new session please follow these instructions:

1. Give the session a name and input the name of the person who will be performing the session.
2. Select the beacons you want to use in this session.
3. Click "UPLOAD FILE" and select an image to be used as a map.
4. Select a beacon from the left panel and click on the map where you want to place it.
5. When all desired beacons are placed, click the green "CREATE"-button in the left corner to create the session.

Session will then show up in the mobile application.

Session Name: SessionName

Session User: Testname

Name: Ebeoo-raud
UUID: fda50693-a4e2-4fb1-afcf-c6eb07647825 : Major: 10006 : Minor: 48406

(a) Create a session page 1/3

Name: Ebeoo-gul
UUID: fda50693-a4e2-4fb1-afcf-c6eb07647825 : Major: 10005 : Minor: 48406

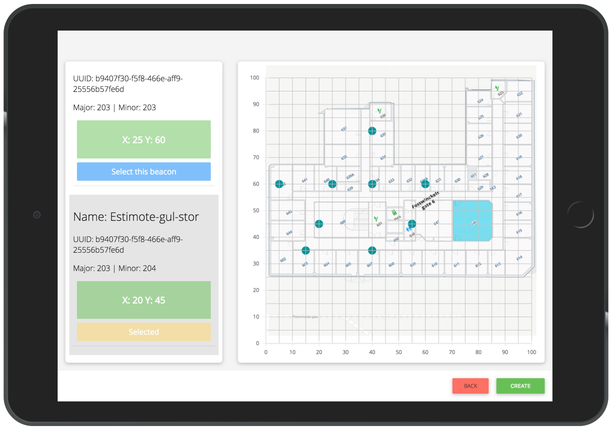
Name: Ebeoo-blaa
UUID: fda50693-a4e2-4fb1-afcf-c6eb07647825 : Major: 10010 : Minor: 48406

Name: Estimote-rosa-liten
UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d : Major: 201 : Minor: 301

Name: Estimote-gul-liten
UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d : Major: 201 : Minor: 302

You need to upload a map image to continue. (It has to be 1:1 ratio)

(b) Create a session page 2/3



UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d
Major: 203 | Minor: 203

Name: Estimote-gul-stor
UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d
Major: 203 | Minor: 204

(c) Create a session page 3/3

Figure 6.5: Screenshots of the "Create Session" module

When opening the "Create Session" module, the first element the user sees is a set of instructions on how to create a session. The user has to give the session a name, and input the user of the session. This can be seen in figure 6.5a. The reason for this is to allow the user to identify the session, both in the Android application and when to see the session's visualization in the "Open Session" module.

Figure 6.5b shows the beacon selector for the session. This is where the user selects which beacons to be used in the session. In this prototype the beacon data has to be written manually into the database as there is no way of using the web application to add new beacons. The user also has to upload an image of the map over the area of the session. The image is then uploaded immediately underneath the grid shown figure 6.5c. On the left side of the map is a list of all the selected beacons. The user is then able to select a beacon by clicking the list element and then clicking on the map where it is to be placed. When a beacon is placed on the map, a node is shown on the beacons position, and the beacon element in the list is updated with the actual coordinate.

6.1.3 Data specifications

In order to communicate the data between the components it needed to be in a format that could be read and written by the different applications and services in the system.

Session JSON structure

The main data object is the Session-object (figure 6.6), it contains properties that define its name, name of user, start and end time, the URL to the map image, and whether if its finished or not. The "finished" is used to determine which state the session is in.

```
{{
  "ID": <int>,
  "CreatedAt": <string>,
  "UpdatedAt": <string>,
  "DeletedAt": null,
  "Name": <string>,
  "User": <string>,
  "StartTime": <long>,
  "EndTime": <long>,
  "Datapoints": [],
  "Beacons": [],
  "Locations": [],
  "Finished": <boolean>,
  "Map": <string>
  }}
```

Figure 6.6: JSON structure of the Session-object

When the user first creates the session in the web application, the "Finished" property is set to "false". This means that the session has not been used yet, but is ready for tracking in the Android application. The Android application only displays sessions where this property is set to "false", meaning that the user cannot reuse an already tracked session. When the session has been uploaded from the Android application, the web server calculates the locations based on the sensor data. After this calculation is finished it sets the property to "true". In the web application, the list of sessions consists only of sessions that has the property set to "true". In this state, the session contains the location data and can be used for visualization.

The properties "ID", "CreatedAt", "UpdatedAt", and "DeletedAt" are generated automatically by the web server when the session object is created in the web application. It also contains three other array objects: "Datapoints", "Beacons" and "Locations".

Datapoint JSON structure

The datapoint objects are stored inside the Session-object. These are the objects where the signal and sensor data is stored. This occurs when the tracking in the Android application is finished, the object is then populated by the data gathered both from the BLE beacons and the device's sensors. The application generates a datapoint object for each measurement of the data. The data is later used to calculate and estimate the locations of the session user.

```
{{
  "SessionId": <int>,
  "UUID": <string>,
  "Major": <string>,
  "Minor": <string>,
  "Timestamp": <int>,
  "RSSI": <int>,
  "Steps": <int>,
  "RotationX": <float>,
  "RotationY": <float>,
  "RotationZ": <float>
  }}
```

Figure 6.7: JSON structure of the Datapoint-object

"SessionId" is the identification number of the session that the datapoint belongs to. The properties "UUID", "Major", "Minor" are the identifiers from the beacon it receives the signal from. "RSSI" is the signal strength. "Steps" are the number of steps the device holder has taken since starting the tracking of the session. This number is generated with the help of the accelerometer. "RotationX", "RotationY", and "RotationZ" are the relative angular position of the device.

Beacon JSON structure

The beacon objects are used to determine which beacons are used in the session and their position in a two-dimensional grid. A session can contain multiple beacons.

The properties "UUID", "Major", and "Minor" are the identifiers of the beacon. "XCoordinate" and "YCoordinate" are the position of the beacon on a two-dimensional grid, which is used together with the the datapoint to estimate the location of the device holder.

```
{{
  "UUID": <string>,
  "Major": <string>,
  "Minor": <string>,
  "RSSI": <int>,
  "Name": <string>,
  "XCoordinate": <float>,
  "YCoordinate": <float>,
  }}
```

Figure 6.8: JSON structure of the SessionBeacon-object

Location JSON structure

This object stores the coordinates and the results of the sensor data. The Location objects are the result of the calculations made on the datapoint objects.

```
{{
  "ID": <int>,
  "CreatedAt": <string>,
  "UpdatedAt": <string>,
  "DeletedAt": null,
  "SessionId": <int>,
  "XCoordinate": <int>,
  "YCoordinate": <int>,
  "Duration": <int>,
  "Walking": <boolean>,
  "HeadMovement": <boolean>
  }}
```

Figure 6.9: JSON structure of the Location-object

The properties "XCoordinate" and "YCoordinate" define the estimated coordinates on the grid where the device holder were located. "Duration" is the amount of time the device holder stayed at the location, and "Walking" and "HeadMovement" indicates whether if the device holder was moving, or moving their head at the location.

6.2 Test of the prototype

The prototype was tested by the training leader of SFRS. After the test an interview was carried out to gain feedback on the practical design and to find it how the prototype was perceived.

The purpose of this test was to get the impressions and thoughts about the usability of the system from the training leader. The test location was SFRS department building in Ågotnes at Sotra Island. The training leader used an iPad for running the web application. The test included a general introduction to the system, what the different components were made up of and how they were related to each other.

The training leader was observed during the test, he was able to ask the researchers question about its usage and the researchers took notes during the entire course of the test.

The test started with creating a session. He was able to use the iPad's integrated camera to take a picture of the map. The map used was a fire exit plan of the department. The next step was to place the beacons around the floor for tracking. This was done by selecting the beacon from the list of beacons in the session (as seen in figure 6.5c) and placing them at his current location, relative to the map.

After the beacon placements and the session was created, the next step was the tracking of the beacons with the Android application.

After the tracking was performed the session was uploaded to the server and opened in the "Open Session" module for review.

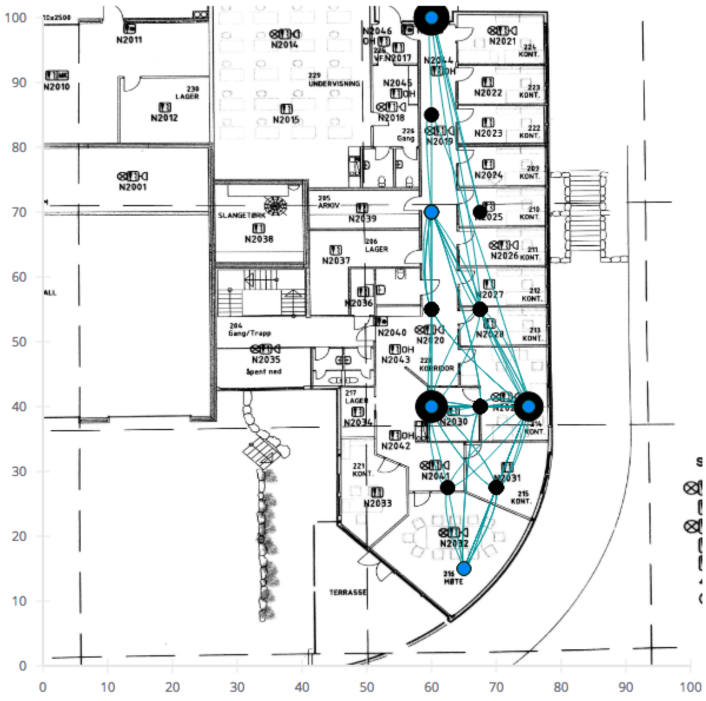


Figure 6.10: Map of the test session done at SFRS station

The graph in figure 6.10 shows a map of the office floor in SFRS station in Ågotnes. The blue nodes on the graph shows where the beacons were placed. The black nodes are recorded positions.

6.2.1 Interview with the training leader

The interview's purpose is to get the training leader's initial thoughts and opinions about the prototype and how it's utilized. The interview started right after the testing was done. The interview guide can be seen in Appendix D.

The interview questions where separated into four different categories: Practical aspect of the prototype, the user interface and user experience, visualization of the session, and data extraction. The training leader was interviewed for 30 minutes, it was audio recorded and transcribed.

Table 6.1: Questions about the practical aspect of the prototype

	Question
1.	How was it setting up a session, in terms of input of the relevant information and placing the beacons?

When asked about how it was to set up a session, see table 6.1, the training leader said that it was simple and painless. He elaborated that it was easy to upload the map by taking a picture with the iPad directly in the web application, and also to place the beacons in the web application.

Table 6.2: Questions about the user interface and user experience

	Question
1.	Were there parts of the system that was noe easy to understand or use? If yes, what can be done simpler or explained better?
2.	Does the system give enough information about how it's supposed to be used? If not, what is missing?

Table 6.2 shows the questions asked about the ease of use, and how the actual user interface was perceived.

The training leader found the system to be both easy to use and understand. He said that he quickly learned its use even though this was the first time using it.

When asked if there was enough about its use, he said that there should be a manual on how to use the system. The reason for this was so that the users could get to know the system before taking in to use. He also said that the system's text should be in Norwegian, as it would make the use of the system easier.

The training leader was asked what he thought about the visualization, see table 6.3. It was a little challenging at first, he said. One of the things that he pointed out was that the list of locations and the map were not displayed within the screen. To see everything correctly it was necessary to scroll up and down on the page. This issue was only present when viewing on an iPad, but as he stated, this is the device they'll most likely use in the on-site evaluation of the exercise.

Table 6.3: Questions about the visualization of the session

	Question
1.	What did you think of the visualization of the session?
2.	Did you get enough information about the session?
3.	Was there anything unclear in the graph or the map?
4.	In its current state, how can the visualization of the session be used?

The leader felt he had enough information abot the session. The timestamps of the location, duration on each location, and the using the map as reference gave a lot of information that can be used in the evaluation, he said. He mentioned that the duration could be used for discussing their use of time at that specific location.

