UNIVERSITY OF BERGEN

Department of Information Science and Media Studies

MASTER THESIS

Bluetooth Low Energy Beacons: Providing movement tracking for firefighter smoke diving training

Author: *Fredrik Vonheim Heimsæter*
Supervisor: *Barbara Wasson*
Co-Supervisor: *Jo Dugstad Wake*

November 30, 2018

Program testing can be used to show the presence of bugs, but never to show their absence!

Edsger W. Dijkstra (1970)

Abstract

This master thesis explores how Bluetooth Low Energy beacons can be used for indoor tracking of firefighters in a smoke diving exercise situation. It investigates how the technology can be used, what kind of data it could provide, and how useful the data is for the evaluation of the exercise. To do this a prototype system for tracking firefighters called *FireTracker* is developed. The system consists of three components, an Android application for collecting data, a back-end for processing and serving data, and an exercise management tool for creating and viewing exercise sessions. This system is evaluated through technical testing, and evaluation by both smoke diving instructors and smoke divers from the fire department. The evaluation shows that there is potential for a system like FireTracker, but the currently available technology needs some improvement before it could actually be used.

Acknowledgment

I would like to thank everyone who made this thesis possible.

My friend and fellow student Edvard Pires Bjørgen for the collaboration on this project.

My supervisors Barbara Wasson and Jo Dugstad Wake for all help and feedback during the project.

The firefighters at Øygarden Brann og Redning for spending time on testing and discussing the prototype.

Fellow students at the Department of Information Science and Media Studies for motivation, discussions, lunch breaks and other needed distractions.

Friends and family for all their support.

Bergen, November 29, 2018
Fredrik Vonheim Heimsæter

Contents

List of Figures

List of Tables

List of source codes

Glossary

ABL Android Beacon Library

API Application Programming Interface

BLE Bluetooth Low Energy

Exercise Management Tool In this thesis: The web-interface where exercise sessions are created and the tracking is visualized

FireTracker The entire system created, including the Android application, the exercise management tool, and the back-end

GLONASS Global Navigation Satellite System

GPS Global Positioning System

HVL Western Norway University of Applied Sciences

IPS Indoor Positioning System

JVM Java Virtual Machine

Orm Object-relational mapping

SDK Software Development Kit

SLATE Centre for the Science of Learning & Technology

ØFR Øygarden Fire and Rescue

Chapter 1

Introduction

Today we have accurate systems for outdoor localization, positioning, and tracking using the Global Navigation Satellite System (GNSS). GNSS data are available almost everywhere, and because most smartphones have a GPS-antenna it is easy to use in applications. Unfortunately, GNSS does not work well enough indoors to give precise locations. There are, however, several emerging technologies for indoor localization and tracking, often referred to as Indoor Positioning System (IPS), such as light (Xiaohan et al., 2010), sound (Schweinzer and Kaniak, 2010), WIFI (Chang et al., 2010), and Bluetooth (Takahashi and Kondo, 2016), and RFID (Jean-Paul Zanlucchi de Sousa Tavares et al., 2017). None of these systems are commonly available or in widespread use yet, however.

One use-case where precise indoor tracking might be useful is for supporting firefighter smoke diving training. As the training building is filled with smoke the visibility is low or nonexistent, thus it is easy to get disoriented or lose track of where you are and where you have been, which is the point of the exercise. For a firefighter it is crucial to check all rooms or parts of a building when searching through it, therefore, smoke diving is one of the important skills they train. Smoke diving is also carried out according to competence-based practice, with standards for movement, communication, equipment use, etc. Yet, there are few tools that provide the divers with data on their performance. How can you get better at it and learn from your errors, if you think you searched all the rooms in the building, and no one is able to tell you that you missed a bedroom? Did you carry out the search optimally? Will visualizations of your movements support the instructor - trainee dialogue and feedback?

To meet this need for information about firefighters movement and activity in a smoke filled building, a system, FireTracker, for tracking firefighter movements during smoke dive training, was created using Bluetooth Low Energy (BLE) beacons and smartphones. FireTracker tracks the firefighters and visualizes the data about their movements. This visualization can be used in the debriefing and evaluation process after the training with their instructor. The instructor can also use the data across the teams to identify training needs.

1.1 Motivation

The motivation for doing this Masters project is that there is a clear need for a tool that provides smoke divers data-based feedback on their activities. We also want to learn about BLE beacons, explore the capabilities of, and see how well they perform in an environment for smoke dive training. The use of Bluetooth technology is almost unexplored within smoke diving practice.

1.2 iComPAss project

This research is part of the "Inquire Competence for Better Practice and Assessment" (iComPAss) project which is a cooperation between the organizations Uni Research Health[1], Centre for the Science of Learning & Technology (SLATE), Western Norway University of Applied Sciences (HVL), ENOVATE AS and Øygarden Brann og Redning[2] (Øygarden Fire and Rescue). The iComPAss project aims to develop an unique approach to planning and monitoring professional competence development, and it investigates how to support data-driven decision-making by individuals, instructors, and leadership, with digital tools. (Netteland et al., 2016).

Some of the central research questions to iComPAss are:

- What are the consequences of developing tools for practice and training at a fire station?
- Can the proposed tools provide better overview of competency- and training needs than the current situation?

[1] Uni Research merged with several other research institutes and changed name to NORCE Norwegian Research Centre AS

[2] Changed name from Sotra Brannvern to Øygarden Brann og Redning after a organizational restructure as of January 2018

- How can competency needs be visualized and give overview over individual and collective competency needs?

1.3 Collaboration with co-student

While this research is conducted together with a co-student, Edvard Pires Bjørgen, what is reported in this thesis is my own individual work. Together we developed the FireTracker system, which comprises an exercise management tool, an android application, and a back end. I was responsible for the back end, Edvard the exercise management tool, and we shared the responsibility for the android application (Bjørgen, 2018). An overview of the FireTracker system with its data flow is shown in Figure 1.1.

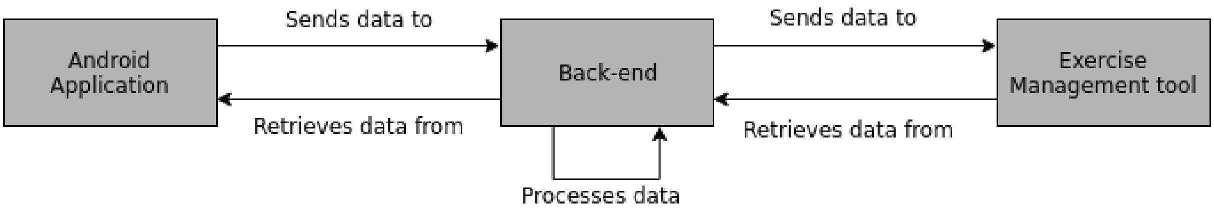


Figure 1.1: Overview of FireTracker with data flow

1.4 Research Questions

In this research the focus is on how well the Bluetooth Low Energy beacons perform in a smoke diving setting and environment. The goal is to answer the following two questions:

1. **How can indoor position data from BLE beacons be used to support firefighter movement tracking under smoke diving training?**

2. **Do the beacons provide high enough quality of data to be used for useful feedback?**

1.5 Overview of thesis

This thesis is divided into ten chapters. The second chapter is an overview of relevant literature and theory. Chapter three is an overview of the technologies used in the project, and why they where chosen. In the fourth chapter the research methodology is described. The fifth chapter describes the first iteration of the development where requirements are established. Chapter six is a description of the second iteration of the development, where the first prototype is developed and tested. In chapter seven the third iteration is described. Chapter eight is a description of the evaluation of the system. In chapter nine findings are discussed, and chapter ten is the conclusions.

Chapter 2

Literature Overview

This chapter presents a review of research that is relevant to this study. It is organized in three parts. First, an account of how the study relates to the field of learning analytics is provided. Second, an overview of existing positioning systems, both for indoor and outdoor positioning is presented. Third a comparison of similar research projects is given.

2.1 Learning Analytics

Learning analytics is described as using data about learning patterns and activity to provide new insights into educational practices and to improve learning, teaching and decision-making (Siemens and Gasevic, 2012) At the *1st International Conference on Learning Analytics & Knowledge* in 2011 learning analytics was defined as: *"Learning analytics is the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs."* (Buckingham Shum and Ferguson, 2012). This is still the most common definition. Often learning analytics is about utilizing existing data sources to enhance opportunities for learning. Accordingly, this study is about utilizing data to improve practice.

Multimodal Learning Analytics

Multimodal Learning Analytics is described as using multiple data sources for extracting data from a learning situation, to predict, understand, and quantify student learning (Worsley and Blikstein, 2010). It has later been defined by Worsley et al. (2016) 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."* While learning analytics often is about utilizing existing data sources, e.g. from university student administrative systems, it can also be about purposefully designing data sources to be used to improve learning as an integral part of the design of the learning activity. For example, Spikol et al. (2016) have designed a system for using learning analytics for supporting hands-on engineering design tasks. Echeverria et al. (2018) have combined role-based nurses' movement data with high fidelity patient manikin logs to implement a zone-based classification model and visualize movements within an emergency response team, which provides the data needed to give real-time feedback for both students and instructors. The research presented in this thesis uses multimodal data.

2.2 Positioning Systems

The literature on positioning systems can be split in two categories: outdoor positioning and indoor positioning.

2.2.1 Outdoor positioning

GNSS enables outdoors positioning. They can provide global or local coverage. There are several infrastructures that provide positioning data for example GPS, GLONASS, Galileo, and BeiDou. The Global Positioning System (GPS) is owned by the United States Government and consists of 24 satellites and delivers worldwide positioning, navigation and timing (United States Department of Defence, 2008). GPS provides an general outdoor accuracy of three meter horizontally and five meter vertically in most situations (United States Department of Defence, 2008), and with mobile phones the horizontal accuracy is between 5.0m and 8.5m (Zandbergen and Barbeau, 2011). This limit on accuracy itself would limit the usability of GPS indoors. As GPS demands a free line of sight from the device to four or more satellites, the indoor precision is even less accurate (Zandbergen and Barbeau, 2011).

Today GPS is available for a very large part of the population as GPS chips are embedded in most smartphones, and it would be convenient to be able to use it for indoor tracking as well, but because of the lack of indoor precision the use case is very limited.

GLONASS (Global Navigation Satellite System) is an alternative to GPS owned by the Russian Federation (Information and Analysis Center for Positioning Navigation and Timing, 2018a). It consists of 26 satellites which covers the globe (Information and Analysis Center for Positioning Navigation and Timing, 2018b). According to Russian system of differentional correction and monitoring (2018) the outdoor horizontal accuracy of GLONASS, as of November 22 2018, is between 4 meters and 18 meters. Indoors GLONASS suffers from the same inaccuracy as GPS because of the obstruction of signals.

2.2.2 Indoor positioning

Indoor positioning systems (IPS) are systems for positioning an object inside a building. Generally such systems can provide either low accuracy over a large area or high accuracy in a small area. Systems that provide high accuracy often require extensive infrastructure, many sensors and time consuming calibration (Curran et al., 2011). Indoor positioning systems can use a variety of technologies, such as WiFi (Chang et al., 2010), Radio frequency identification (RFID) (Saab and Nakad, 2011), light (Xiaohan et al., 2010), sound (Schweinzer and Kaniak, 2010), or Bluetooth, to achieve positioning.

Correa et al. (2017) has classified indoor positioning systems into three groups: network based systems, inertial based systems, and hybrid systems. Network based systems are built on wireless networks placed in the building and uses information from the wireless signals to estimate the position of the user who carries a wireless device. Inertial based systems estimates the position of the user using self-contained sensors that measures the motions of the user relative to a starting point. Hybrid systems combine techniques from the other categories to estimate the position of the user. Figure 2.1 is an overview of the classification taxonomy created by Correa et al. (2017). This research uses a network based IPS.