The training leader felt that most of the graph were clear, except for the amount of points on the graph. He also mentioned that he was was a bit biased, as he was the one to place the beacons in the area and plotting them into graph. He also said that if a person not involved with the creation of the beacon were to see this, it would have been difficult for that person to understand the graph.

The leader said that the visualization would be very difficult to interpret, because of the number of points in the graph. It made it cluttered and it was not easy to follow the path of the device holder.

Next, he was asked bout the the data, see table 6.4.

Table 6.4: Questions about the data extraction

	Question
1.	What do you think of using data about head movements to see if a firefighter is active during the exercise?
2.	Would a visualization of the amount of sound be interesting? I.e. too see on the graph where the firefighters communicated?
3.	The mobile application has a step counter implemented to see whether a firefighter is moving or not inside the exercise area, is this information interesting?
3.1	Would it also be interesting to see the actual counted steps, and an estimated distance based on these steps?

When asked about if would be good to show data about the firefighters head movements, he said that it could be too much data, as the firefighters are in constant movement, and it would maybe be difficult to distinguish when they are moving or not. However, he stated that this is not so important as the top priority and the most interesting aspect of the system is the movement tracking.

When asked about visualizing sound on the graph, he said that this could be of interest. It would be possible to see where and if they reported points of interests, such as a staircase.

The training leader said it would be interesting to see the number of steps they walk, as it could be used to see how active the firefighters have been in their footwork during the exercise.

Summary of the interview

The training leader confirmed many of the design choices and the implementation that were made. The practical aspects of the prototype, such as placing the beacons and creating of the session were described as simple and painless. The visualization had a few issues such as the graph being difficult to interpret due to many points and issues with the viewport and the display on certain devices. There was also expressed an interest in sound and other sensory data, but the priority should be in visualizing movement in the graph.

6.3 New Requirements

Based on the on the testing and the interview with the training leader, two new requirements were set for the next iteration:

- The system should be able to fully display the graph and its information on the screen of the device.
- The system should provide a user manual that explains how to use the system.

Chapter 7

Third iteration - Refinement

This chapter addresses the third iteration, where the mobile application and the web application were redesigned. It also presents the development of a new module, the user manual module.

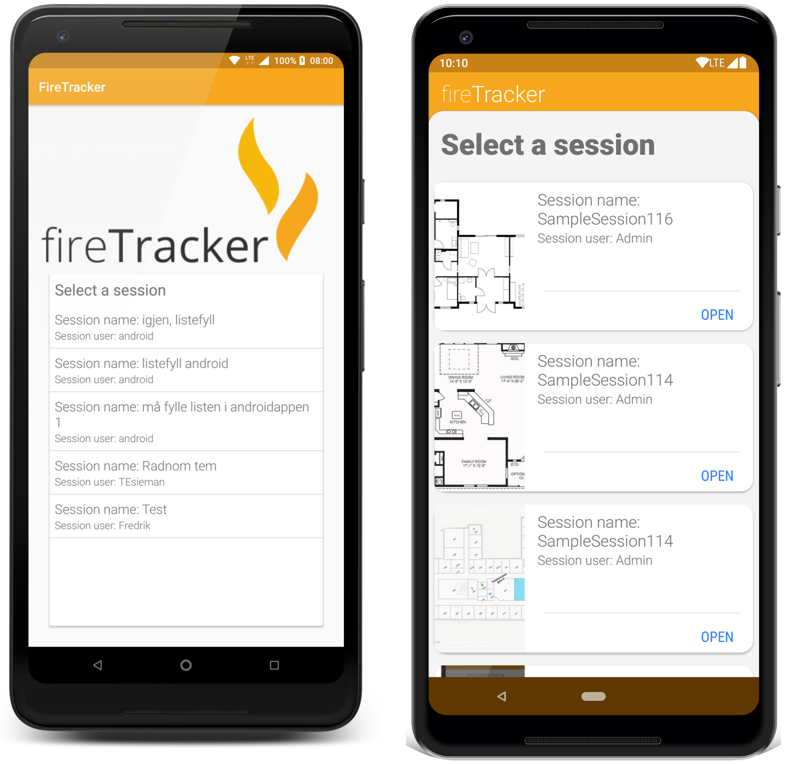
7.1 Redesign

This iteration began with a redesign of the web and mobile applications. The main goal for this was to make the applications not only more visually appealing, but also to improve usability of the applications based on the feedback.

The web application's design was updated to adapt better to the different screen sizes, meaning that the application can be used on several screen sizes from mobile to desktop. Based on observations of the prototype in use and user feedback, there was room for improving several parts of FireTracker, to better meet the goals of supporting firefighter training.

7.1.1 The mobile application

The redesign of the mobile application focused on highlighting the session list, where the users selects a session for tracking.



Select a session

Session name: igjen, listefyll
Session user: android

Session name: listefyll android
Session user: android

Session name: må fylle listen i androidappen 1
Session user: android

Session name: Radnom tem
Session user: TEsieman

Session name: Test
Session user: Fredrik

Select a session

Session name: SampleSession116
Session user: Admin

Session name: SampleSession114
Session user: Admin

Session name: SampleSession114
Session user: Admin

(a) Session list before redesign (b) Redesigned session list

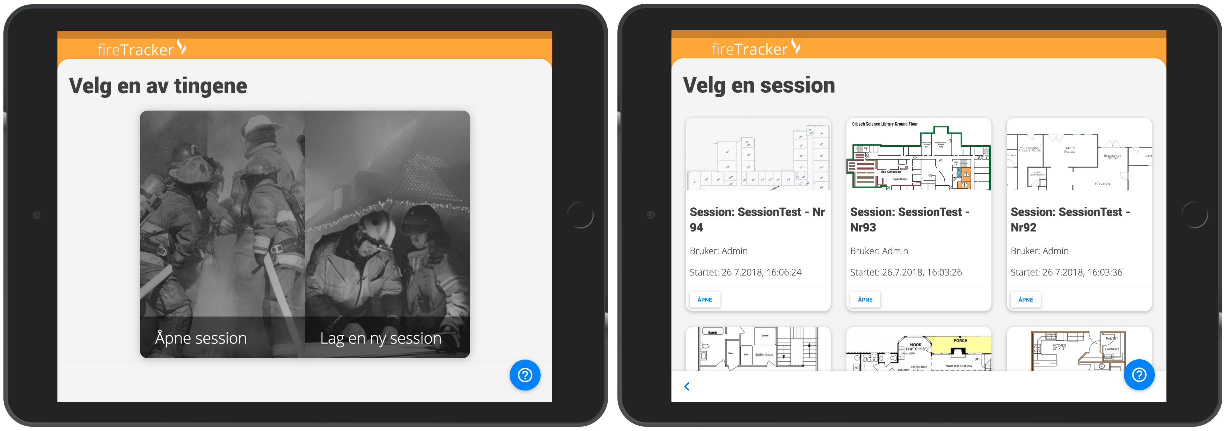
Figure 7.1: Screenshots of the mobile application, before and after redesign

The largest change in the session list was that the sessions are listed as separate elements. It also displays the map image of the session. The map image enables the user quickly to identify which session they want to use. The functionality of the list remains the same. The previous design, see figure 7.1a, was more basic. It listed up the name of the session and the user, and the session elements had little visual separation in the list.

7.1.2 The web application

The redesign of the web application focused on highlighting the available interactions, such as buttons and making clear which actions the user could perform, see figure 7.2.

The home page (figure 7.2a) was redesigned to highlight the main actions of the application. The images are clickable and cover a large area of the screen, making it easy for the user to click it using a touch screen.



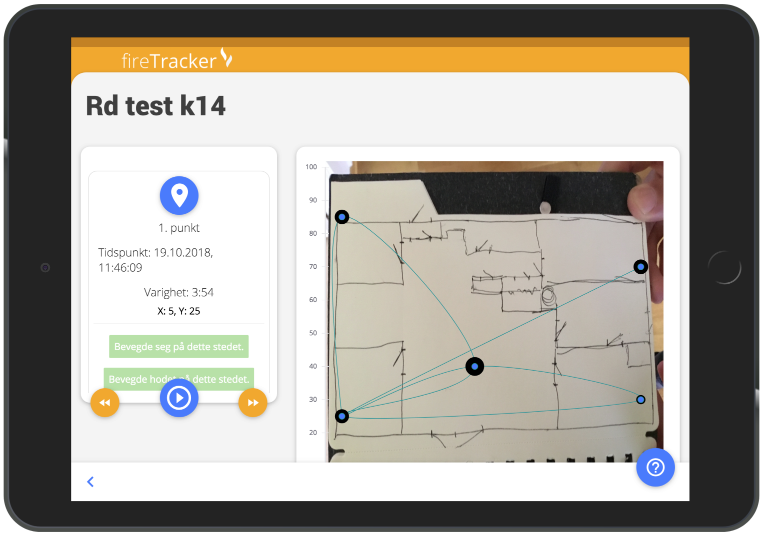
Session: SessionTest - Nr 94
Bruker: Admin
Startet: 26.7.2018, 16:06:24

Session: SessionTest - Nr93
Bruker: Admin
Startet: 26.7.2018, 16:03:26

Session: SessionTest - Nr92
Bruker: Admin
Startet: 26.7.2018, 16:03:36

(a) Redesigned homepage

(b) Redesigned list of sessions



1. punkt
Tidspunkt: 19.10.2018, 11:46:09
Varighet: 3:54
X: 5, Y: 25
Bevegde seg på dette stedet.
Bevegde hode... å dette stedet.

(c) Redesigned session view

Figure 7.2: Screenshots of the "Create Session" module

The redesign of the session list (figure 7.2b) focused on the same elements as the redesign of the mobile application, highlighting and separating the sessions.

Another addition is a fixed button in the bottom right corner. That enabled the user to access the user manual where the functionality of the system is explained.

The redesign also took mobility of use into consideration. Smoke diving exercise are very much mobile events, therefore the actions of applications must be prominent and intuitive, so that the user knows exactly what actions are available in the several modules of the application.

The session was redesigned to show only the current selected location, see figure 7.2c. The functionality remains the same as described in section 6.1.2.

7.2 The user Manual module

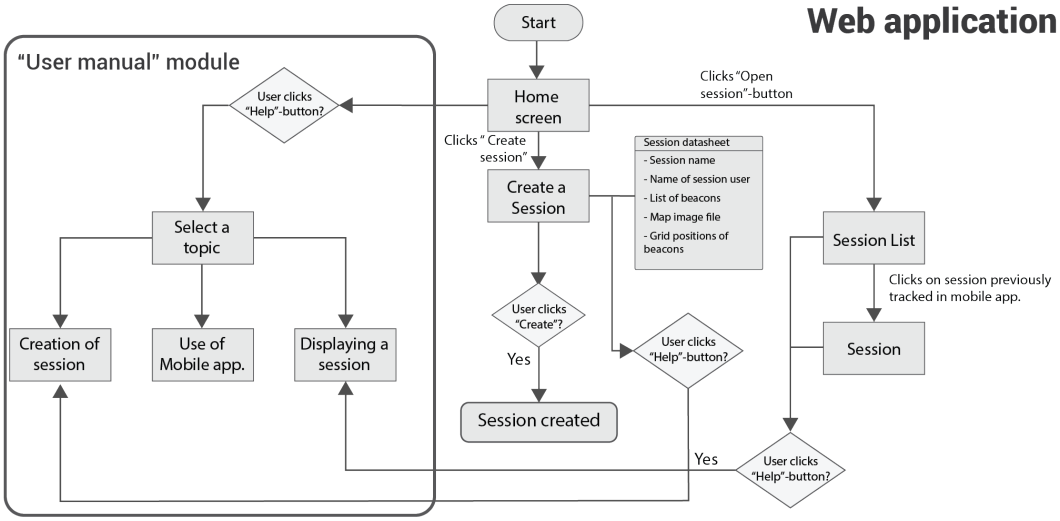


Figure 7.3: Flowchart of the web application with the User Manual module

In the interview after of the test of the prototype in the second iteration (see section 6.2.1) the training leader said that our system, FireTracker, would require a manual explaining how to use it.

One of the requirements set in after the test of the second prototype (see section 6.2.1) was the the system should provide a user manual that explains how to use the system.

The flowchart (see figure 7.3) shows the web application together with the user manual module. The user can access the user manual from every part of the web application. For example if the user is currently in the session list in the "Open Session" module, the user can click the fixed "Help"-button in the right corner, and will then be redirected to the manual page describing the session list, the "Help"-button can be seen in figure 7.2b.

Figure 7.4 shows the page that displays the manual for all of the modules. This page can only be accessed from the home page.

The manual pages are used to describe to the user what the module contains, and how to use it. Figure 7.5 shows the manual for the creation of a session. The manual is split in three sections: Input of the session's name and user, the selection of available beacons, and the assigning of beacons to the map.

The user is able to to go back and forth between these sections, by using the on-screen navigation buttons on each side of the screen. The sections are also paginated, there is an page indicator in the middle of the on-screen navigation buttons. When the user is on the last page, the button on the right-hand side the icon is changed into an "X", signifying that this an exit button. It allows the user to return to either the main page

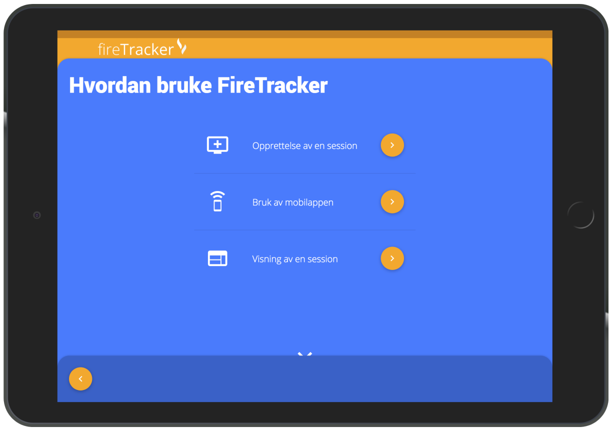


Figure 7.4: Screenshot of the "Select user manual" page

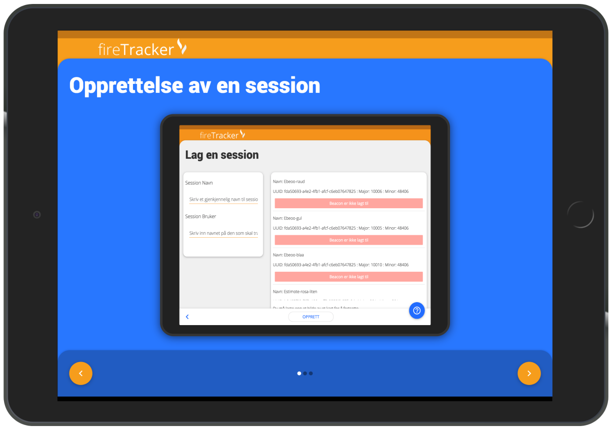


Figure 7.5: Screenshot of the first manual page of the "Create Session" module

of the user manual (figure 7.4), or back to the module from where the manual was opened.

7.3 Heuristic Evaluation

The prototype in this iteration was evaluated by four IT experts using Nielsen's heuristics. The reason for evaluating the prototype with Nielsen's heuristics is the limited access to the intended user group, the firefighters and instructors of SFRS. The IT experts are Information Science master students in the Department of Information Science and Media Studies. The heuristic evaluation consisted of two phases. The first phase was a general run-through of the entire system and the second phase was the actual evaluation. The first phase lasted for 15 - 20 minutes, and in the second phase, the expert took about 30 minutes evaluating the system. A full description of the heuristics can be found in Appendix A

The experts were asked to evaluate the system one heuristic at a time, and were asked to identify usability problems, meaning if they found an issue that caused confusion in the use of the system or an error they would report it as a problem. They were also instructed tell which parts of the system they thought matched with the heuristics. The experts used an iPad for testing the web application, along with a smartphone for the mobile application. They also had access to Bluetooth beacons for testing the tracking.

The data was collected by audio recording, and transcibing the recordings, the audio recordings totalled 1 hour and 50 minutes. Notes were also taken during the evaluation. The experts were left to their own devices, but a researcher was present for observation and for technical issues or questions.

7.3.1 Evaluation results

The results of the evaluation brought several usability issues to our attention, and also affirmed many of the design choices taken. The results are presented as a summary of the experts individual assessment.

Visibility of system status

The experts found that the system is in accordance with the visibility of system status heuristic. By having a title on top of every page, it shows the user what part of the system is currently in use. This applied to both the web application and the mobile application. When tracking, the mobile application showed whether it was tracking or not. This was shown by an icon changing its color when the tracking state changes, as can be seen in figure 6.2b and figure 6.2c.

One of the experts noted that the system also shows the user when its loading data from the web server; this is displayed with a rotating gear icon.

Match between system and the real world

All of the experts agreed that the language in the system matched the conventions used in the real world. The language used, especially in the user manual, was descriptive and explained most of the actions very well.

However, the experts also found problems with the system. One of the experts said that the word "session" was not a good choice, since the system language is in Norwegian. It was found to be forced and unnatural. The word "økt", the word for "session" in Norwegian, was proposed.

Several of the experts also reported a problem with the natural order and logic in the "Create Session" module. One of the experts said it was difficult to identify which task was to be done first when opening the module. It was said that the list of available beacons drew too much attention and caused difficulties in discerning the order of the tasks that had to be done.

User control and freedom

In the web application, the experts reported that they could easily leave the unwanted state by using the navigation bar in the bottom of each page. It was said that it was quite useful in the "Create Session" module, as many of the experts thought this module to be difficult and confusing to use.

One of the experts also mentioned that the user manual module was lacking a clear and defined "exit"-button. To exit the user manual the user has to click through to the last page of the manual to get back to where to the module was opened from. However, when the "Backwards" button was pressed on the first page, it took the expert back to the select user manual page.

Another expert said that the map in the "Create Session" module would benefit from having a method to clear the uploaded image and the beacons plotted onto the map.

Consistency and standards

The experts agreed that the system was consistent, there was little doubt as to what the functionality of the buttons and which actions they performed, both in the web application and the mobile application.

There was a problem, however, with the selection of the beacons in the "Create Session" module. All of the experts said that the selection of the beacons was not obvious. There were no clear indicators on how to select a beacon, the text bar only stated that the beacons were not selected, and had no signifiers on how to actually select the beacon. Another expert noted a lack of consistency in the text bar; it was said that the bar resembled more of a status bar, and did not seem clickable. The main reason for this was that the bar had the same design as other elements in the system that indicated the state or current status.

Error prevention

The experts noted that there where few places in the system where errors could be made. If the user attempts to create a session before the necessary data is input, a pop-up dialog shows up describing what kind of data is missing. The session is not created and the user is given a chance to input the missing data.

In the mobile application an expert discovered that it was possible to cancel the uploading of the session after the tracking was stopped. This was an unexpected feature, and was considered to be a serious problem.

Another problem was discovered when one of the experts clicked on the "Help"-button in the middle of the creation of a session. The expert had already input name and selected beacons, before accessing the manual. When the expert returned to the "Create Session" module, the inputted data was reset. The expert suggested that the information should be retained when returning from the user manual, or that there should be a confirmation option that informs the user of what is to happen when entering the user manual.

Recognition rather than recall

Many elements of the system where perceived as intuitive; especially the "Help"-button. They said there was no doubt of what the button did and if instructions were ever needed, it was easily retrievable from anywhere in the system.

Flexibility and efficiency of use

The experts did not have much to add about flexibility and efficiency of use. There were few ways that the system could benefit from adding accelerators. One of the experts said that perhaps adding a shortcut, or a suggestion for what to do next, after the session was created could be useful.

However, all of the experts said there were no need for accelerators that could cater to both experienced and inexperienced users.

Aesthetic and minimalist design

It was said that the aesthetics were consistent in both the mobile application and the web application. The colors were used consistently in both applications. In the "Open Session" module, the elements in the list of sessions were easily distinguishable and the actions related to elements were clearly visible.

All of the experts reported the same issue with the list of available beacons in the "Create Session" module. They thought it to be very confusing and difficult to understand because each beacon contained a lot of technical information. This information competed directly with the information actually necessary to select the beacons.

Help users recognize, diagnose and recover from errors

The only error message that could be found in the system was when trying to create a session before all the necessary data was input.

All of the experts said that the text in the error message was clearly understandable and indicated the problem. However, several of the experts said that the message could be more granular, as the message stated all of the possible issues. It would be more helpful if it stated exactly what information or data was missing or contained an error.

Help and documentation

The documentation of the system was pointed out as being more than adequate. The experts said that the language was clear, navigation was simple and intuitive, and the content was very helpful in answering their questions about the usage.

It was reported that it would be beneficial if the mobile application also provided a way of accessing the user manual.

Summary of the evaluation

The evaluation yielded useful results. By using Nielsen's heuristics the experts were given strict guidelines on what to evaluate and it kept the evaluation more concise and focused. Some of the uncovered problems were unknown prior to the evaluation, and the feedback on the "Create Session" module indicated that the module needs to be reworked to increase its usability. The "Create Session" module was reported as cluttered and difficult to use. Even after the experts learned and memorized how to use the module, they said it that there was a lot of distracting information being displayed. There were also reports on other issues, such as mismatching words between norwegian and english, error messages when trying to create a session and resetting of inputted data when opening the user manual module.

In total, the experts found 31 usability problems, where 21 of them where unique. The list of issues can be found in Appendix F.

7.4 New Requirements

The usability problem identified during the heuristic evaluation will be the primary focus of the next iteration.

Chapter 8

Fourth iteration - Finalizing the prototype

This chapter describes the finalization of the prototype. The usability issues discovered in the evaluation of the third iteration were corrected. A new module for managing the beacons was also developed.

In the previous iteration the evaluation of the prototype discovered several issues that impacted the user experience and usability. This resulted in a list of issues, see Appendix F. These were ranked after the number of occurences, the more experts found it to be an issue, the higher the priority. Most of these issues had concrete solutions, like consistency in various elements or simply fixing bugs, but there were other issues that required a more complex solution.

8.1 Usability issues

This iteration describes primarily the issues concerning the "Create Session" module. As mentioned in the evaluation of the third iteration (see section 7.3). It was clear that the "Create Session" module had difficulties matching up with the heuristics.

All of the issues seen in Appendix F were corrected, but not all of them are described in this chapter. This chapter focuses on the issues regarding the "Create Session" module.

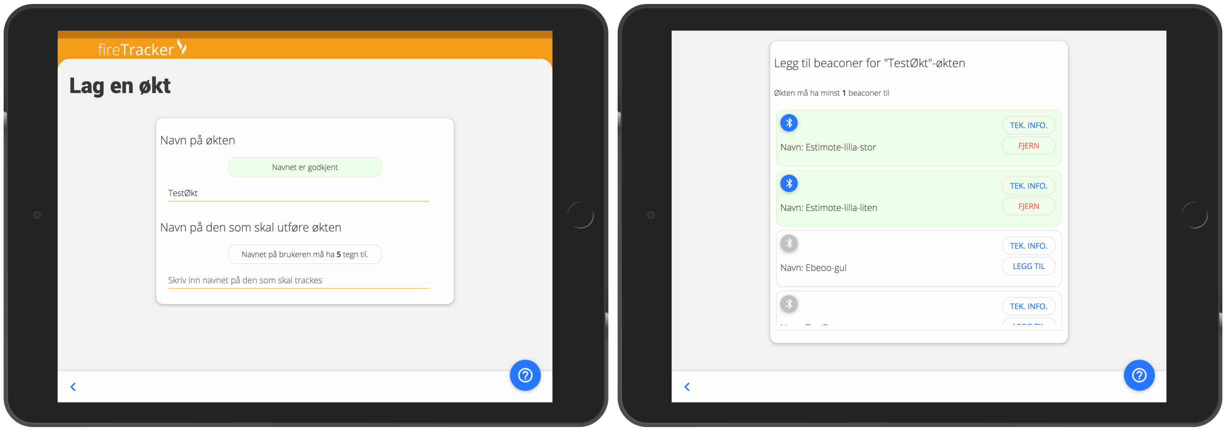
8.1.1 Issues in the "Create Session" module

Out of the 21 unique issues the experts found, 15 of them were related to the "Create Session" module. The issues concerning the "Create Session" module are listed in table 8.1.