There are several ways of using Bluetooth Low Energy (BLE) beacons for positioning. Normally the beacons are placed as anchors in the area the IPS is supposed to cover, and a device with a Bluetooth receiver is used to collect the signals transmitted from the beacons. The collected signals are then used to calculate the position. Depending on the availability of beacons and accuracy needed from the IPS the setup could use one beacon in each room, or multiple beacons in each room.

If one beacon in each room is used, the tracking device can read the received signal strength from all beacons in it's vicinity, and assume that the strongest signal strength must be from the closest beacon. Therefore the tracking device can assume that it is located in the same room as the beacon which sent the strongest signal. This could then be used to visualize and

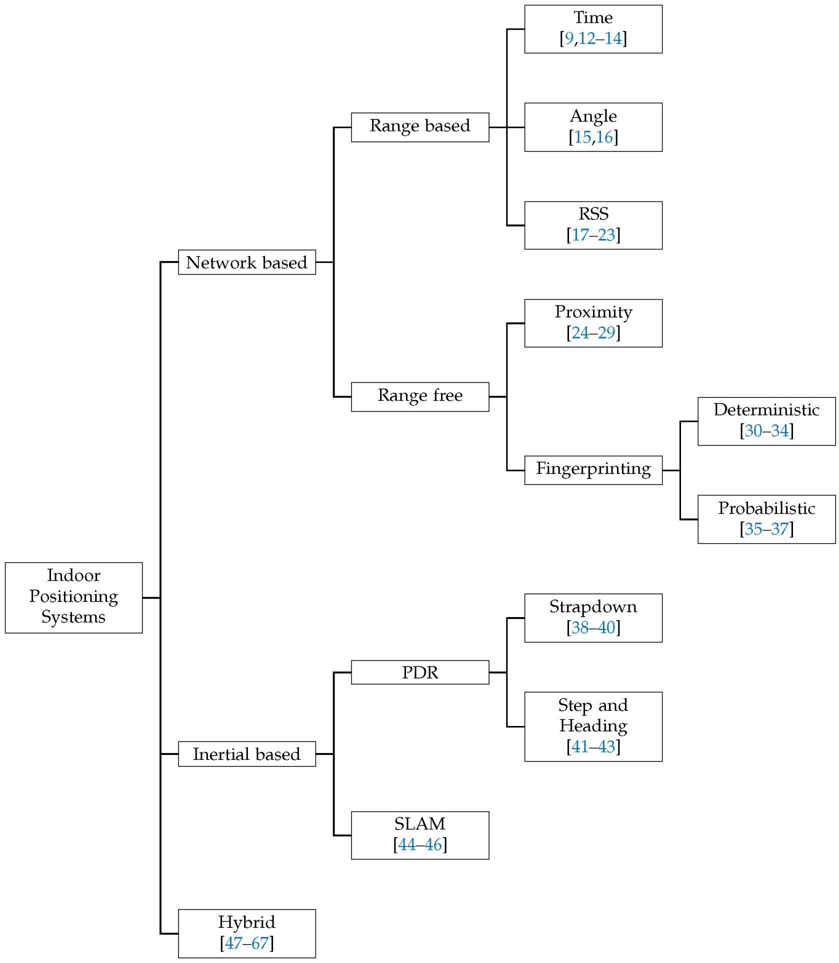


Figure 2.1: Classification of Indoor Positioning Systems (Correa et al., 2017, p. 2)

present the device's location, for the user, on a map.

If several beacons are placed in each room, one approach would be to use trilateration to determine the position. Trilateration is a trigonometric method of positioning an object. It requires the tracked object to have a line of sight to at least three beacons simultaneously. The distance from each of the three beacons to the object must be calculated. The position of the object is then the intersection of three circles, each centered at one of the three beacons (Chawathe, 2008).

Figure 2.2 illustrates an example of trilateration. The blue dots are BLE beacons with a known position, and the red dot is the object with an unknown position. The calculated distances from each beacon to the object are used as the radius of the circles around each beacon. The position of the object can then be determined using trigonometric methods.

The problem with using trilateration for positioning is that it requires the computation of the distance between the beacon and the receiver using the signal strength. According to Chawathe (2008) the correlation between the received signal strength index and the distance

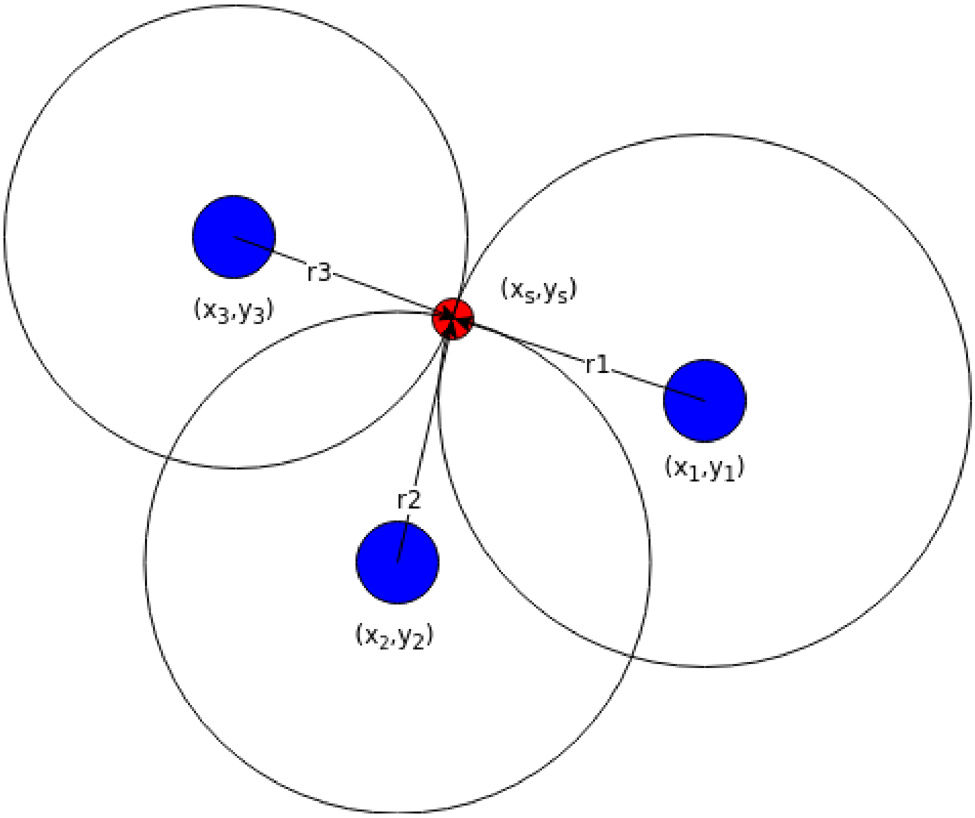


Figure 2.2: Trilateration: Three blue beacons with the distances $r1$, $r2$, and $r3$ to a red point

between the objects is not sufficiently high enough to be used to determine an exact position.

Another approach to positioning with multiple beacons in the same room is using the nearest-neighbor algorithm (Takahashi and Kondo, 2016). Using this algorithm Takahashi and Kondo (2016) present a maximum error distance of 2.0m. This algorithm requires the average RSSI, of 50 samples, from each beacon to be measured at predefined positions to be measured before the tracking starts. It also requires the average RSSI, of 50 samples, to determine a position during the tracking (Takahashi and Kondo, 2016). These requirements makes this approach unsuitable for temporary setups, and for tracking moving objects.

2.3 Related studies

This section presents a review of previous research that has relevance to the study presented in this thesis. The selection criteria are that they:

- Use Bluetooth for indoor positioning
- Enable firefighters to use data to improve efficiency

- Enable firefighter supervisors to plan work

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

Oosterlinck et al. (2017) investigated the applicability of indoor Bluetooth tracking in a shopping mall, and how it could be used for marketing purposes. In their study (Oosterlinck et al., 2017) found that Bluetooth tracking is usable to analyze the spatio-temporal behavior of the customers in the shopping mall. They also found that the collected data is richer and of higher quality than traditional surveys used to collect information about customers movements, and therefore it could be useful for marketing purposes. Their study relates to this thesis by using Bluetooth Low Energy technology for tracking humans, but in another situation and by using a slightly different approach.

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

In this research Feese et al. (2013) developed a smartphone based sensing system for monitoring temporal and behavioral performance in firefighting missions. Their goal was to use the collected data to compare the performance metrics of one firefighter team with other firefighter teams participating in the same mission. They used sensors on smartphones to sample data which was stored on the smartphone and transmitted the data so it could be used for real-time monitoring. CoenoFire utilizes smartphones to monitor and firefighters, which is also what the research reported in this thesis does.

2.3.3 Designing a Tangible Interface for Manager Awareness in Wilderness Search and Rescue

In their research Jones et al. (2018) presents a tangible interface for supporting wilderness search-and-rescue managers. The use case for this interface is a search-and-rescue operation involving multiple rescue teams. During the operation the interface will represent information about the makeup of the search area, the positions of the search teams, and the weather in the search area. The intention is to present this information to the search-and-rescue managers, so they can use it in the planning of the operation. Their study aims to track and monitor the movements of firefighters, but in another context, and using different technologies, than this thesis.

2.3.4 Accurate indoor positioning of firefighters using dual foot-mounted inertial sensors and inter-agent ranging

Nilsson et al. (2014) have developed a real-time localization systems which utilizes foot-mounted inertial sensors and RF-based communication to position firefighters. Their results indicate that the system could provide a position accuracy of two to three meters in a realistic firefighter operation. Their system also aims to track the positions of firefighters, but unlike the research presented in this thesis their goal is to use it in real missions, and the chosen technology is different.

2.4 Summary

In this chapter learning analytics was introduced, an overview of existing positioning systems was given, and four similar research projects were described.

Chapter 3

Technologies

Several technologies have been used for this project, and they can be divided into three categories, depending on the part of the system to witch they belongs: app, back end, and front end. This chapter provides an overview of the technologies used in the research, and provides an explanation of how and why they where chosen and used. It will also describe some alternative technologies that could have been used. The intention is not to give a comprehensive presentation of the technologies, but instead give a brief introduction to support and explain the choices made.

3.1 Bluetooth Low Energy Beacons

3.1.1 Bluetooth

Bluetooth is a low-power, short-range wireless technology used to connect two or more devices together so they can share data such as images, audio and information between them (Bluetooth Special Interest Group, 2017). Today Bluetooth-antennas are included in a wide range of electronic devices such as laptops, mobile phones and tablets. There are two different radio version within the Bluetooth standard: Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR), and Bluetooth Low Energy (LE) (Bluetooth Special Interest Group, 2018). This project is utilizing the features of the Bluetooth Low Energy radio in small and easily movable beacons, or transmitters.

3.1.2 Bluetooth Low Energy

The Bluetooth Low Energy (BLE) standard is a subset of the Bluetooth standard. It is designed for low power operation transmitting data in short bursts instead of continuous data streaming (Bluetooth Special Interest Group, 2018). As Mackensen et al. (2012, p. 2) explain "BLE is a connection oriented wireless technology, i.e. two devices which want to exchange data must enter a fixed connection before a data transmission is possible".

3.1.3 iBeacon protocol

In 2013 Apple released the iBeacon protocol which is a wireless BLE protocol. It is native to iOS, but it is also compatible with other devices such as Android. A beacon using the iBeacon protocol will periodically broadcast a data packet consisting of three data points: Universally Unique Identifier (UUID), Major, and Minor (Apple, 2014). Those data points are described in Table 3.1.

This data packet is received by other devices within its range. Those devices are then able to read the data and use it.

Table 3.1: Description of iBeacon data packets(Apple, 2014, p. 3)

Field	**Size**	**Description**
UUID	16 bytes	Application developers should define a UUID specific to their app and deployment use case.
Major	2 bytes	Further specifies a specific iBeacon and use case. For example, this could define a sub-region within a larger region defined by the UUID.
Minor	2 bytes	Allows further subdivision of region or use case, specified by the application developer.

3.2 Android application

Android is the most used operating system for smartphones (International Data Corporation, 2018). It is developed by Google and is based on the Linux kernel. Android was initially released in 2005 (Morrill, 2008) and the most current version is Android 9 "Pie" (Samat, 2018).

The main alternative to using Android would be to use Apples iOS. Since both had experience developing for Android and neither have developed for iOS earlier, Android was chosen to save time due to my familiarity with programming for Android. Another reason for choosing Android is access to devices for testing (both have an Android) A recommendation is that if you are developing for iOS you should use a Mac, to which we did not have access.

If the system was to be developed for commercial use the best choice would be to develop for both Android and iOS, but due to time limitations only the Android version will be developed. It is also outside the scope of our project.

There are a great variety of libraries available when developing applications for Android. Some of these add new functionality and some simplify an existing task. A few libraries used in FireTracker are described below.

3.2.1 Java

Java is a programming language developed by Sun Microsystems in 1995 (Sun Microsystems, 1996). It is a general-purpose, concurrent, class-based and object-oriented language (Gosling et al., 2018, p. 1). Java code is compiled to bytecode which can run on a Java Virtual Machine (JVM) independent of computer architecture (Venners, 2000). Java is the most common language to use when developing applications for Android, which is the main reason for choosing it.. The other reason is that out of the three languages Java, Kotlin and C++ (Google, 2018a) available for developing Android apps, Java is the only one we have prior experience with.

3.2.2 Android Beacon Library

Android Beacon Library (ABL) is an Android library that enables Android devices to interact with BLE beacons. It simplifies the process of searching for beacons and retrieve information, such as id, name and RSSI from them. The library can also be used to listen for beacons in the background (Radius Network, 2015). This library was chosen because it is one of few libraries that is actively maintained. It is also compatible with several different beacon-standards, and does not require proprietary beacons such as the Estimote SDK (Estimote, 2017). This is an advantage because we are not limited to using only one beacon manufacturer or beacon type.

3.2.3 Retrofit

Retrofit is a type-safe HTTP client for Android and Java (Square Inc., 2017). This library was used to handle all HTTP requests from the app to the back end. It makes it easy to define your API endpoints as an interface in the app and send requests to the endpoint. This results in consistency because the endpoints are used in the same way each time you use them, you cannot suddenly forget to add a required parameter one place in the code and remember it somewhere else. Another benefit is that the code is more reusable, so the same code lines so not need to be written over and over again. Retrofit also handles the response from the server and takes care of failures as well.

3.2.4 Eventbus

Eventbus is a library that makes it easier to send data between activities and threads in Android. It is simple to use. Wherever you want to send data you post an “event” containing the data, and then you listen for the events where you want to use the data (Greenrobot, 2016). This simplifies the common task of updating GUI-elements with data fetched from a server. One of the alternatives to using Eventbus is storing all download data locally on the device and then reading the data from storage again when it is needed, this is both slower and more unstable as one cannot always be sure that the data is stored before you try to load it.

3.2.5 Butter Knife

Butter Knife is a library for binding the user interface objects in the code to the XML representation schema using annotations. This reduces the amount of code needed to use user interface elements. Butter Knife also simplifies adding listeners and events to buttons and other elements to make them do something when interacted with (Wharton, 2018).

3.3 Back end

3.3.1 Go

Go is a programming language developed by Google and released in 2012 (Google, 2018b). It is a statically typed, concurrent and compiled language (Pike, 2012). Go is often referred to as Golang. The Go project is open source, meaning everyone can contribute to the development of the language. Lately Go has become a popular choice for developing scalable web services. I chose to use Go because we had some experience using it for developing an REST-API in another project and we wanted to develop our skills with the language.

3.3.2 Gin

Gin is a web framework for Go for creating HTTP servers. It enables the easy writing of a simple web server which provides a REST-API that can be used by the Android app and web front end. Using Gin routes and HTTP requests types for the server to respond to can be specified together with the definition of how it should respond to those requests (Martínez-Almeida, 2017).

3.3.3 GORM

Gorm is an Object-relational mapping (ORM) framework written for Go. It enables the creation of database models using Gos native data structures (JInzhu Zhang, 2018). The benefit of using Gorm, or any kind of orm, is that it adds a layer of abstraction over the database management. One only has to care about and work with Go structures and Gorm takes care of creating database queries and building SQL queries for the chosen dialect of SQL.

3.3.4 SQLite

SQLite is a SQL database where the entire database, with tables, indices, views and triggers, is stored in a single disk file. This is easy to use and suitable for smaller applications where a full database back end is not needed (Hipp, 2015). It makes it easier to test your system as you do not have to set up and connect to a local or remote database. The entire database is just a single file which is easy to create, back up or delete when need be.

3.4 Exercise Management Tool

3.4.1 JavaScript

JavaScript is a programming language released in 1995 (Netscape, 1995). It is one of the three core technologies used for building web sites, the other two being HTML and CSS. JavaScript is a interpreted, high-level, untyped, dynamic programming language (Flanagan, 2011). As the admin interface and visualization tool in FireTracker is a web-application, JavaScript was the natural choice of programming language.

3.4.2 React

React is a JavaScript library for building user interfaces. It is developed by Facebook (Facebook Inc., 2014). React lets you create views for each state in your application, and when data changes it will update and render only the affected components. React was chosen because Edvard wanted to use this opportunity to learn a new JavaScript framework.

3.5 Alternative Technologies

In many cases there were alternative technologies that could have been chosen. When choosing languages and libraries decisions are often based on preference and prior experience, but when deciding which tracking technology to use an informed choice was made as it could directly influence the research result. In the following paragraphs the relevant technologies are described along with the arguments for their choice.

3.5.1 Pozyx

Pozyx is a platform for accurate indoor positioning. A couple of months into the development we were made aware of the “Pozyx Accurate Positioning” project. Pozyx uses Arduino-based anchors and tags together with ultra-wideband technology to achieve indoor tracking with centimeter precision (Pozyx, 2017). At a first glance it seemed like exactly what we needed, but when we delved a bit further into this system we made three observations that would have a negative effect on usability:

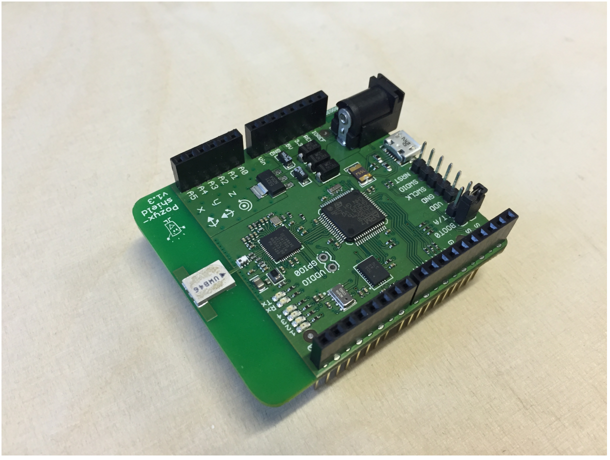


Figure 3.1: Picture of Pozyx tag/anchor (Photo: http://pozyx.io)

1. Both the anchors and tags needs external power. The anchors can easily be connected to a power outlet if there are any nearby, but the tags need to be portable. In our use case we would have to attach some kind of battery to them. Adding a battery would also make the already large and bulky device larger, see Figure 3.1. This would be a problem as the devices will be attached to either the firefighter's helmet or oxygen tank, and therefore it needs to be small, lightweight and with a minimal risk of hooking onto something.

2. In the beginning it seemed like the only way to retrieve data from the Pozyx tags was to physically connect them to another device and extract data. It was decided that this would be too cumbersome and restrictive. Later it was discovered that it is possible to remotely retrieve data via a web-API.

3. One of the goals of the project was to create a system that is easy to use and set up for firefighter instructors with little or no technical background. Therefore, a system that requires assembling of circuit-boards and batteries was considered not to be user-friendly enough.

3.5.2 Arduino

At a very early stage it was discussed as to whether it would be possible to create our own tracking devices using Arduino boards and soldering and connecting Bluetooth-antennas to them to create a Bluetooth-transmitter. We soon discovered that this was a field neither of us had any experience with, and it would probably have taken far too much time to develop this solution. The probability of us creating a product, in such a short time, that would be comparable to the available off-the-shelf products is also low.

3.5.3 Estimote

Another popular beacon manufacturer is Estimote who produces a variety of BLE beacons (Estimote Inc., 2018). Together with their beacons Estimote also supplies a Software Development Kit (SDK) which theoretically should make it easy to interact with the beacons, however, there are warnings against using these Beacons and SDK because of the many bugs and instabilities in the SDK, and they even dropped support for their old version of it to create a new one from scratch (Sætre, 2017).

3.6 Summary

This chapter has presented technologies used in this research and the reason they were chosen.

Chapter 4

Research methodology

This chapter describes the research methodology, methods, and frameworks used in this research that addresses the two questions presented in Chapter 1.4:

1. **How can indoor position data from BLE beacons be used to support firefighter movement tracking under smoke diving training?**
2. **Do the beacons provide high enough quality of data to be used for useful feedback?**

4.1 Design Science

This study is inspired by Design Science. Research based on design science can be performed in an organizational context or an academic environment (Lacerda et al., 2015). As the goal of this research is to create and evaluate an artifact, the design science methodology fits well.

Hevner et al. (2004) claims that design is both a process and an artifact. The design process produces an innovative artifact, which is evaluated to provide feedback about the artifact itself, and a better understanding of the problem. This information is used to improve both the artifact itself and the design process.

Design Science can be seen as a problem solving process. The foundation on which design science is based is that knowledge about, and understanding, of a design problem, and the solution to that problem, is something you achieve through the development and use of an artifact. Artifacts as a result of design science is according to March and Smith (1995) *constructs, models, methods,* and *instantiations.*

4.1.1 Artifacts

Within design science artifacts are created to address unsolved problems, and when they are evaluated by looking at the utility they provide in solving the problem. Hevner et al. (2004, p.78-79) identify those four artifacts as follows:

1. *Constructs*: provides the language, vocabulary and concepts, which are used to define and communicate the problems and solutions.
2. *Models*: are representations of a real world situation of the design problem and its solution space created using constructs. They help with the understanding of the problem and the solution, and is often used to represent the connection between them.
3. *Methods*: provide guidance on how to search the solution space and solve problems.
4. *Instantiations*: is an implementation of a construct, model or method in a working system.

In this research the main artifact is the back end of the FireTracker system, which determines the movements and activity of the fire fighters based on the collected data, thus, it is an instantiation.

4.1.2 Guidelines

Hevner et al. (2004) defines a set of seven guidelines for implementing and evaluating design science research. Those guidelines and their definitions are listed in table 4.1. The guidelines gives the researchers clear requirements for executing design science research. Using these guidelines and focusing on quality, efficiency, and functionality makes it easier to satisfy the requirements of design science research. The guidelines will be used throughout the process of this research to ensure that it is conducted properly.

Table 4.1: Design Science Research Guidelines (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.

4.2 Interaction Design Lifecycle

Figure 4.1 illustrates the development process used in this research. This development process is a variation of the interaction design lifecycle. The first iteration of the project is establishing requirements and creating design alternatives. This iteration is described in Chapter 5. Then there are two iterations of developing prototypes, evaluating them and creating new requirements. These iterations are described in Chapter 6 and 7. The last iteration is the final evaluation of the product, which is described in Chapter 8.