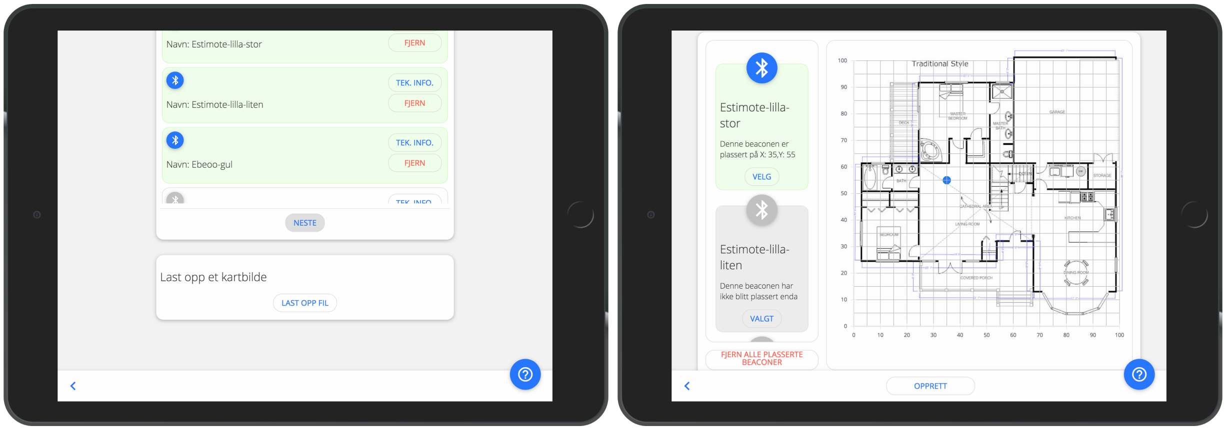
Table 8.1: Issues regarding the creation of sessions

Rank	**Issue**	**No. of occurence**
1	Too much technical information in available beacon list, not sure of what information was relevant	4
2	Not sure on how to select an available beacon, not sure if it contained a button or a status bar	3
4	Difficult to know what task to be done first in "Create Session" module	2
5	Error message in "Create Session", URL in message was cryptic	2
6	Difficult to know what to do after beacons are placed on map	2
7	After filling out name, user, and selecting available beacons, not sure if "Create Session" was going to be clicked or "Upload Image"	2
8	Error message when trying to create a session did not change, not sure what was wrong with session	1
9	The word "Session" did not make sense in a Norwegian context	1
10	Difficult to know what to do after a session is created	1
11	Confusion as to why list of "Available beacons" had "Upload Image"-button it	1
12	After placing beacon on map, there was not a clear confirmation that the beacon had been placed	1
13	Was able to ignore the error message when creating a session so that it didn’t pop up again if a new error was made	1
16	No error message if the web application had no internet connection	1
20	When replacing an already placed beacon, a new the old position of the beacon was not removed	1
21	When accessing the user manual from the "Create Session" module, the input data was removed and user had to start over again	1

The "Create Session" module was completely reworked. The module had been mainly untouched since the second iteration and consisted of several tasks that had to be completed in two steps. The first step included the input of the name and user, selecting beacons, and uploading the map. The second step was placing the beacons and creating the session. This can be seen in figure 6.5.



(a) Naming the session and user (b) Available beacons



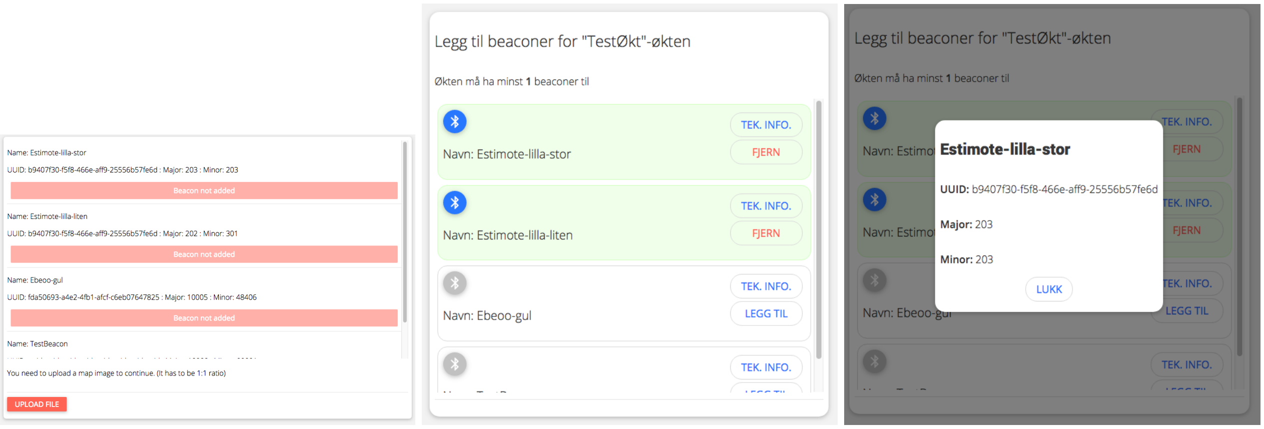
(c) Uploading map (d) Placing the beacons

Figure 8.1: Screenshots of the steps in the "Create Session" module

The largest changes are the tasks are now separated into four steps, intead of two. It also includes a popup with a summary where the user has to confirm the creation of the session, figure 8.1 shows the order of the steps.

This type of step-structure allows for large improvements in error handling and prevention, which was also an issue several of the experts mentioned. By checking the input data for each step the errors can be caught and corrected in time so that the session is created properly. It also gives the user a way to recognize the errors immediately, where in the previous iterations the data was checked and given an error message when the session was created.

A more detailed explanation is that the system now gives the user proper feedback if data is not input correctly. In figure 8.1a and figure 8.1b the user has to fulfill a minimum requirement to continue. In figure 8.1a the user has a minimum limit of characters to input for the session name and the name of the session user, and in the 8.1b the user has to select at least three different beacons to use in the session. When the minimum requirement is fulfilled, the user is given proper feedback in form of a green text box and a text saying that the requirement has been met, and the appearance of a button with a label saying "Next". This button takes the user to the next step.



Name: Estimote-lilla-stor

UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d : Major: 203 : Minor: 203

Name: Estimote-lilla-liten

UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d : Major: 202 : Minor: 301

Name: Ebeoo-gul

UUID: fda50693-a4e2-4fb1-afcf-c6eb07647825 : Major: 10005 : Minor: 48406

Name: TestBeacon

You need to upload a map image to continue. (It has to be 1:1 ratio)

Legg til beaconer for "TestØkt"-økten

Økten må ha minst **1** beaconer til

Navn: Estimote-lilla-stor

Navn: Estimote-lilla-liten

Navn: Ebeoo-gul

Estimote-lilla-stor

UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d

Major: 203

Minor: 203

(a) Previous list of available beacons

(b) Reworked list of available beacons

(c) Pop-up dialog of beacon information

Figure 8.2: The previous and reworked designs of the available beacons list

The highest ranking issue was the list of available beacons, as seen in table 8.1. They said it that the amount information each beacon element contained was distracting, and that it was difficult to know exactly what to look for when selecting beacons for the session. They said that it wasn't necessary at this point in the creation process to see the technical details, such as the UUID and the Major/Minor values (See figure 8.2a). This issue was reported by all of the experts.

The solution was to separate the technical information from the list itself into a pop-up dialog. The pop-up dialog can be opened by clicking the "Tek.Info"-button on each list element in the beacon list. (See figure 8.2b and 8.2c) In the list element, the only the beacon name remains.

There were several issues with this list, another issue was that the experts reported was the ambiguity of the status bar in the previous design. The status bar indicated whether the beacon was added to the session or not. The experts said that it was not clear what it did, as they had the seen status bar design in other parts of the system where it was not clickable, whereas in the available beacons list, it changed when clicking.

The list elements were reworked with a new button that indicated that the beacon was added when it was clicked, also the entire list element changes its color to green. The status bar was completely removed, this can be seen in figure 8.2b.

8.2 Beacon Manager module

As the prototype grew larger, the need for deploying large fleets of beacons had to somehow be managed. For SFRS to successfully use the system, there had to be a way of adding and deleting beacons. Up until this point, managing the beacons was done by sending HTTP-requests to the endpoint with the necessary beacon data directly to the server. This was seen as a tedious and non-intuitive way of dealing with the beacons. A user interface was needed to facilitate this.

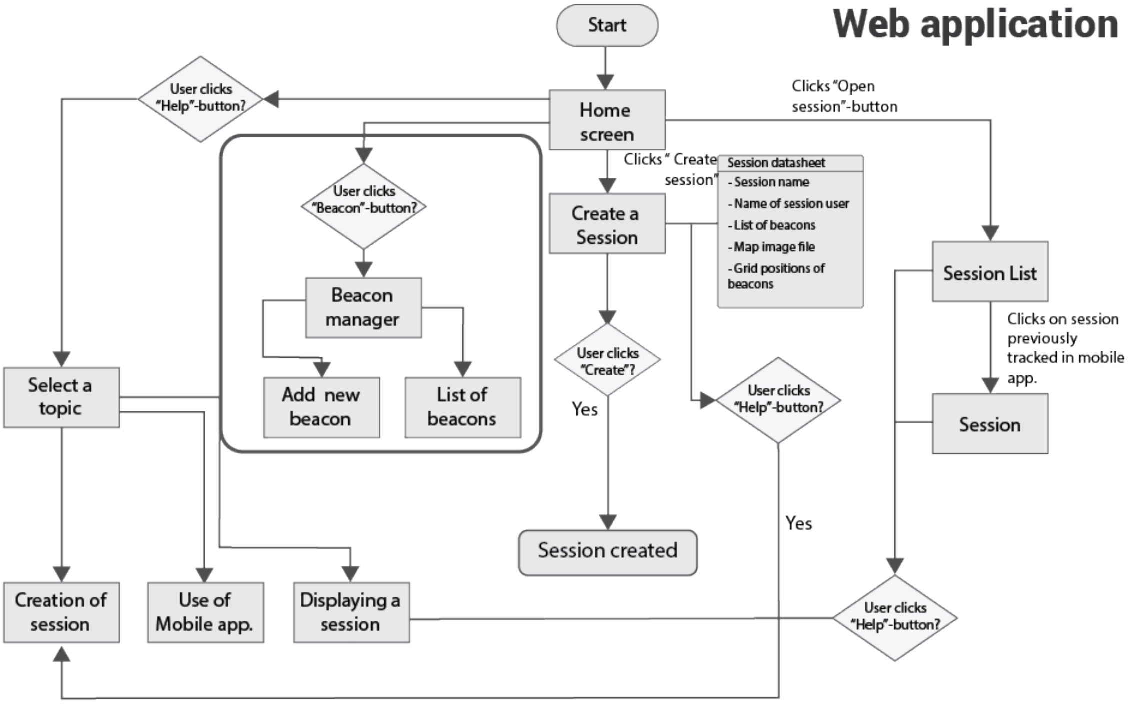
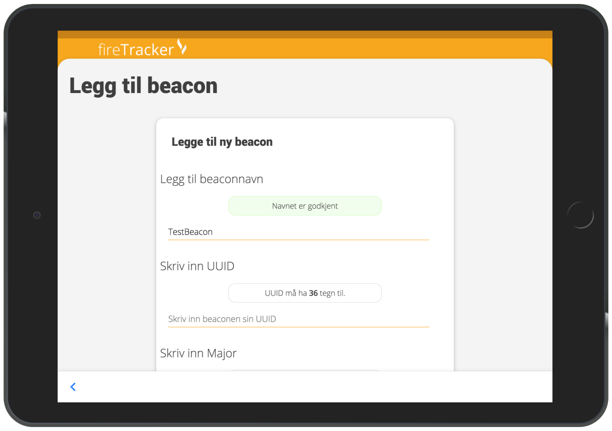


Figure 8.3: Flowchart of the fourth prototype, with the "Beacon Manager" module outlined

The flowchart in 8.3 represents the prototype and all its modules. The new addition is the beacon manager, which can be seen outlined in figure 8.3, and can be accessed from the home screen. When opened it presents the user two options: To add new beacons, or open a list of all the existing beacons.