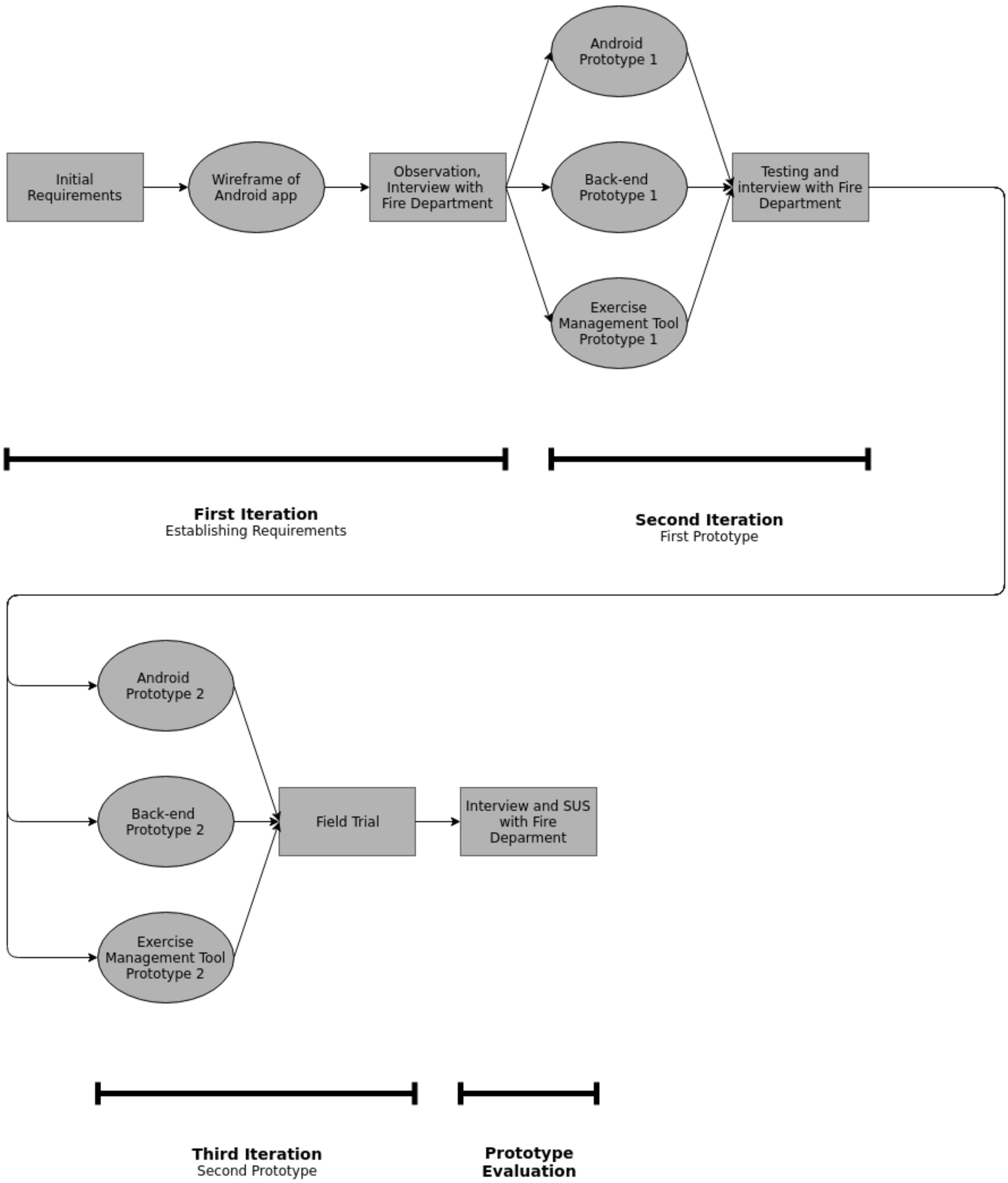


Figure 4.1: Overview of the development process

Preece et al. (2011) defines a lifecycle model for interaction design. This model is a simplified version of reality, and it is intended as an abstraction. An overview of this model is shown in Figure 4.2.

In their model Preece et al. (2011) divides the interaction design process into four basic activities: *Establishing Requirements*, *Designing Alternatives*, *Prototyping*, and *Evaluating*. These are briefly described below.

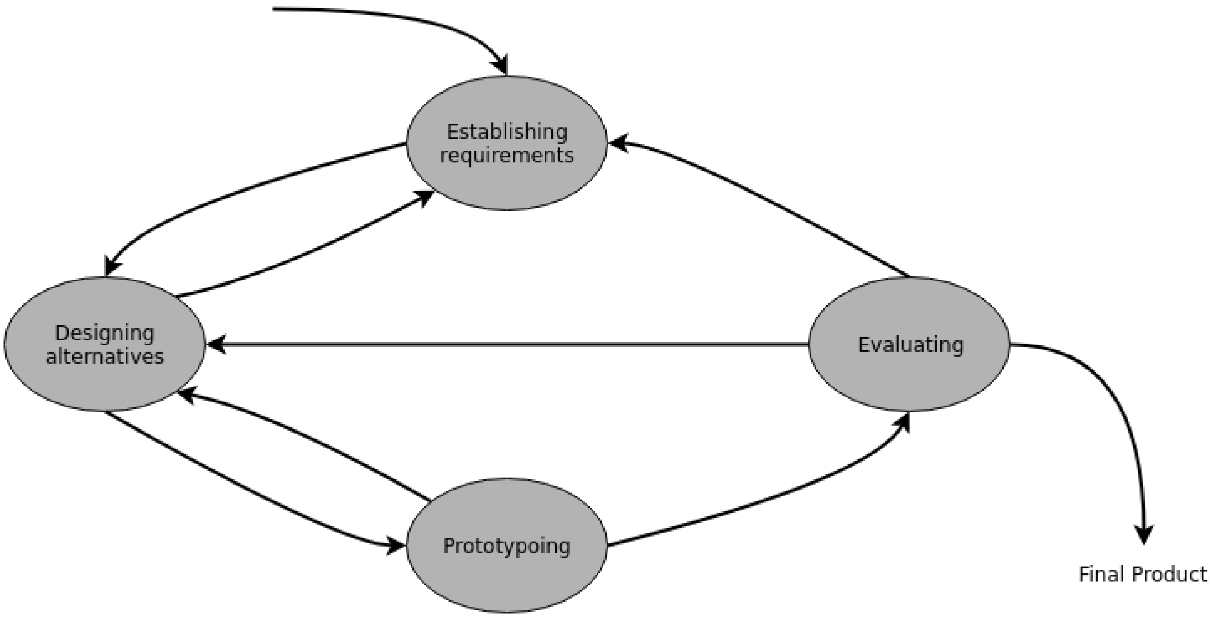


Figure 4.2: A simple interaction design lifecycle model (Preece et al., 2011, p.332)

4.2.1 Establishing Requirements

To create something that can support people, one needs to know who those people are, and what kind of support a product can provide. This need for support forms the requirements for the product. Establishing requirements is very important in interaction design, and a fundamental part of a user-centered approach to development (Preece et al., 2011).

4.2.2 Designing Alternatives

Designing alternatives is the core activity of the interaction design lifecycle: suggesting ideas for meeting the requirements. It can be divided into two sub-activities: conceptual design and concrete design. Conceptual design is creating an abstraction or model of the product, and how it can be used. Concrete design is determining details of the actual product, involving choosing colors, sounds, and images (Preece et al., 2011).

4.2.3 Prototyping

Prototyping is the creation of a low- or high-fidelity prototype. It is described in Section 4.3.

4.2.4 Evaluating

Evaluation is determining the usability and acceptability of the product measured in terms of usability and user experience criteria. In interaction design a high level of user involvement is required throughout the development process to enhance the chance of delivering an acceptable product (Preece et al., 2011).

4.3 Prototyping

A prototype is a early version of a product. It is supposed to demonstrate some features or properties of an artifact which can be evaluated and analyzed to gain some understanding about how the product can be revised in the next iteration of the development (Oates, 2005). There are two types of prototypes: *low-fidelity-prototype* and *high-fidelity-prototype* The goal of prototyping is to get user feedback.

Low-fidelity prototyping is a way of translating high-level designs into testable artifacts (Babich, 2017). The purpose of a low-fidelity prototype is to test and check functionality, not visual designs and appearances. In a low-fidelity prototype only the most important elements of the content is included, and only general visual attributes are presented.

High-fidelity prototypes look and function as similar to the actual product as possible (Babich, 2017). They are usually created when there is a solid understanding of the final product and it needs to be tested on actual users. In a high-fidelity prototype most of the content is included, and the design is realistic with all details in place.

In this research the goal is to create a High-fidelity prototype with tracking-functionality.

4.4 Data Collection

Collecting data is an important part of the research process, and therefore choosing the right methods also important. This section presents the methods used in this project: observation, semi-structured interview, field-trial, technical testing, and SUS questionnaire.

4.4.1 Observation

Observation is a data gathering technique that can be used at any stage in the development process. During observation the user can be observed directly by the investigator, or indirectly through video or audio recordings. There are two main types of observation: controlled environment observation and field environment observation (Preece et al., 2011).

Observations will be used to set the initial requirements, and during testing and evaluation.

Controlled Environment

Observation in a controlled environment often happens in a laboratory where the observer has the possibility to control different factors that can influence the testing. Controlled environment observations are more formal in their character than field environment observations (Preece et al., 2011). The observations in the technical testing in iteration 3 will be made in controlled environment.

Field Environment

Observation in a field environment is used when observing a user in their natural environment. They are useful as it can be difficult for users to explain what they do, and how they think, when solving a task (Preece et al., 2011). A field environment was used in the field trial of the final prototype.

4.4.2 Interview

Interviews are one of the most common techniques for collecting qualitative data. There are three types of qualitative interviews: unstructured interview, semi-structured interview, and individual in-depth interview (DiCicco-Bloom and Crabtree, 2006). The interviews in this research will be conducted as semi-structured interviews.

A semi-structured interview combines the features of unstructured and structured interviews and use both open and closed questions (Preece et al., 2011). The general way of performing a semi-structured interview is to have a set of open questions which is used as guidance, and with open answers to inquire as much information as possible. From those open questions other new questions can emerge during the interview (DiCicco-Bloom and

Crabtree, 2006).

Semi-structured interviews will be used to establish requirements, and to get feedback from the firefighters during the development process and in the evaluation.

4.4.3 Technical Testing

Technical testing will be done as experiments in this research. Experiments are scientific procedures with the purpose of either testing a hypothesis, making a discovery, or demonstrating a known fact. The core part of an experiment is to collect data under specific and controlled circumstances (Hellevik, 2002).

Technical testing will be used to improve the prototypes in iteration 3.

4.4.4 Field Trial

Field trials, or field experiments, are experiments where the researchers observe events in a real-life setting instead of in a laboratory setting (Oates, 2005). In field trials the researcher cannot control all variables in the same way as in a laboratory experiment.

Field trials will be used to test the final prototype during a smoke dive exercise.

4.4.5 System Usability Scale Questionnaire

The System Usability Scale (SUS) is a scale used to quickly measure how people perceive the usability of a system they are working with (Brooke, 2013). It is a questionnaire with ten questions, five of them positively worded, and five negatively worded. This is done to avoid response biases (Brooke, 2013).

The respondent answers each question on a five point scale from Strongly agree to Strongly disagree (Assistant Secretary for Public Affairs, 2013). The overall SUS score for the system is then calculated on a scale from 1 to 100, where a score between 68 and 100 is considered an acceptable or good usability score, as shown in Figure 4.3 (Assistant Secretary for Public Affairs, 2013).

The System Usability Scale will be used to get feedback on the firefighter's perception on the final prototype.

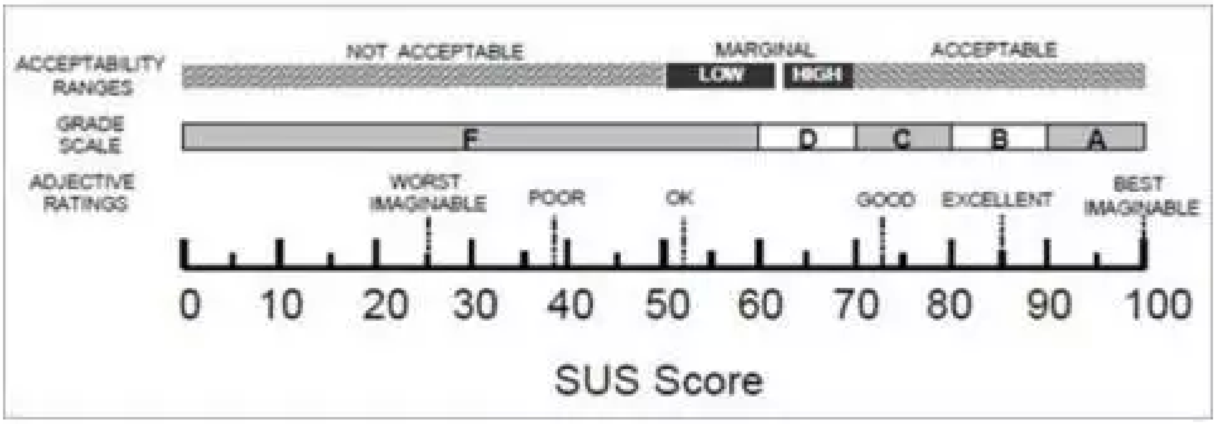


Figure 4.3: SUS scores and how they can be interpreted (Brooke, 2013, p. 36).

4.5 Summary

This chapter has described the research methodology and methods that will be used in this research.

Chapter 5

First Iteration - Establishing requirements

This chapter describes the first step in the development process: establishing requirements for the system.

5.1 Initial requirements

The first requirements that were established was the overall structure of the system and which technologies should be used. It was decided that BLE should be used as the technology for localization. The data from the BLE beacons should be collected using cellphones, running the Android operation system, attached to the smoke divers. This data should then be visualized in a web interface.

The initial requirements was then:

1. An Android application that could track the Bluetooth signal from the beacons and upload them to a server.
2. A back-end that could receive data from the cellphone, process the raw data and present it through a REST API.
3. A web-application for presenting and visualizing the processed data from the back-end.

5.1.1 Android Application

Before the initial meeting with Øygarden Fire and Rescue (ØFR) a design-prototype of the Android application was created. This purpose of this prototype was to showcase both a suggestion of how the application would be used, and, most important, how the app should function. The first step in creating the prototype was to create the flowchart shown in Figure 5.1, visualizing user actions in the app.

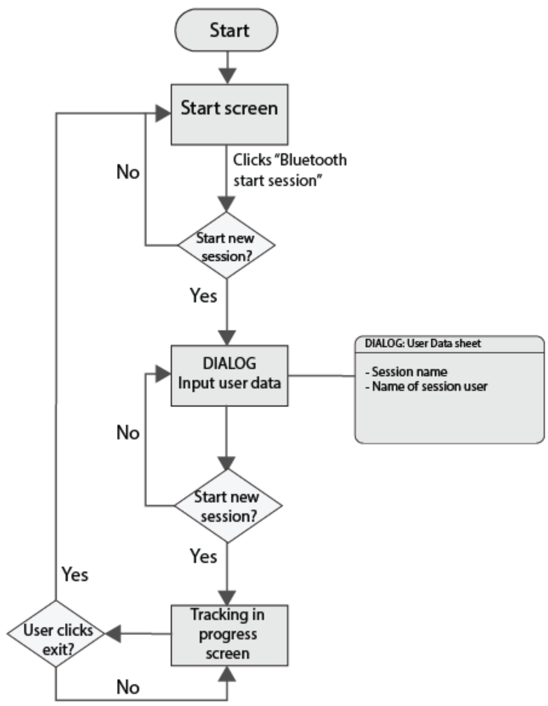


Figure 5.1: Flowchart of the Android application

As the application only has one feature, it should be as simple as possible. The user of the application should be able to create a new session with a name and a user and start the session. Then the application should collect data from nearby BLE devices until the user ends the session. The application should then upload the collected data to the server for processing.

When the initial requirements were included in the flowchart a wireframe was created as shown in Figure 5.2. This was created both to present a possible design, and to present how the app could be used, to the firefighters.

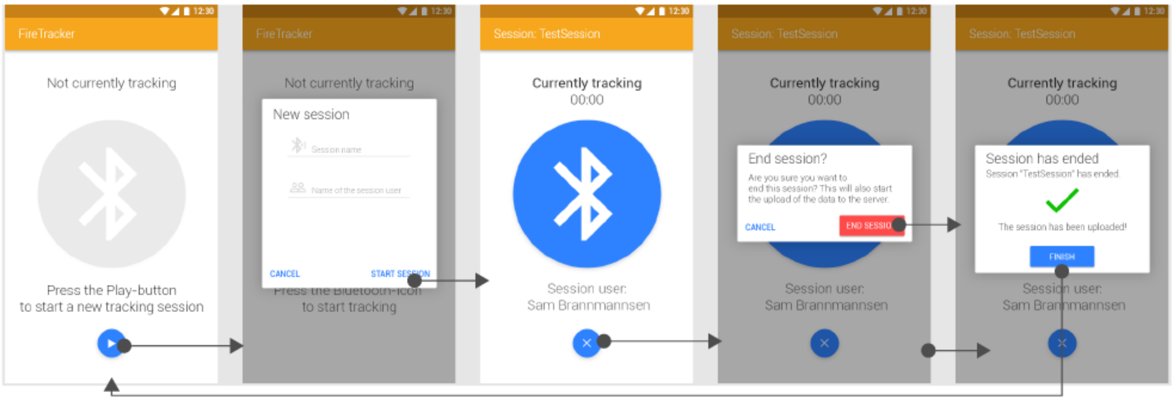


Figure 5.2: Wireframe of the Android application

5.1.2 Back-end

At this stage the only defined requirements for the back-end was that it should be able to receive data through a REST API, process the data, and present it through a REST API.

5.2 Input from the fire department

The requirements established this far were based on previous experience with development, an idea of how this system could be used, and what the fire department needed. To better understand what they actually need and how they think they can use the system, an observation of a training and a semi-structured interview with the fire chief and one of the instructors was conducted. The interview can be divided into three main themes: practical aspects, visualization and presentation of data, and use of data. The interview was 20 minutes long, and it was recorded and transcribed. The Norwegian interview-guide is attached in Appendix A.

5.2.1 Practical questions

In this section the fire chief and instructor were asked about practical aspects of the exercise and use of the system. The following questions were asked:

- How do you prepare for the exercise?
- Where can the cellphone be placed on the smoke diver?

- How many smoke divers participate in an exercise?

Summary of answers:

Preparation: The smoke divers know there is going to be an exercise, but not where or how it is going to be, and they try to vary the locations to prevent the smoke divers from "getting used" to a location or building. ØFR has three teams of firefighters operating out of different fire stations so they also try to get locations that can be used for four weeks to use it for all three teams. The instructors are able to prepare the location before the exercise and can then place beacons in the building.

Placement: As Bluetooth signals are easily blocked or reduced by the body it could be useful to place the receiver as high as possible on the smoke diver. The device could be attached to the helmet or on top of the oxygen-tank.

Participants: The number of participants vary. At this exercise they were 7 or 8, but if they exercise with firefighters from all three stations they could be 12. In the building itself there are usually one team consisting of three smoke divers in total, two smoke divers are inside the building and one is waiting outside the building. The firefighter on the outside is responsible for communicating with the two firefighters who are inside, and if something happens and they need assistance he can go in to help them get out.

5.2.2 Visualization questions

- What information can this kind of data give?
- How should the data be presented?

Summary of answers:

Information: The data should give useful information about their search-technique, and search-coverage as one could see if there are areas or rooms that was not covered in the search. If there is a room that was not searched by the smoke divers the information from FireTracker could be used, during the evaluation, to discuss why this happened. The data can be used as a reminder of events for the smoke divers in their evaluation after the exercise.

Visualization: The fire chief thought that a visualization of the data on top of a map or drawing of the floor plan for the building would be useful. Furthermore, a list of visited locations with information about the time spent there would also be useful.

5.2.3 Questions about using the data

- Could this system have any negative consequences for the training, evaluation or feedback?
  - Could it make the firefighters focus on the fact that they are being tracked instead of their tasks?
- Could this system give the firefighters better feedback after the exercise?
- Could this system be used in further training of the firefighters?
  - If yes: How?

Summary of answers:

Negative Consequences: The system should not affect the firefighters in any particular way. They are so focused on their tasks, and they do not have time to think about other elements such as this system. If anything it could lead them to put in extra effort perfecting the tasks that are in focus in this exercise.

Feedback: As both the instructor and the firefighter would be able to actually see how they searched the building they could get a more detailed feedback with more information to reflect upon.

Further Training: It could be useful for the other firefighters, who did not perform a smoke dive in this exercise to see how the smoke divers performed, and to learn from their experiences and feedback.

5.2.4 Analysis of interview

Øygarden Fire and Rescue are clearly interested in a system such as FireTracker as it could improve the evaluation of an exercise, and enable individual feedback to each smoke diver. For their search-technique training, which is a major part of the smoke diving training, it would be useful to see which rooms or areas the smoke divers have visited and which they have not visited, together with the route they took through the area. As they change locations for their training fairly often, a mobile system that is easy to set up and move is needed.

5.3 Summary

In this chapter the first iteration of the development process was described. The iteration consisted of establishing some initial requirements before observing a smoke diving exercise and interviewing people from Øygarden Fire and Rescue to extend those requirements. The requirements for the system are:

- The system should be mobile and easy to set up at a new location
- The tracker should be lightweight and easy to attach to the body of the smoke diver
- The system should visualize where the smoke divers have been searching.

Chapter 6

Second Iteration - First prototype

This chapter describes the second iteration of the development. In this iteration a prototype of both the Android application and the back-end was developed. The iteration ended with a demonstration and test of the prototypes for Øygarden Fire and Rescue.

6.1 Android application

The goal for this iteration was to implement the Bluetooth data collecting functionality, and the possibility to upload a completed session to the server, using the design proposed in Chapter 5.

This version of the app is shown in Figure 6.1. The first screen in the application (see Figure 6.1a) contains a list of available sessions. Each session is represented with a name and the name of the person who is supposed to use that session. When a smoke diver is getting ready for the exercise he chooses the appropriate session from the list which takes him to the next screen.

The second screen in the app (see Figure 6.1b) tells the user that the app is not currently tracking and has a blue play-button and instructions telling the user to press the button to start the tracking. When a user presses the play-button a dialog-box is shown asking for confirmation that the user want to start the tracking. If the user confirms he is taken to the third screen (see Figure 6.1c) and the app starts searching for BLE-signals. Every time the app receives a BLE-signal it stores the signal-strength, identifiers of the beacon transmitting the signal, data from the gyroscope and accelerometer in the phone, and a timestamp, as a datapoint in the current session. When the user has finished the tracking and presses the stop-button, a new dialog appears to confirm that the user want to end the tracking. If the user confirms all the recorded data is uploaded to the server for processing, a upload-dialog is shown (see Figure 6.1d). After the uploading is finished the user is taken back to the list of available sessions.

(a) List of sessions (b) Tracking activity (c) Active tracking (d) Uploading data

Figure 6.1: Screenshots of the Android application

Use of sensors

In addition to tracking the Bluetooth-data the app also records data from the built-in accelerometer and gyroscope in the smartphone. The accelerometer was used to detect movement and create an estimate of how many steps the user takes during the tracking. This information was then used to determine if the smoke diver was walking around or standing still within a location.

The gyroscope was used to collect information about the relative orientation of the smartphone. The intention was to use this data to determine the orientation of the smoke diver within the building, but it turned out that different devices had different zero positioning. Therefore, it was not possible to determine a consistent orientation across devices. Instead the difference of orientation over a time interval was used to determine if the user rotating the device, and thereby rotating their head as the device.