Legg til beacon

Legge til ny beacon

Legg til beaconnavn

Navnet er godkjent

TestBeacon

Skriv inn UUID

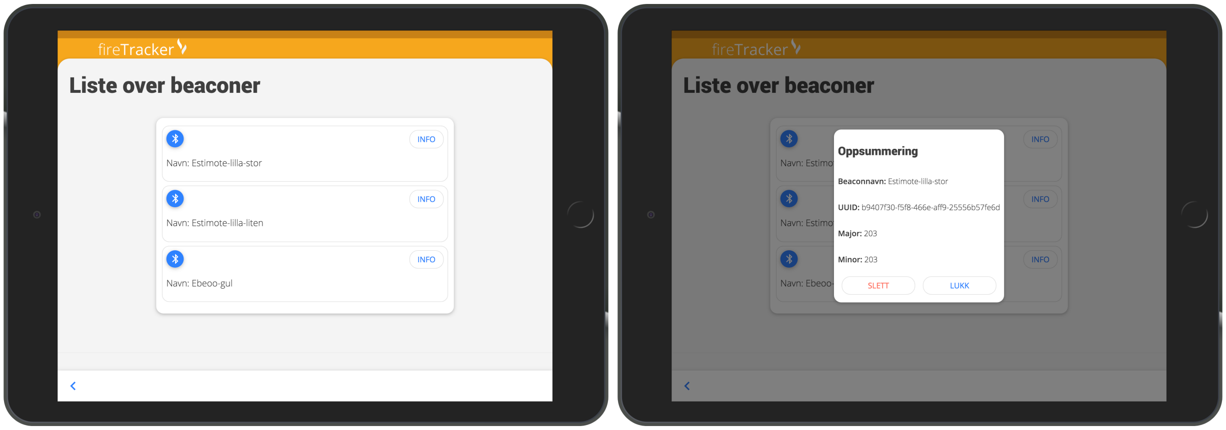
UUID må ha 36 tegn til.

Skriv inn beaconen sin UUID

Skriv inn Major

Figure 8.4: Screenshot of adding beacons

The add new beacons has several input fields where the user has to input the beacons information, see figure 8.4. There are minimum input length requirements to each input field. The reason for this is that incorrect data or too short strings could possibly cause further fatal errors when utilizing the beacons in a session. By inputting wrong beacon data when added, especially the UUID, Major, and Minor, the tracking will not record the data received from the beacon, which could cause an entire exercise to go untracked.



Liste over beaconer

Navn: Estimote-lilla-stor

Navn: Estimote-lilla-liten

Navn: Ebeoo-gul

Oppsummering

Beaconnavn: Estimote-lilla-stor

UUID: b9407f30-f5f8-466e-aff9-25556b57fe6d

Major: 203

Minor: 203

(a) Screenshot of the list of existing beacons (b) Screenshot of the pop-up dialog of selected beacon

Figure 8.5: Screenshots of list of existing beacons

The list seen in figure 8.5a represents all the existing beacons currently stored in the database. By clicking on the "Info"-button on the beacon, a pop-up message shows the technical information of the beacon, such as the UUID, Major, and Minor (See figure 8.5b). There is also an option to delete the selected beacon in the pop-up message. When deleted the beacon is completely removed from the database.

8.3 Summary

In this iteration usability issues found in the evaluation the third iteration were fixed and corrected, also it introduced a new module for managing beacons.

Chapter 9

Prototype evaluation

This chapter describes the field trial that included testing of FireTracker and the qualitative interviews that were carried out during the final evaluation of the project. The goal of this field trial was to evaluate the system's value to the firefighters and to see whether the visualizations of the tracked data was important to their training. In addition, the testing would give a confirmation of the choices made in the development of FireTracker. After the test, a summative evaluation consisting of a semi-structured interviews and SUS questionnaires followed.

9.1 Test of Firetracker in smoke diving exercises

The field trial began with a test of FireTracker in a real-life cold smoke exercise.

9.1.1 Setup

To not obstruct or hinder the firefighters exercise, the testing had to be planned and set up accordingly.

Figure 9.1 shows the structure of the testing. The first step was to introduce all the involved firefighters to the system, including both the smoke divers and the instructors. While explaining the different modules of FireTracker, the firefighters were encouraged to ask questions about the use of the system. The training location, the beacons, and the sessions had to be set up accordingly. SFRS didn't have floor plans readily available, therefore the building plan was hand-drawn on site. With technical assistance, the instructors placed beacons in the exercise building based on their opinion of what could be points of interest. In the pre-exercise, moments before they enter the exercise building and starting the exercise, the mobile phones were set-up with the correct sessions, the tracking was activated and the mobile phones were placed in the container on the smoke diver's helmet, as seen in figure 9.2. After finishing searching

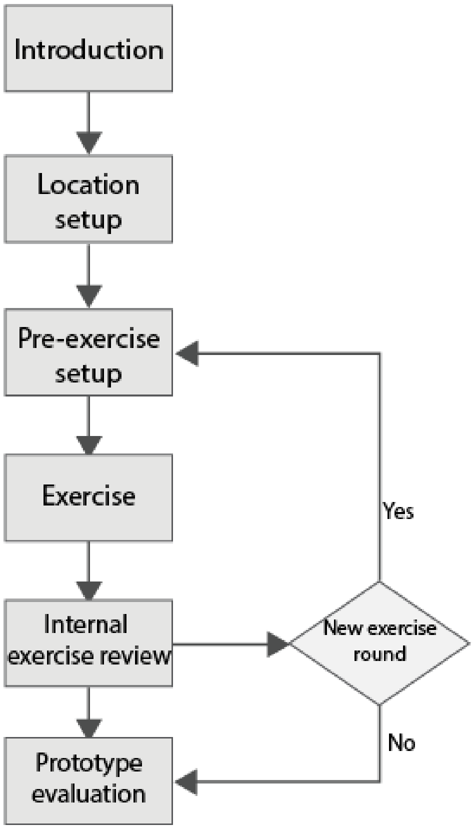


Figure 9.1: Structure of the evaluation

the exercise building, the mobile phones were carefully taken out and the tracked data were uploaded to the server.

In the internal exercise review, the firefighters were given feedback from the instructors on their performance and they also told about the choices they made in the exercise. When all the exercises were complete, the evaluation of the prototype began, see section 9.2. This was done at SFRS's station.

9.1.2 Participants

The system was tested with four firefighters in SFRS at their training location in Ågotnes, Fjell. Two of them were smoke divers and two of them were instructors. The building that was used for the exercise was a small house with only one floor. The system was tested in four different cold-smoke diver exercise sessions. The instructors also played the roles of the fire brigade chief and the on-duty chief. The smoke divers has two roles; smoke diver 1 and smoke diver 2. Smoke diver 1's role is to supply the hose to the other smoke diver in the doorway, and smoke diver 2 is a more active role

Figure 9.2: Container attached to the firefighter helmet

where the tasks are to lead the hose and search the room.

9.1.3 Data collection

The exercise sessions were observed. Pictures and notes were taken during the exercise sessions. The researchers were also allowed to observe the first session from inside the building. In this exercise session the firefighters used plastic bags to cover their vision instead of smoke, allowing for direct observation of the firefighter's actions.

9.1.4 The exercise

Throughout the three first exercise sessions, the firefighters used their gear as if it were a real life smoke diving situation. Table 9.1 lists the four exercise sessions that were carried out.

Table 9.1: Overview of the exercise sessions

Exercise session	**Details**	**Participants**
1	No smoke, helmets covered with plastic bags	Smoke divers: 2 Instructors: 2
2	Cold smoke, with full gear	Smoke divers: 2 Instructors: 2
3	Cold smoke, with full gear	Smoke divers: 2 Instructors: 2
4	Cold smoke, with no gear except helmet and container	Smoke divers: 1 Instructors: 1

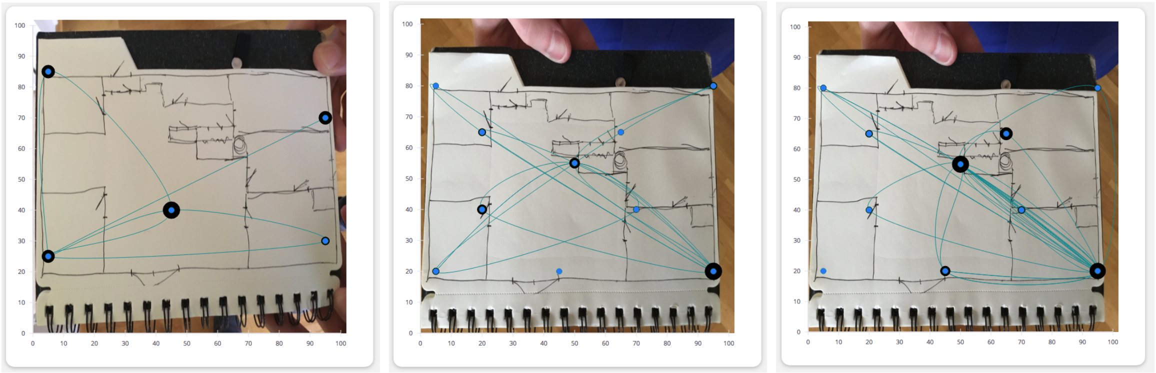
The first exercise session was performed without any smoke. The firefighters were given black plastic bags to cover their helmets, rendering them virtually blind. With the lack of cold smoke it gave the oppurtunity to observe the smoke diver while performing the exercise (see figure 9.3). The cold smoke was used in the rest of the exercises. This resembled a real life smoke exercise, as it only reduced and not completely removed the visibility. The last exercise was done without an oxygen tank connected to their helmet mask, and no hose was used. Another difference in this exercise was that there was only one smoke diver and one instructor participating. After each exercise session, data was collected with the Android application were uploaded.

Figure 9.3: Firefighters in exercise session 1, with no smoke

9.1.5 Analysis

The visualizations were results of the tracked data in the Android application. All of the visualizations can be seen in appendix G.

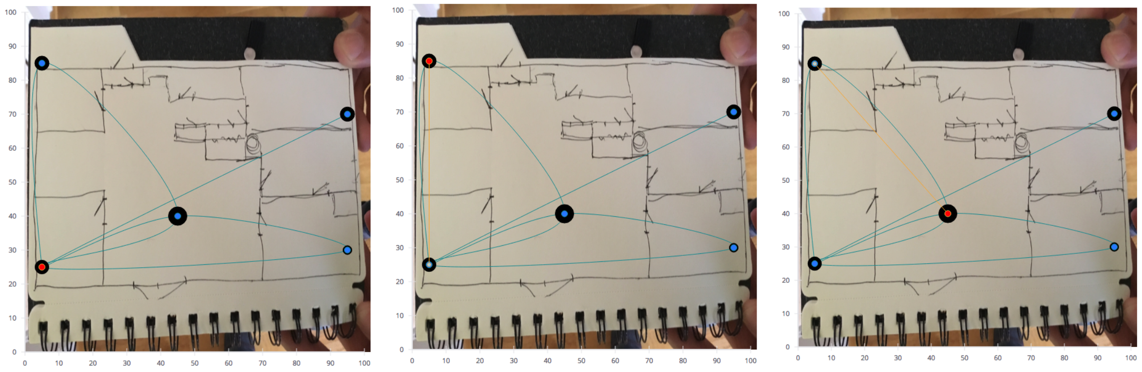
As described earlier, the generated visualizations are placed on top of a hand-drawn floor plan. In the first exercise session, five beacons were placed on the exercise site, see figure 9.4a. This was primarily as a minimum test to cover the four corners of the building and the living room, which was the central area of the building. In the second exercise session (figure 9.4b and figure 9.4c) and the following exercises (see Appendix G) several more beacons were introduced. The reason for this was that it was discovered in the first exercise that the cellphone received signals from other beacons that were not in its vicinity.



(a) Smoke diver 1, exercise session 1 (b) Smoke diver 1, exercise session 2 (c) Smoke diver 2, exercise session 2

Figure 9.4: Visualizations from the first and second exercise sessions

In exercise session 2 (figures 9.4b and 9.4c) both of the smoke divers took the same route, but the smoke diver in figure 9.4c has more registered locations than the smoke diver in figure 9.4b. The smoke divers had different roles, the smoke diver visualized in figure 9.4b had the role of smoke diver number 1, and did not search the entire room. Smoke diver in figure 9.4c had the role of smoke diver number 2, who searched the enitre room.



(a) First detected location (b) Second detected location (c) Third detected location

Figure 9.5: Chronological sequence of detected locations in the first exercise round, according to the visualizations

When the Android application detects beacon signals it sets the location to the beacon's location in the session until it detects a stronger signal from a different beacon. During the tests the smartphone received stronger signals from other beacons that were not in its immediate vicinity. This caused the locations in the visualization to display a path that was not representative of the actual path taken by the firefighters. Therefore the visuaized path was different from the actual path. Figure 9.5 shows the path according to the signals received from the smartphone, the currently selected location is represented by a red dot. However, the actual path taken by the firefighters was the red points in figures 9.5b - 9.5c - 9.5a. This signal phenomenon also occurred in other exercises.

9.2 Evaluation

After the prototype had been tested, a semi-structured interview of the involved subjects and a SUS questionnaire followed (see Appendix B). The interview guide (see Appendix H) for these sessions were premade and ensured that the topics were relevant to the research questions, SFRS's expectations of the system, related research, and the heuristic evaluations; these can be found in Appendix H. In addition, the interview sessions allowed the subjects to reflect on their own use of the system. As the observation and testing was done under controlled conditions, questions involving whether this affected their performance in the exercise were also included. The smoke divers and instructors were asked different sets of questions.

9.2.1 Evaluation with the smoke divers

The smoke divers were asked questions about whether the visualizations gave them more information about the exercise and their own performance, and how it contributed to the internal evaluation of the exercise.

During the interview, the smoke divers highlighted that the system didn't require much from them, which they saw as a positive aspect. Both of the subjects said that they didn't interact too much with the system, which was a good thing seeing as they could concentrate on the regular exercise routines. One of the subjects said that they were a bit worried before the exercise began. He thought that he had to perform the building search in a different manner to have the mobile phones easier pick up the Bluetooth signals, however, he said that when he immediately entered the building, he forgot about the head-mounted cellphone and continued the exercise according to his training.

When it came to visualizations and their value during the internal evaluation, they both said that it didn't contribute too much, saying that the visualizations would have to be more precise to actually give them an indication of their whereabouts in the building. Another issue was the graph in the visualization. One of the smoke divers found the graph to be confusing as it was, he said that it took a couple of minutes before he understood how it worked. He would have preferred if the locations in the graph could be displayed stepwise. The firefighters also answered the SUS questionnaire (see Appendix B), measuring the usability of the system. The scores of the SUS questionnaire can be seen in figure 9.6. It shows that the smoke divers found the system to be under the accepted score of 68 (Brooke, 2013).

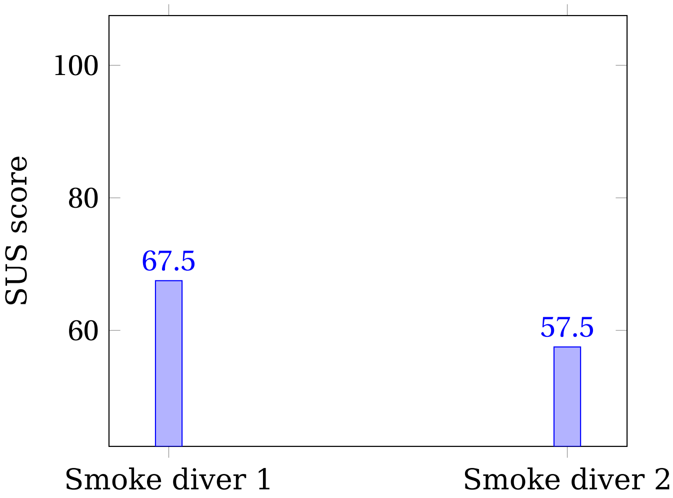


Figure 9.6: The SUS scores from the evaluation of the prototype with two smoke divers.

9.2.2 Evaluation with the instructors

The questions the instructors were asked dealt with UI and UX, how they perceived the use of the system, and what the data contributed in terms of learning and training, for a complete interview guide see Appendix H.

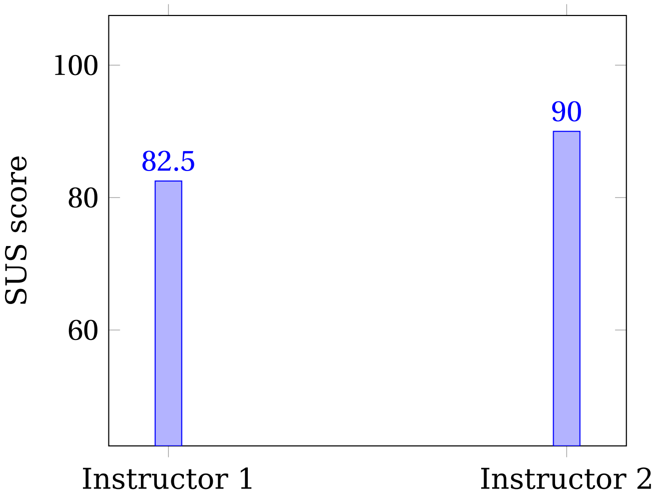


Figure 9.7: The SUS scores from the evaluation of the prototype with two instructors.

Both of the instructors pointed out that the system was user friendly. One of the instructors had never used the system before, he said that the he didn't need the use of a manual to create a session as he managed to figure it out by himself after a few minutes. The same instructor made a remark about the graph in the visualization, he found it to be visually disturbing, as it presents all the nodes and edges when the graph is first displayed. His proposal was to have the visualization sequentially insert the node and graph by clicking the next button, displaying the path of the smoke divers stepwise, something also mentioned by one of the one of the smoke divers.

When asked about the data the system tracks and its usage, both of the instructors said that the data is quite useful, but in its current state they said it wasn't fine grained enough. They couldn't use it to catch errors in the smoke divers searching techniques. However, it was mentioned that with head-mounted cameras filming the exercise, the time stamps of the locations in the system could be useful in estimating the location of smoke divers in the filmed material in an retrospective review of the exercise.

One of the instructors said if the system could give more precise positions of the movements of the smoke divers it could be used to see patterns in where the smoke divers faced problems in certain exercise buildings. This could be used for training purposes of new smoke divers, and it could be used as point of discussion in evaluating the performance of the smoke divers.

They both concluded their interviews by saying that the visualizations in its current state had little to no value in the evaluation of the exercise, but the system around the set-up and managing the sessions and the associated equipment was something they would use, given that the visualizations were more precise.

The isntructors also answered the SUS questionnaire. Figure 9.7 shows the SUS scores obtained from the instructors. Both of them found the system to be over the acceptable score of 68 (Brooke, 2013).

9.3 Summary

In the field test four exercise sessions were carried out. Some issues with the Bluetooth signals were discovered, making the visualizations hard to interpret. The instructors expressed positive regards towards the user experience of the system, however both the smoke divers and the instructors agreed that the visualizations needed more work to be used in their own internal exercise evaluation.

Chapter 10

Discussion

This chapter discusses the methods and the iterations through which the FireTracker system was developed. It answers the research questions and reflect on Design Science as the research framework.

10.1 Semi-structured interviews

All interviews with SFRS were conducted as semi-structured interviews. It allowed freedom to the firefighters to use the questions as a starting point and it also made it easier for them to provide input they felt was relevant. The method provided necessary and valuable qualitative data that helped in the design and the development of the system.

The responses helped establish requirements to what functions the system should be capable of and how these were supposed to be used. Asking open ended questions gave way for the instructors to include their own ideas of what they personally would want in such a system and opened for new questions that allowed for closer examinations of these ideas. This would not have been possible from the use of questionnaires with close-ended, pre-defined questions with a check box or a scale. Conducting semi-structured interviews was time-consuming as it required a planned meeting with SFRS. It was, however, a key element and highly beneficial in establishing the design and development of the prototype.

10.2 Collaboration with SFRS

To actually establish the requirements in such a system, close collaboration with SFRS was needed. This proved to be somewhat challenging, but manageable. The SFRS station is located in Ågotnes, about 26 km outside of Bergen. It was discovered early in the research period that a tight cooperation with SFRS was needed, however the distance and their schedule made it difficult to get continuous input on the prototype. While it would've been beneficial with more frequent meetings, it forced the design and development to focus on delivering and showing the firefighters a functional prototype with which they could interact and provide feedback.

The firefighters have different periods throughout the year where they focus their training on different exercises. We observed them on a real cold smoke exercise in the beginning of the research period. The exercise in the final evaluation was not in their exercise plan, but the training leader managed to arrange an exercise for the sole purpose of testing the prototype.

10.3 SUS

The SUS usability scale is another well-established tool used in the final evaluation of the prototype. The SUS provided quantitative data based on the perceived usability and value of the prototype which was useful to get an another view on their opinion of the prototype. However, the usage of SUS with the firefighters had some moments with confusion. All of the firefighters had difficulties assessing the sixth question in the SUS questionnaire:

6. *I thought there was too much inconsistency in this system.*

The firefighters did not know immediately how to rate this statement. One of the instructors remarked that the statement might be more applicable to larger systems that supports a variety of functions. The inconsistency part of the statement was explained by adding whether the design felt inconsistent or not (i.e., if similar design elements, such as buttons, executed or displayed the anticipated functions).

Due to the smoke divers little involvement in the use of the system, the question about giving the SUS questionnaire to them can be raised. The only part of the system they are exposed to is the visualization, they don't use any of the other functions or modules. The fact that the visualization were not precise enough to indicate their movements, is a probable cause of the low SUS scores shown in figure 9.6.

10.4 Heuristic evaluation

The heuristic evaluation proved to be important as it highlighted challenges in the functionalities and how they were presented to the user. The evaluation was done by four IT-students in Information Science. They inspected the system by using Nielsen's heuristics. Due to the distance and the schedule of SFRS, the feedback from the students was instrumental in for further development. Not only did it help identify weaknesses in the system, but also gave an oppurtunity to observe how a user perceived and interacted with the system.

10.5 The Design Science Research

The Design Science research framework was used throughout this this research project, and also its main principles: *design as an artifact, problem relevance, design evaluation, research contribution, research rigor, design as a research process* and *communication of the research*.

The design as an artifact means that the research must provide viable artifacts in the form of a construct, model, method or instantiation (Hevner et al., 2004). This research has produced an IPS, FireTracker, consisting of a web application and mobile application. These are the main artifacts.

The problem relevance means that the purpose should be technology-based solutions to important and relevant business problems (Hevner et al., 2004). This guideline was fulfilled by developing artifacts that could improve the performance and evaluation of cold smoke exercises. Those who potentially benefits from this are firefighters, such as smoke divers, instructors, and firefighters in training.

Design evaluation means that the utility, quality, and efficacy of the design artifact must be rigorously demonstrated via well-executed methods (Hevner et al., 2004). The evalution methods used were both qualitative and quantitative. They included the intended user group and yielded evaluation results that showed that many aspects of the artifacts were accepted by SFRS.