6.2 Back-end

The back-end of the FireTracker system consists of two parts. A web-server that handles requests from the Android application and the exercise management tool, and returns data to them An algorithm that processes the raw data from the Android app and outputs data about the locations and movements of the firefighters that can be used by the exercise management tool to create a visualization. In this iteration the web-server functionality was implemented together with a basic processing algorithm.

6.2.1 Web-server

The web-server handles HTTP requests from the other components of the FireTracker system and stores data it receives in a database. It also fetches data from this database and returns it to the Android app or the exercise management tool when they ask for data. In this iteration a variety of endpoints were implemented allowing the creation of new sessions, retrieving a list of unprocessed or processed sessions, retrieving a single unprocessed or processed session, updating an unprocessed session, adding beacons and maps, retrieving a list of beacons, and retrieving a map. An overview of all the endpoints is shown in Table 6.1.

Table 6.1: Web-server endpoints implemented in the second iteration

Relative path	**Request Type**	**Parameters**	**Description**
/session	OPTIONS		Create a new session
/raw/sessions	GET		Get unprocessed sessions
/raw/session/:id	GET		Get a unprocessed session with the ID “id”
/raw/sessions	POST	Finished	Get unprocessed sessions where the finished-flag is set to “Finished”
/raw/session/:id	PUT		Update a session with the ID “id”
/session/:id	GET		Get a processed session with the ID “id”
/beacon	POST		Create a new beacon
/beacons	GET		Get a list of all beacons
/sessionbeacon	POST		Create a new beacon for a specific session
/map	POST		Upload a map
/maps/:filename	GET		Get the map with filename “filename”

6.2.2 Data processing

The data processing is executed when a session is updated with data from the tracking. The algorithm creates a list of locations which are positions of the smoke diver at a given time. The first location is the first data point in the list. Then the algorithm goes through all of the remaining data points and checks if the signal is from one of the beacons used in the session. If the data point is from one of the associated beacons it checks if the signal is from the same beacon as the location it is currently working on. If it is the same beacon it updates the duration of the location and checks the difference in steps and rotation values of the gyroscope to see if the walking and head movement flags should be set to true. If it is a new beacon and it has a stronger signal strength than the last received signal from the previous beacon it creates two new locations. The first location is an estimation of the movement of the smoke diver and is placed at the mid-point between the previous and the new beacon. The second location is at the position of the new beacon.

6.3 Data Specifications

As the three components of FireTracker need to communicate and transfer data between them, a data specification was created. This specification was created using the JSON-standard, as the technologies used for all three components are able to create, send, receive, and use JSON-objects.

6.3.1 Session

The *session-object* is an object containing all the information about a single session. It has an unique ID, a name, the name of the smoke diver, the start and end time of the session, a list of data points, a list of beacons used in the session, a list of generated locations, a finished-flag, and the URL to the map used for this session. The JSON-structure of a session, with the types of each field, is shown in Source Code 6.1.

The *finished-flag* is a boolean value that is set to false when the session is created, and set to true when the Android app updates it with data from the tracking. This makes it possible to filter sessions on their finished-status so the Android app only lists sessions that have not already been used for tracking, and the exercise management tool only lists sessions that are finished and has a tracking.

```
{
        "ID": <integer>,
        "Name": <string>,
        "User": <string>,
        "StartTime": <integer>,
        "EndTime": <integer>,
        "Datapoints": [<datapoint>],
        "Beacons": [<beacon>],
        "Locations": [<location>],
        "Finished": <boolean>,
        "Map": <string>
}
```

Source Code 6.1: Session JSON-object

6.3.2 Datapoint

A *datapoint* is a registration of a single signal from a BLE beacon. The JSON-structure of a datapoint, with the types of each field, is shown in Source Code 6.2. It contains an ID, the ID of the session it is associated with, the UUID, Major and Minor of the beacon emitting the signal, a time stamp, the received signal strength index(RSSI) of the signal, the number of steps taken, and rotation-values from the gyroscope.

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

Source Code 6.2: Datapoint JSON-object

The steps are the total number of steps the device has registered since the tracking started. The RotationX, RotationY and RotationZ values are the relative rotation of the device at the time of the registration of the BLE-signal.

6.3.3 Beacon

The beacon object is a representation of the BLE beacons used in the project. It has an ID, a name, a Universally Unique Identifier (UUID), a Major value, and a Minor value. The beacon object is used to show and select available beacons when a user creates a new session in the exercise management tool. The JSON representation of a beacon is shown in Source Code 6.3.

```
{
        "ID": <integer>,
        "UUID": <string>,
        "Major": <string>,
        "Minor": <string>,
        "Name": <string>
}
```

Source Code 6.3: Beacon JSON-object

6.3.4 SessionBeacon

A SessionBeacon is a beacon that is used in a specific session. It has the same fields as a beacon described in the previous section with some more information added. The extra information is the ID of the session to which it belongs, the x-coordinate it is located at in that session, and the y-coordinate it is located at in that session. The JSON representation of a SessionBeacon is shown in Source Code 6.4.

```
{
        "ID": <integer>,
        "SessionId": <integer>,
        "UUID": <string>,
        "Major": <string>,
        "Minor": <string>,
        "Name": <string>,
        "XCoordinate": <float>,
        "YCoordinate": <float>
}
```

Source Code 6.4: SessionBeacon JSON-object

6.3.5 Location

A *location* is a position of the user at a given time during the exercise. It is created by the data processing algorithm. A location has an ID, the ID of the session it belongs to, an x-coordinate, an y-coordinate, a duration, a walking-flag, and a head movement-flag. The coordinates is the coordinates of the beacon this location is associated with. The JSON representation of a Location is shown in Source Code 6.5.

```
{
        "ID": <integer>,
        "SessionId": <integer>,
        "XCoordinate": <float>,
        "YCoordinate": <float>,
        "Duration": <integer>,
        "Walking": <boolean>,
        "HeadMovement": <boolean>
}
```

Source Code 6.5: Location JSON-object

6.4 Testing

This iteration concluded with a test of the prototype and an interview with Øygarden Fire and Rescue.

6.4.1 Demonstration and testing

The test took place at Ågotnes fire station in the office section of the building. It started with a presentation of the prototype for the fire chief with a summary of what had been developed and how the system works. After that the fire chief got to try out the creation of a session included placing out beacons in the building. A picture of him while creating the session is shown in Figure 6.2.

When the session was created and all the beacons were placed the fire chief started up the Android app and selected the session he created and started tracking. With the tracker active he walked slowly through the upper floor where all the beacons was placed. After he had finished walking through the building he ended the session and uploaded the data. The generated visualization was then showed to him. This visualization is shown in Figure 6.3.

Figure 6.2: Fire chief (sitting in the middle) testing the FireTracker system

In the visualization the blue dots are the position of the beacons. The black dots are the visited locations, including the estimated midway points. The blue lines are the movements between locations.

In this test five beacons were used. The beacons were borrowed from another project, as the beacons intended for this project were not yet available. The borrowed beacons where two different models from Estimote. Three of them were placed in a straight hallway, one was placed in an office in the bottom right (on the figure) end of the hallway, and one was placed in a meeting room next to the end of the hallway. The tracking began in the upper end of the hallway, and he walked through the hallway, into the office, back to the hallway, and into the meeting room where the tracking ended.

When he was testing the visualization in the exercise management tool the fire chief said that it felt very cluttered because of all the points and lines. He would have preferred to not have the estimated mid-points between two locations, and rather used more beacons with a shorter range. The reason for all the lines in the graph is probably both because the beacons used for this test were transmitting using different, and too strong, signal strength,

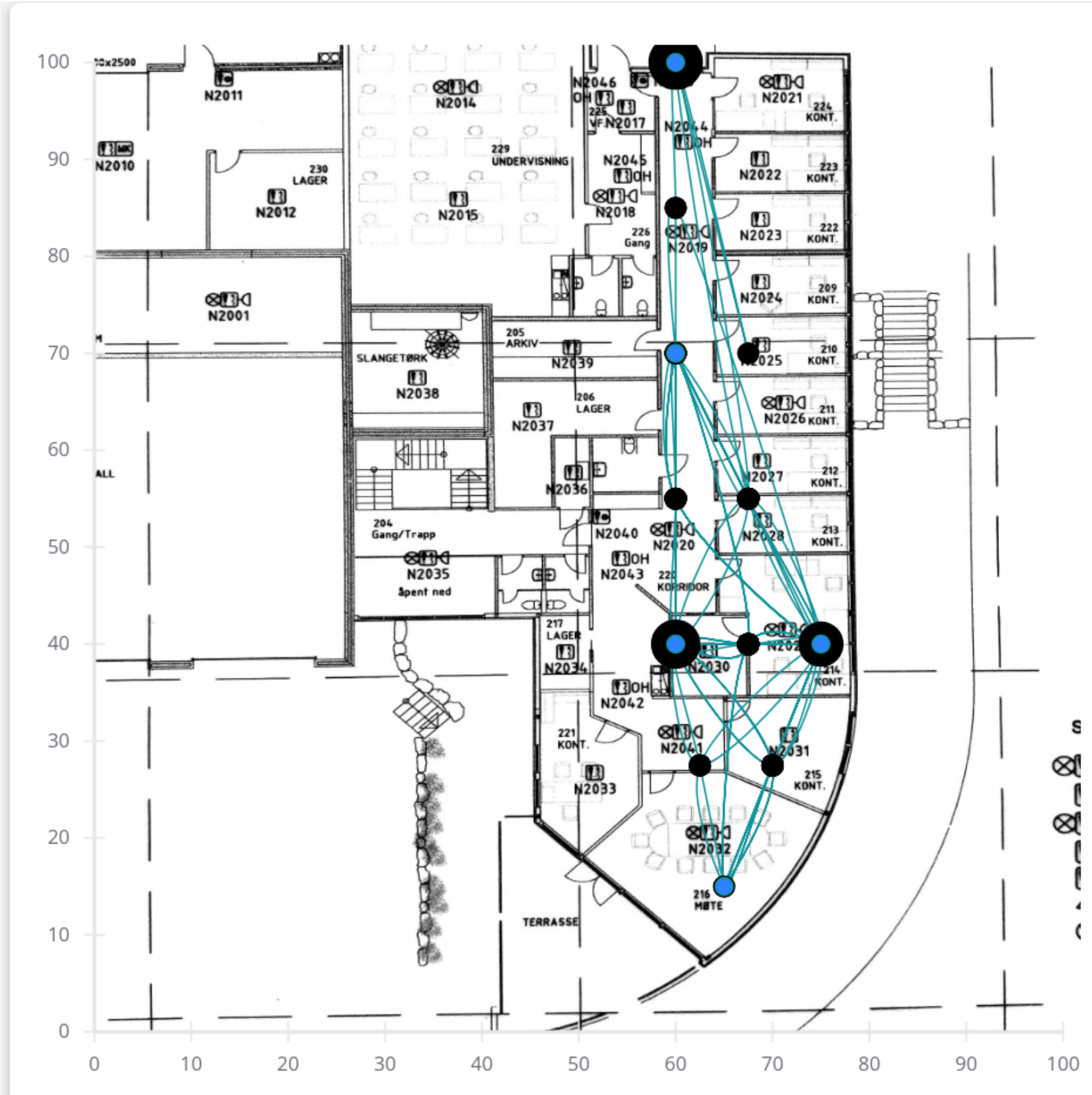


Figure 6.3: Map with tracking from test in iteration 2

and because many of them were placed in the same room. Using beacons transmitting with a lower signal-strength, and therefore having a shorter range, would probably solve aspects of this problem as well.

6.4.2 Interview

After the test the fire chief was interviewed using a semi-structured interview. The interview lasted for 30 minutes and was transcribed afterwards. The interview guide is included in Appendix B.

The questions for the interview was divided into four categories: practical, user interface, visualization, and data.