The research contribution means that the research conducted by the Design Science research must provide clear and verifiable contributions in the specific areas of the developed artifacts and present clear grounding on the foundations of design and/or design methodologies (Hevner et al., 2004). The artifacts developed in this research have contributed to the field of learning analytics, in particular, data collection and visualization. The results show that the collected data was not fine-grained enough, and also shows the need to build tools to collect needed data. The foundations the artifacts are built upon the needs and requirements from the firefighters. The artifacts can be used as a basis in further research in IPS.

The research rigor means that the research should be based on an application of rigorous methods in both the construction and the evaluation of the artifacts (Hevner et al., 2004). The development has gone through low-fidelity to high-fidelity prototypes. In addition, the final artifact was a functional prototype. The prototypes were evaluated with the firefighters and IT-students. Also, the development has utilized several methods to build the artifacts in four iterations.

Design as a search process means that the search for an effective artifact requires the use of means that are available to achieve the desired purposes, while satisfying the laws governing the environment in which the problem is being studied (Hevner et al., 2004). The artifacts of this study were developed in an iterative process. Throughout the modelling, development, and implementation, the impact of the artifact was being observed and evaluated. These observations and evalutions took notice of any discrepancies of the artifacts and compared it to the requirements of the proposed finished solution. If the artifact, at its current level, did not fulfill the final requirements, the iterative cycle restarted until it the artifacts acceptably fulfilled the requirements.

Communication of the research means that it must be presented effectively both to technology-oriented as well as management-oriented audiences (Hevner et al., 2004). This research took both of the audiences of the research into consideration. The audiences being the technology-oriented, such as other researchers and the audience that are interested in its direct contribution, the firefighters. For the research to be presented for the technology-oriented audience, the focus must be on how the study is executed, its contribution to the knowledge base and how it can be used to draw further knowledge about the field on which the research focuses. This is done through this thesis and future articles. When presenting it to SFRS, the emphasis was placed on how FireTracker can benefit their learning and training.

10.6 Research questions

The research question raised in this research have involved how to design and develop an IPS, how the IPS can support both firefighter instructors and firefighters in training exercises, to find out which data are of most value, how these data can be created and extracted and how they thay can be presented to make them valuable.

RQ: *How can an indoor positioning application be developed to support instructors and firefighters in smoke diving training exercise?*

To answer the research question, the sub-questions have to be answered first.

SQ1: *Which indoor position data are of most value to the instructors and smoke diving in training?*

In this research, the data extracted using the Firetracker-system were temporal data, signal data, and gyroscopic data to indicate direction and movement. The signal data and temporal data was combined to estimate the positions of the firefighters, while the gyroscopic data was used to get a more detailed understanding of the actions of the firefighters at the different positions. During several interviews with SFRS, they said that the aforementioned data could support them in the feedback and evaluation of a training exercise.

The indoor position data that they deemed most valuable in the system was the the actual positioning data in the graph. The gyroscopic data only complemented the positioning data.

SQ2: *How can these data be created and extracted?*

By using BLE signals transmitted by BLE Beacons, a mobile device mounted on the helmets of the firefighters received these signals. With an application on the mobile device recording the signals, assigning it a timestamp and the current gyroscopic data, these data where sent to an back-end server where it was calculated into a set of locations, containing data to be visualized.

SQ3: *How can the indoor position data be visualized, to make them most pedagogically valuable?*

For the data to be pedagogically valuable, it first had to be presented in a user-friendly and clutterless manner. This was done by developing and designing the prototypes after the needs of the intended user group. Several instructors and firefighters in SFRS were involved in the evaluation of the prototypes. Through several interviews with them, they expressed which moments they would be interested to be visualized. The result of this was the data to be represented in a graph displayed over a floor map of the exercise building, allowing both the instructors and the smoke divers to see their movement in retrospect. In addition to the graph, the details of each position were displayed in a list next to the graph, where timestamp and whether the firefighter was moving or rotating his or hers head at the moment, were displayed. The presentation of the data in the final prototype of the system was clear to the firefighters, but due to the location precision of the beacon signals, the firefighters said that it had little pedagogical value at this point.

To answer the research question, "*How can an indoor positioning application be developed to support instructors and firefighters in smoke diving training exercise?*" several firefighter instructors and smoke divers have been involved. Primarily, knowledge of which data to create, extract and present was necessary. The instructors and firefighters expressed which aspects of the exercise they deemed most crucial to their training and evaluation of the exercise, and how they would like to see this prestented.

Their expectations were formalised as requirements that were to visualize the movements of smoke divers in an exercise building, how to manage and set-up the involved equipment, and how this can quickly and easily be put to use. This was implemented as a mobile application and a web-application containing four modules: *Create Session-module*, *Open Session-module*, *User Manual-module* and a *Beacon Management-module*.

10.7 Results of the evaluation

The feedback from the firefighters was mostly positive. The FireTracker system and especially is user interface received positive feedback and was perceived as user-friendly. Based on the interviews and the questionnaire presented in section 9.2 the smoke divers found the visualizations to be too inaccurate to see their movements in the exercise building. The reason for this was that the mobile device received signals from the other beacons placed in the exercise building. This caused the path in the visualization to be incorrect according to the smoke diver's own perception of their movements. The instructors had a different view on the system. While sharing the same opinions on the visualization with the smoke divers, they found the system's user interface to be user-friendly and intuitive. The instructor's SUS scores were quite high, well over the accepted score of 68.

The most likely reason why the smoke divers scored considerably lower than the instructors is due to their use of the system, or lack thereof. The Firetracker system is barely exposed to the smoke divers. They only interact with the mobile application and the visualizations, out of these two the visualization was the most important component. When it didn't manage to represent their actual movement in the exercise building, the value of the system to them was considerably lowered.

Chapter 11

Conclusion

This chapter presents a summary of the thesis, its contribution to research, and suggests what work should be done in the future.

11.1 Summary

Design Science Research has been used to develop an indoor positioning system to track firefighters position in cold smoke exercises. The development has been conducted in four iterations in a user-centered design process including several firefighters and firefighter instructors from SFRS, and IT experts in the heuristic evaluation. By the end of the fourth iteration, the FireTracker System comprised 1) an Android application for tracking and registering data, 2) a back-end for calculating, serving, and sending data, and 3) a web-application consisting of four modules: *Create Session-module*, *Open Session-module*, *User Manual-module* and a *Beacon Management-module*.

The first iteration started with a preliminary sketch of the system. The requirements were based on the technical functions of the system. The sketches were worked into a low-fidelity prototype that was shown to two firefighter instructors at SFRS. The qualitative interview that followed assessed how the firefighters train for cold smoke exercises, what kind of roles the firefighters and instructors have, and what aspects of the exercise they give feedback on. The purpose was to find out which data was of importance to them and how the proposed prototype could be further expanded and which aspects of the training and exercise they would like to see implemented and visualized.

The second iteration marked the beginning of the development of the system. The structure of the system was revised and resulted in a new module, the *Create Session-module*. By the end of the development in this iteration it was possible to create a new session, and opening a tracked session. The evaluation of the prototype developed in this iteration consisted of a demonstration of the prototype and a semi-structured interview with one of SFRS's training leader. The results showed that many of the design choices taken were accepted with some issues on displaying the session information, along with interpreting the graph. There was also expressed interest in a user guide.

The focus of third iteration was improving the usability of the system both in terms of the user interface and user experience, but also documentation. Therefore the system was redesigned, highlighting the important functions through visual cues, and introducing a new module, the *User Manual-module*. The heuristic evaluation of the prototype developed in this iteration uncovered multiple usability issues. The severity of the issues were ranked through the number of occurences. The evaluation also uncovered that it was difficult and confusing when trying to create a session.

In the fourth and final iteration, the focus was on improving the prototype based on feedback and issues from the evaluation in the previous iteration. A way of managing the the beacons was also needed, therefore the *"Beacon Management" module* was developed and added in this iteration.

The evaluation of the final prototype was performed with SFRS, where two smoke divers and two instructors participated. The evaluation results indicated that the system was easy to use and could potentially be used in a real cold smoke exercise. The evaluation also suggested that the tracking of the firefighter's movements had to be more precise. The visualization in the final prototype was hard to interpret, SFRS said that it would be difficult to use it in an internal review of the exercise.

This research has shown that it is possible to develop an indoor positioning application to support insructors and firefighters in training exercise.

The data and work done in this research could be basis for further studies and development of similar indoor positioning systems. The system in itself can applied to scenarios where the tracking is taken place on a pre-defined site. It can also give an indication of which data is important to review when developing an indoor positioning systems and which effect it could have on the intended user group.

11.2 Limitations

This research had a number of limitations imposed on it, including:

- Beacons
- Quality of data from Beacons
- Time constraints
- Access to personnel from SFRS

These limitations resulted in several weaknesses. During the course of the research *beacons* of different manufacturers were used. The *beacon's signal strength* (data from beacons) varied greatly, resulting in great variations of how the signal was received by the mobile devices. With more *time on hand* (time constraints), the research could have focused more on a quantitative testing of the beacons that could have given more information on the behaviour of the beacon.

If the system could have been *tested with SFRS more often*, the issues regarding the signal would perhaps have been uncovered earlier in the research period. This could also resulted in the research focusing more on the signal data rather than the user interface and user experience of the system. This means a larger project to develop a production like this needs to include both technical and HCI-aspects.

11.3 Future work

The future work concerns technical implementations and refinement. Particular improvements would be enhancing the graph of the visualizations of the movements, by instead of having the entire graph display at load time, the graph could have an additional option of being displayed in user-controlled sequences. Furthermore, the Android application could include the support of heart-rate monitors, giving the instructors a way of seeing the current heart-rate at a specified location, making it a new point of discussion in the internal review. A future step would be to perform a thorough test of the Bluetooth LE technology. It would be necessary to find out which beacons give optimal results and how versatile the technology is in different types of exercise buildings.

11.4 Conclusion

This research has presented the design, development, and testing of an IPS for firefighters in cold smoke diving exercises. This research concludes with that FireTracker is a viable system for tracking indoor movements, in terms of usability, and user experience. However, the use of Bluetooth beacon signals for determining indoor movements is something that has to be explored further.

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Appendix A

Nielsens 10 Heuristics for User Interface design

A.1 Visibility of system status

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

A.2 Match between system and the real world

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

A.3 User control and freedom

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

A.4 Consistency and standards

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

A.5 Error prevention

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

A.6 Recognition rather than recall

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

A.7 Flexibility and efficiency of use

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

A.8 Aesthetic and minimalist design

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

A.9 Help users recognize, diagnose, and recover from errors

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

A.10 Help and documentation

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

Appendix B

System Usability Scale questionnaire

Table B.1: SUS Questionnaire

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

Appendix C

Interview guide for testing prototype in first iteration

Table C.1: Questions about the practical aspect of smoke diving exercise

	Question
1.	Which preparations do the firefighters do before an exercise?
2.	Where can the signal receiver (phone) be placed on the firefighter during the exercise?
3.	How many persons are there on a smoke diving exercise?

Table C.2: Questions about the visualizations of the indoor movements

	Question
1.	What kind of information can this type of data give you?
2.	How should this data be presented?

Table C.3: Questions about feedback and evaluation

	Question
1.	Could this system have any negative consequences in terms of feedback and evaluation?
1.1	Could this perhaps make the firefighters focus on different elements of the exercise, knowing that their movements being recorded?
2.	Could this give the firefighters better feedback in retrospect?
3.	Could this system or the data be used in further training of the firefighters? - If yes, how?

Appendix D

Interview guide for testing prototype in second iteration

Table D.1: Questions about the practical aspect of the prototype

	Question
1.	How was it setting up a session, in terms of input of the relevant information and placing the beacons?

Table D.2: Questions about the user interface and user experience

	Question
1.	Were there parts of the system that was noe easy to understand or use? If yes, what can be done simpler or explained better?
2.	Does the system give enough information about how it’s supposed to be used? If not, what is missing?