Practical

- How was it to set up a session?

Summary of answer:
Setup: It was easy both to understand and create a session. It was really easy to take a picture of the map, upload it and place the beacons on the map.

User Interface

- Were there parts of the system that was difficult to understand or use?
- Does the system (app+exercise management tool) give enough information on how to use it?

Summary of answers:
Difficulty: It was easy to use. The fire chief got the first presentation of the system less than an hour before the setup and has already created and used a session without problems.

Use Information: The fire chief meant that there should be a user manual for the system that can be read before using the system. If that user manual explains the process simply and with pictures it should be no problem to use the system. They would also prefer to have the system entirely in Norwegian.

Visualization

- How was the navigation of the visualization?
- Did you get enough information about the session?
- Was there anything in the graph or map that was unclear?
- What could the visualization in its current condition be used for?

Summary of answers:
Navigation: Navigation was a bit challenging to begin with. It would have been easier if

everything was onscreen at the same time to avoid having to scroll up and down. It looked okay on the PC, but on the iPad, which is what they are going to use, it was some scrolling.

Enough Information: The duration of each location, together with their placement on the map, can be used to discuss why the smoke divers spent much or little time in different parts of the building.

Unclear: The fire chief thought the map was very clear, except for the number of dots and lines in the graph. As he set up the session one could wonder if it might be a bit harder for someone else to understand, because of all the dots and lines.

Visualization: In the current state it would be hard to interpret and use the visualization because of the large number of points in the graph.

Data

- What do you think about using information on head movement to say something about how active a firefighter is?
- We use step counter to see if a smoke diver moves inside the area of a beacon. Is this information interesting?
  - Would it be interesting to show the number of steps or the distance?

Summary of answers:
Head Movement: Using head movement to indicate activity could end up being too much data as the smoke divers use their bodies actively and are in constant movement. The fire chief meant that the most important and interesting information is the tracing of their location.

Step Counter: The fire chief thought that it could be interesting to show the number of steps walked as the smoke divers are supposed to use their feet actively in the search, and this could be an indicator on how much they used their feet.

6.4.3 Analysis of interview

It is clear that the fire department is interested in using a system such as FireTracker, and they think it could be a valuable form of feedback when evaluating smoke diving exercises. The system is easy to understand and use, and with the addition of in-system instructions, it would be even better. At the moment the problem with the system is the large amount of points in the visualization, which are caused by the estimated mid-points between two locations. Those should be removed to reduce the clutter.

6.5 Summary

This chapter has described the second iteration of the development process. In this iteration a working prototype of the system was developed, and tested together with Øygarden Fire and Rescue. The new requirements for the next iteration are:

- Reduce information in the visualization
- Use Norwegian everywhere in the system
- Add safety features to prevent data loss

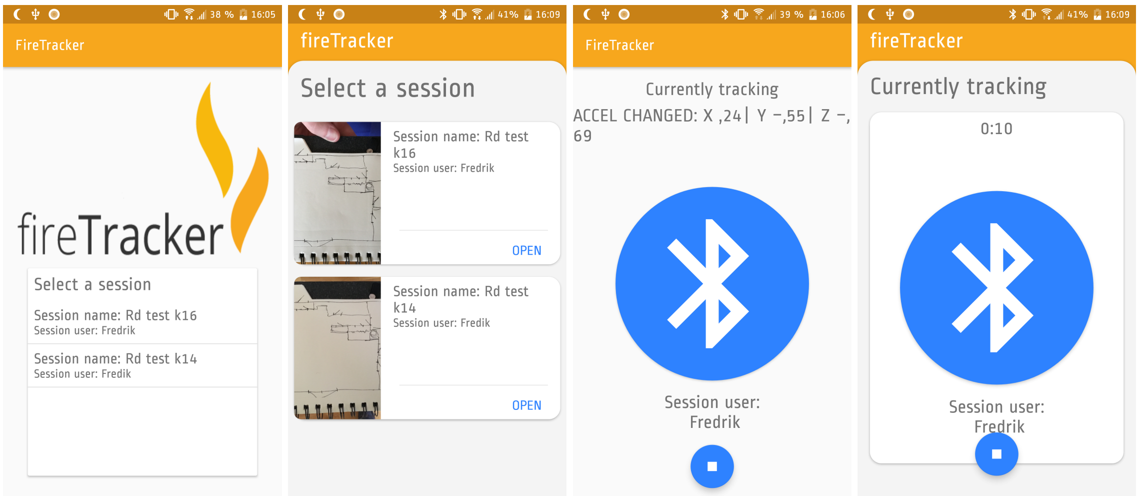
Chapter 7

Third Iteration - Second prototype

This chapter describes the third, and final, iteration of the development process. In this iteration the prototypes presented in Chapter 6 were improved and tested.

7.1 Android application

The Android application went through some changes in this iteration. The most visible change is a new design for the app. Some of the design changes are shown in Figure 7.1. It was redesigned to be more user friendly and consistent with the design of the exercise management tool.



(a) Old design (b) New design (c) Old design (d) New design

Figure 7.1: Design changes in Android application. List of sessions screen (left) and tracking activity (right)

As the fire department would prefer to have the system in Norwegian the app was translated into both Nynorsk and Bokmål. The app will use the language which is set as default in the phone settings. A safety feature was also added to prevent loss of data. If the app is unable to upload data from a session for some reason, the user is given the opportunity to save the session locally on the device for later uploading. This way the exercise can continue and the device can be used for another session immediately.

On the tracking screen a timer was added to make it easier to see how long the session has lasted. The settings for how often the phone should search for BLE signals was also changed to the shortest possible interval.

7.2 Back end

During this iteration there improvements were made to the back-end, both to the web-server part and to the data processing part. Those changes are described in the following sections.

7.2.1 Web-server

An endpoint for deleting beacons from the database was added to the web-server during this iteration. The other endpoints were restructured removing the “raw” part of the session related URLs. Instead of specifying if the session should be unprocessed or not the default is to return processed locations if they exists, but not return all the collected data associated with a session. This was done to reduce the amount of data that is returned, which effected the loading time of large sessions. If one wants all the data points for a session it is possible to specify that. When getting a list of sessions the default is to exclude both locations and data points. All available endpoints with their description are presented in Table 7.1.

7.2.2 Data processing

The data processing algorithm went through a massive overhaul in this iteration. The estimation of mid-points between two locations was removed, and the collected data were “cleaned” to avoid jumping back and forth between locations with short duration. The final version of the algorithm that was developed in this iteration is described in the following paragraphs.

Table 7.1: Web-server endpoints after the third iteration

Relative path	**Request Type**	**Parameters**	**Description**
/session	OPTIONS		Create a new session
/sessions	GET		Get all sessions
/sessions	POST	Finished	Get sessions where the finished-flag is set to "Finished"
/session:id	GET		Get a session with the ID "id"
/fullsession:id	GET		Get a session with the ID "id" including datapoints
/session:id	PUT		Update a session with the ID "id"
/beacon	OPTIONS		Create a new beacon
/beacon/delete	POST	Id	Delete the beacon with the ID "id"
/beacons	GET		Get a list of all beacons
/sessionbeacon	POST		Create a new beacon for a specific session
/map	POST		Upload a map

The first step of the algorithm is to go through the list of datapoints and check whether each datapoint is associated with a beacon registered for this session. If the UUID, Major and Minor value of the datapoint, matches one of the beacons for the session the datapoint is kept, otherwise it is discarded. When the list of datapoints is updated to contain only relevant data the creation of location begins.

The first datapoint in the list is chosen as the basis for the first location, using the coordinates from the beacon associated with the datapoint as the coordinates for the location. The duration is set to zero, the start time and end time is both set to the time stamp of the datapoint, and both the walking and head movement flag is set to false. Then for all of the remaining datapoints in the list it checks if the signal it represents is from the same beacon as the location it is currently working with. *If it is the same beacon* it sets the end time of the location to the time stamp of the data point, updates the duration of the location, and checks the difference in steps and gyroscope values between the previous data point and this data point to determine if the walking and head movement flags should be set to true.

If it is a new beacon, and it has a stronger signal strength than the last received signal from the previous beacon the current location is finished and added to the list of locations. Then a new location is created using the information from this new beacon.

When all data points are converted to locations, the process of cleaning the list of locations begin. The cleaning process compares the length of locations before and after the cleaning and is repeated until there is no change in length. The first step of the cleaning is to go through the list of locations and check if adjacent locations have the same x- and y-coordinate. If they are the same, the two locations are merged into one. The merged location gets the start time of the first location and the end time of the second location. The duration of the new location is set to the sum of the two locations. If either location has the walking set to true this flag is set to true in the new merged location, the same applies to the head movement flag.

The next step of the cleaning process is to go through the new list of locations and check if there are occurrences of two locations with the same coordinates which are separated by a location with a very short duration. If this is the case the location in between is removed and the two other locations are merged. Then the first step of merging adjacent locations with the same coordinates are repeated.

When the cleaning process is finished and no more locations to merge or remove are found, the list of locations are stored in the database and are ready to be visualized by the exercise management tool.

7.3 Data specifications

There were some minor changes to the data specifications in this iteration. To improve the visualization of the time the smoke divers use in each location it was decided to add the time they arrive and leave each location, in addition to the duration of the stay. This change can be seen in Source Code 7.1. All other data specifications remained as they were described in Chapter 6.3.

7.4 Testing

During this iteration some testing was done to ensure the system was ready for the final evaluation. This testing was done on campus at the Department of Information Science and Media Studies. A map of the floor used for the test is shown in Figure 7.2. The participants in this test were Fredrik V. Heimsæter and Edvard P. Bjørgen.

```
{
  "ID": <integer>,
  "SessionId": <integer>,
  "XCoordinate": <float>,
  "YCoordinate": <float>,
  "Duration": <integer>,
  "Walking": <boolean>,
  "HeadMovement": <boolean>
}
```

```
{
  "ID": <integer>,
  "SessionId": <integer>,
  "StartTime": <integer>,
  "EndTime": <integer>,
  "XCoordinate": <float>,
  "YCoordinate": <float>,
  "Duration": <integer>,
  "Walking": <boolean>,
  "HeadMovement": <boolean>
}
```