Table D.3: Questions about the visualization of the session

	Question
1.	What did you think of the visualization of the session?
2.	Did you get enough information about the session?
3.	Was there anything unclear in the graph or the map?
4.	In its current state, how can the visualization of the session be used?

Table D.4: Questions about the data extraction

	Question
1.	What do you think of using data about head movements to see if a firefighter is active during the exercise?
2.	Would a visualization of the amount of sound be interesting? I.e. too see on the graph where the firefighers communicated?
3.	The mobile application has a step counter implemented to see whether a firefighter is moving or not inside the exercise area, is this information interesting?
3.1	Would it also be interesting to see the actual counted steps, and an estimated distance based on these steps?

Appendix E

Informed consent form

See next page.

Informed consent form

Institution responsible for research project: University of Bergen

Project ending: December 2018

Anonymization of data: August 2018

Introduction

Introduction FireTracker is a system that can visualize sensor data collected from a mobile device. The visualization is presented in a graph. Examples of these sensor datas are Bluetooth-signals, device acceleration and gyroscopical data. The evaluation will be using Nielsen's heuristics for assessing problems and issues of the system. There will also be possible to ask questions and offer opinions after the evaluation.

Eligibility to participate in this evaluation?

You have a general technical aptitude and have used a mobile and a web application before. You have a general knowledge of Nielsen's heuristics and how to utilize them.

Practical information

Participation in this study will be a 30 minutes to 1 hour session.

There are no known risks associated with your participation in this research beyond those of everyday life.

Your responses will be kept confidential by the researcher.

Participation in this study is voluntary. You may refuse to participate or withdraw at anytime without penalty.

You have the right to skip or not answer any questions you prefer not to answer.

Participants will be referred to anonymously in the final delivery of the research paper.

Subject / date	Edvard Pires Bjørgen
____________________	___________________________

Appendix F

Issues from the heuristic evaluation

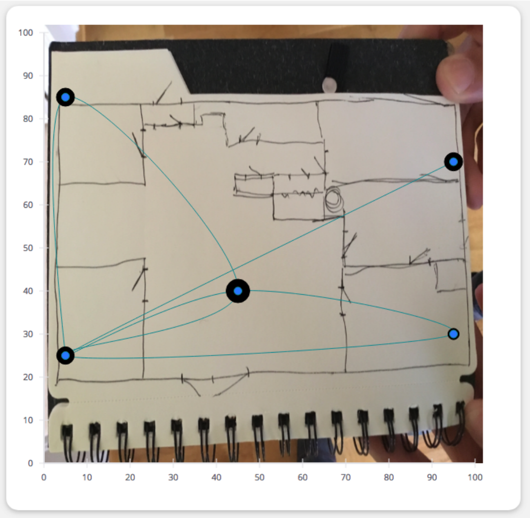
See next page.

Table F.1: Issues found in the heuristic evaluation

Rank	**Issue**	**No. of ocurence**
1	Too much technical information in available beacon list, not sure of what information was relevant	4
2	Not sure on how to select an available beacon, not sure if it contained a button or a status bar	3
3	Difficult to find overview of the application	2
4	Difficult to know what task to be done first in "Create Session" module	2
5	Error message in "Create Session", URL in message was cryptic	2
6	Difficult to know what to do after beacons are placed on map	2
7	After filling out name, user, and selecting available beacons, not sure if "Create Session" was going to be clicked or "Upload Image"	2
8	Error message when trying to create a session did not change, not sure what was wrong with session	1
9	The word "Session" did not make sense in a Norwegian context	1
10	Difficult to know what to do after a session is created	1
11	Confusion as to why list of "Available beacons" had "Upload Image"-button it	1
12	After placing beacon on map, there was not a clear confirmation that the beacon had been placed	1
13	Was able to ignore the error message when creating a session so that it didn't pop up again if a new error was made	1
14	In the view of the session in "Open Session" module, the indicators of movement in the event list were to similar to buttons in the "Available Beacon" list in the "CreateSession" module	1
15	It was possible to cancel the upload in the Mobile application	1
16	No error message if the web application had no internet connection	1
17	No exit button in user manual	1
18	When opening the user manual from a module, the back button in the manual went back to the main screen of the "User Manual" module	1
19	Exiting the manual of a module could only be done from the last page of the manual	1
20	When replacing an already placed beacon, a new the old position of the beacon was not removed	1
21	When accessing the user manual from the "Create Session" module, the input data was removed and user had to start over again	1

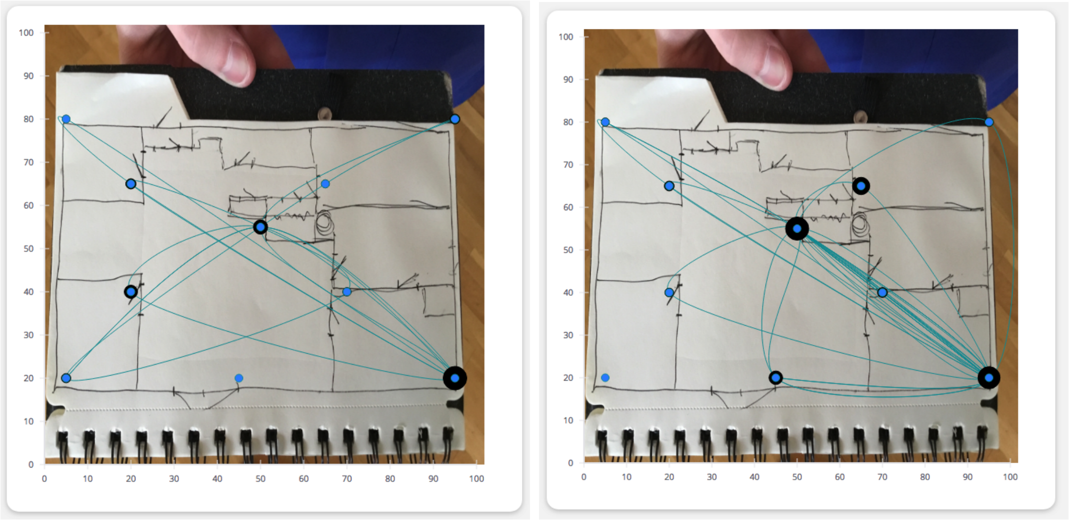
Appendix G

Visualizations from the final prototype



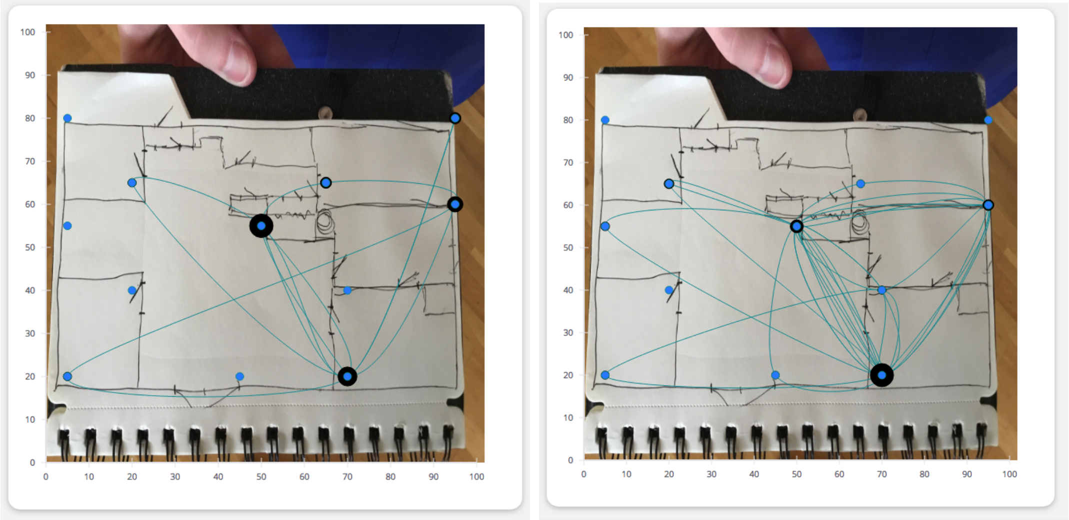
(a) Smoke diver 1, exercise session 1

Figure G.1: Visualizations from the first exercise session



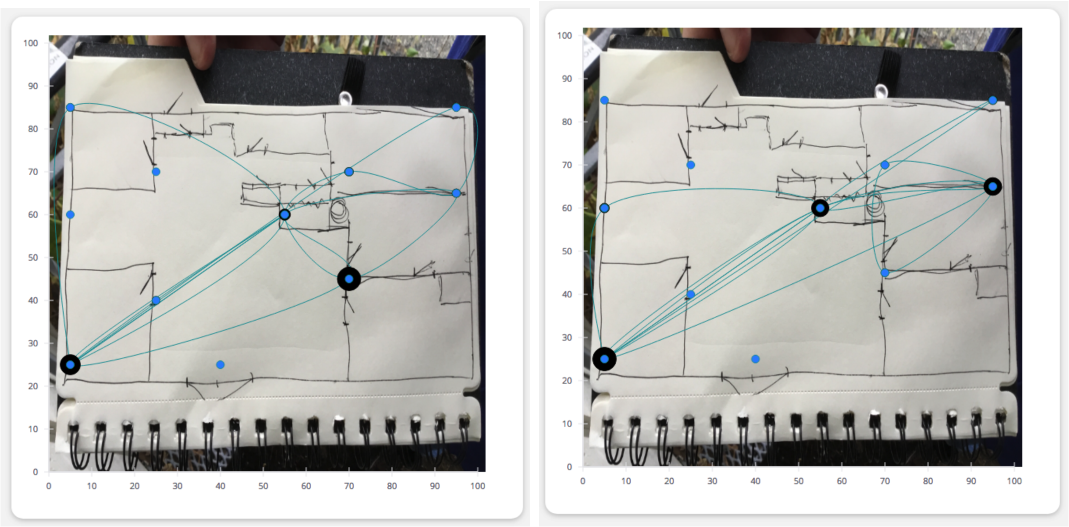
(a) Smoke diver 1, exercise session 2 (b) Smoke diver 2, exercise session 2

Figure G.2: Visualizations from the second exercise session



(a) Smoke diver 1, exercise session 3 (b) Smoke diver 2, exercise session 3

Figure G.3: Visualizations from the third exercise session



(a) Smoke diver 1, exercise session 4 (b) Instructor 2, exercise session 4

Figure G.4: Visualizations from the fourth exercise session

Appendix H

Interview guide for evaluating final prototype

H.1 Interview guide for interview with smoke divers

Table H.1: Questions about the system and how it affected them

	Question
1.	Did you do anything different during the exercise, knowing that you were being tracked?
2.	Did the mobile device on the helmet affect your performance?
3.1	Did it prevent any tasks?
3.2	Did it restrict your mobility?
4.	Did attaching the mobile device affect the exercise? If yes, how?
5.	Did you think the system contributed to anything new in the internal review?
6.1	If yes, what is different?
6.2	Do you feel you have a better insight in the exercise with this information?
7	Can you see any difference in your movements and the other smoke diver?
8	What do you think about the precision of the tracking?
9	Would it be more beneficial with a more precise tracking?
10	Is there anything missing or could have been different in the system?

H.2 Interview guide for interview with instructors

Table H.2: Questions about user interface and user experience

	Question
1.	What did you think of the system's user interface?
2.	How did the system affect the internal review of the exercise?
3.	While creating a session, was there anything in the UI that was unclear or difficult?

Table H.3: Questions about the data and visualization

	Question
1.	Were the data relevant?
2.	Did any of the types of data contribute anything?
3.	How did they contribute to the internal review?
4.	Was there anything the data could be used for, in terms of exercise feedback?
4.1	If yes, what difference did it make?
5.	Would this system help in training new firefighters? How?
6.	What do you think of the precision of the tracking?
7.	Would it be more beneficial with a more precise tracking?