Source Code 7.1: Updated Location JSON-object

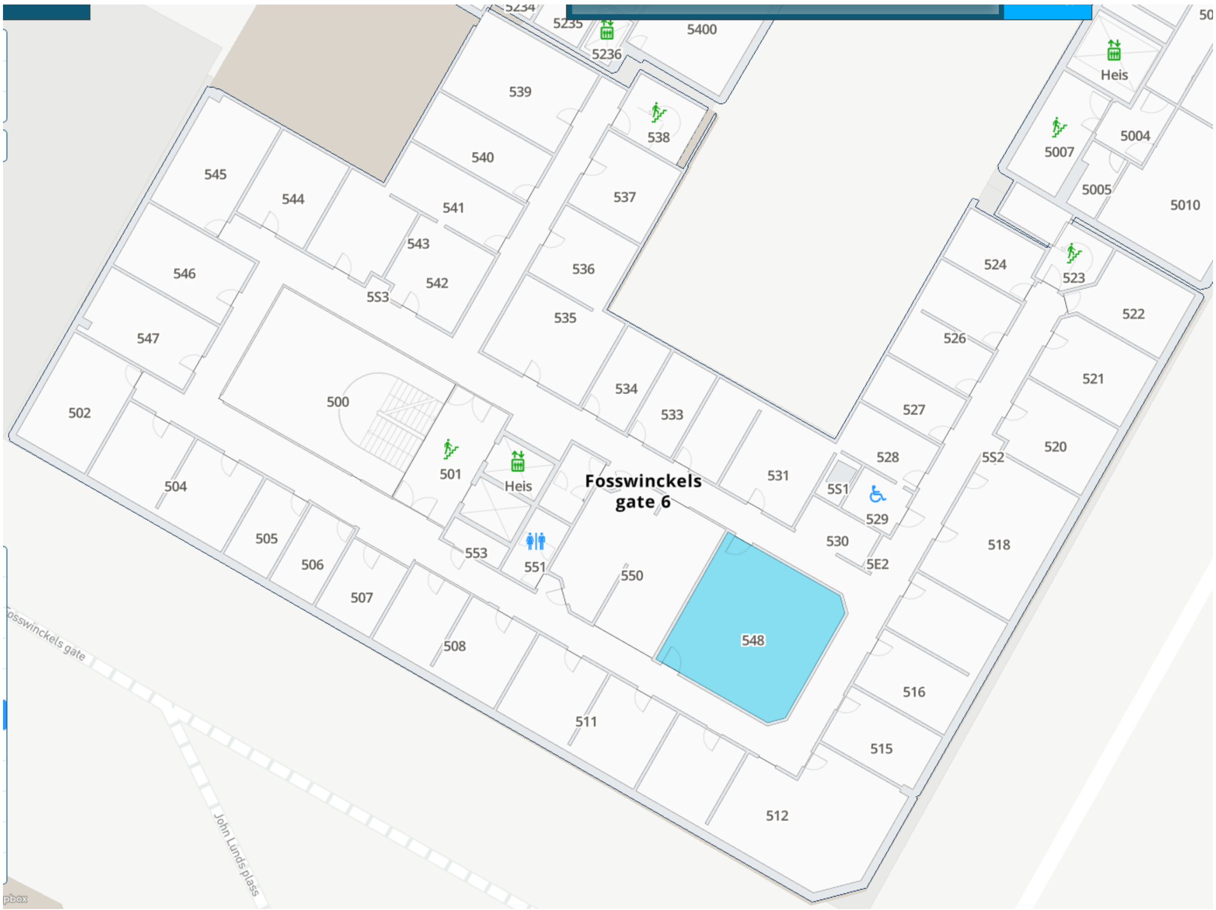


Figure 7.2: Map of the Department of Information Science and Media Studies (Map taken from https://use.mazemap.com/)

For these tests the beacons were taped to the roof along the hallways of the building. Ideally they should have been placed inside the different rooms and offices, but that was not possible as the rooms are in use. The floor has glass walls and some open areas between the hallways. These tests were done with the BLE beacons from Ebeoo. All beacons were set up with the same UUID. They were grouped into three different groups depending on the physical color of the beacons. All beacons with the same color got the same Major value, and each beacon in the same group got an unique Minor value. All beacons were set to transmit with the lowest possible signal strength. Five different Android devices was used during the testing.

From the tests two major observations were made. The first was that the different Android devices registered different numbers of data points when walking the same route through the building with the devices side by side. This is probably because the manufacturers use different Bluetooth-antennas. The result of this observation was that the scanning interval in the Android application was set to the lowest possible value, in an attempt to force the devices to scan more often. This change improved the scanning results, and the devices that previously had the least number of data points came closer to the number of data points collected by the devices that got the largest number. Therefore, the two devices that collected the largest amount of data points was selected for the rest of the testing and the final evaluation.

The next observation was that even though the beacons were set to transmit at the lowest possible signal strength the beacons had a longer range than expected. Because of this the devices received signals from several beacons at the same time, and the difference in RSSI between the closest beacon and a beacon 15 meters away was both small and inconsistent. This discrepancy made it hard to use any kind of measures to decide which beacon was the closest. Another result was that the actual time a smoke diver spent in an area was split into several locations with locations from other beacons with a very short duration in between. This effect was reduced by the cleaning process described in Section 7.2.2.

Attempts were made to reduce the signal strength of the beacons. The beacons were partly wrapped in aluminum foil, but that did not have any significant impact on the signal strength. The beacons were totally wrapped in aluminum foil, but that resulted in no signal received from the beacon at all. The Android devices were wrapped in aluminum foil, and the result was that they received no BLE signals at all.

Due to time constraints for this research, a decision on how to handle this problem had to be made. The fact that the beacons were mostly placed in the same room, or were separated by glass walls seemed like a plausible explanation of why this problem occurred. It was also expected that spreading the beacons across different rooms with thicker walls that blocks the signals better would improve the result. Therefore, it was decided not to do anything more with the system and beacons at this time.

7.5 Summary

This chapter described the third, and last, iteration of the development. During this iteration the prototypes were finalized and tested.

Chapter 8

Prototype Evaluation

This chapter describes the final evaluation of the FireTracker system. The evaluation consisted of a field trial of the FireTracker system, semi-structured interviews, and SUS questionnaires. The goal of this evaluation was to evaluate the FireTracker system in terms of usability for the fire department as a step in answering the research questions.

8.1 Field Trial of FireTracker

The field trial of the FireTracker system was carried out during a cold smoke exercise with Øygarden Fire and Rescue.

(a) Entering building (b) Starting search (c) Discovering hallway (d) Searching hallway

Figure 8.1: Images of smoke divers during exercise

8.1.1 Setting

Figure 8.2 shows the planned structure of the evaluation. The first step was to present and introduce the project and system to all involved firefighters, including smoke divers, instructors, and other observers. During this presentation both the exercise management tool and the Android application were demonstrated and explained, and questions from the firefighters regarding the use of the system were answered. The location for the exercise was one of Øygarden Fire and Rescue's empty, one floor, exercise buildings. Before the exercise could start the building, beacons, and sessions had to be set up. As there was no floor plan available for the building one had to be drawn using pen and paper. The instructors created a session in the exercise management tool and placed beacons in areas they thought could be interesting.

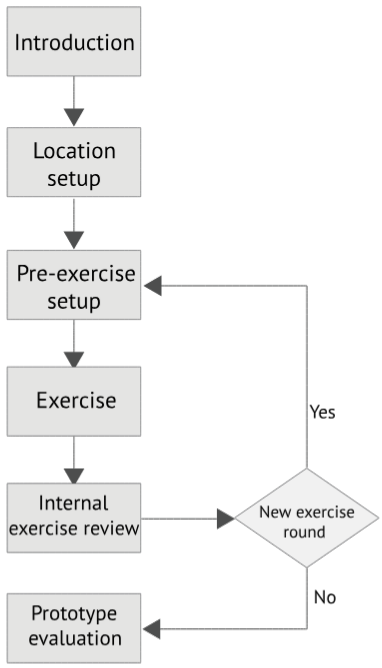


Figure 8.2: Wireframe of evaluation

When the beacons were placed in the building, and other necessary equipment, such as the smoke machine, was in place the mobile phones was set up with the correct sessions for each smoke diver, the tracking was activated and the phones were placed in a container attached to the smoke diver's helmet as shown in Figure 8.3.

(a) Front of helmet (b) Backside of helmet (c) Right side of helmet (d) Left side of helmet

Figure 8.3: Plastic box for smartphone attached to helmet

8.1.2 Participants

Øygarden Fire and Rescue provided four firefighters for the evaluation. Two of them were smoke divers and two of them were instructors. The instructors also played the roles of smoke diver leader, fire chief, and firefighter squad leader. The smoke divers has two roles: smoke diver 1 and smoke diver 2. Smoke diver 1's role is to lead the work, use the firehose, and search the area (Direktoratet for samfunnssikkerhet og beredskap, 1994). Smoke diver 2's role is to feed the firehose to smoke diver 1, carry equipment, open doors, and search the area (Direktoratet for samfunnssikkerhet og beredskap, 1994). The smoke diver leader's role is to maintain contact with the smoke divers, keep track of time and oxygen levels of the smoke divers, be ready to enter the building in case of an emergency, and feed the firehose to the smoke divers.

8.1.3 Data Collection

The exercises were observed by the researchers who also took notes and pictures during the sessions. The first session was done without smoke, instead the smoke divers' masks were covered with plastic bags, which allowed the researchers to observe from inside the building.

8.1.4 Flow of Exercise

There were four smoke diving sessions. The first three of them were performed with full smoke diving gear, as in a real-life situation, and the last was performed without gear.

Setup of each smoke dive:

1. Two smoke divers and one instructor. No smoke in the building, but the smoke divers' mask was covered in plastic.

2. Two smoke divers and one instructor. Building filled with smoke.

3. Two smoke divers and one instructor. Building filled with smoke.

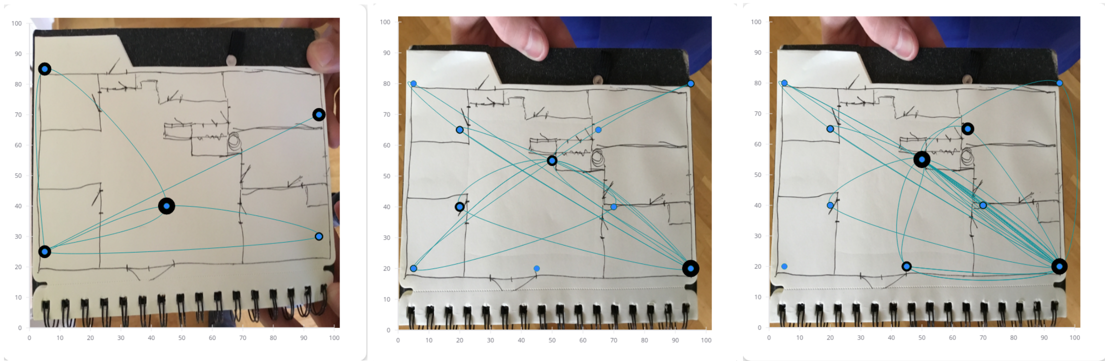
4. One smoke diver and one instructor. No smoke in building.

As the smoke divers' masks were covered in the fist session their visibility was zero and they had to rely on their other senses. For the second and third session the building was covered in cold smoke, which give the smoke divers some visibility. The last session was done without gear and smoke to present more data about where the actions of the smoke divers were observable. After each session the collected data from the Android application was uploaded and the visualizations were presented to the smoke divers and instructors who discussed them. Figure 8.4 shows the smoke divers discussing search strategy with the instructor before entering the building.

Figure 8.4: Firefighters with smartphones mounted on their helmet

8.1.5 Analysis

In the first exercise five beacons were used, with one in each corner of the building and one approximately in the center, as shown in Figure 8.5a. This visualization gives a somewhat accurate overview of the smoke divers movement, but there are some lines that do not match the actual movements. This inaccuracy exists because the Android application registers signals from several beacons at the same time, and cannot decide the exact position, as explained in Chapter 7.4[1].



(a) Exercise 1, smoke diver 1 (b) Exercise 2, smoke diver 1 (c) Exercise 2, smoke diver 2

Figure 8.5: Visualizations for exercise 1 and 2

In the later exercises the number of beacons used are increased, as shown in Figure 8.5b and Figure 8.5c. This was done to test if having multiple beacons in the same room would give a better tracking and information about the search technique. In this case the effect of the too strong signal strength is even clearer, but there is also a difference in the number of lines on the visualization for smoke diver 1 (Figure 8.5b) and smoke diver 2 (Figure 8.5b), where smoke diver 2 has much more lines. This could be an indication on a higher level of activity on smoke diver 2, which fits well with their tasks, as smoke diver 2 is supposed to move more around. It also matches what the smoke divers themselves told about their activity level.

The third and fourth exercise shows similar results as exercise 2. There is much noise in the visualizations because the Android app detects beacons that are not nearby. A difference in activity level can also be seen in those visualizations, and they those exercises as well they correspond to the smoke divers roles and reported activity. The visualizations for these exercises can be found in Appendix C.

[1]This problem was discovered at the end of the testing session, and there was no time to fix it before the field trial

8.2 Evaluation

After the testing there was an evaluation session. The evaluation was performed as a semi-structured interview with each of the participants followed by a SUS questionnaire. The interviews were recorded and transcribed. Interview guides can be found in Appendix D. The SUS questionnaire can be found in Appendix E.

8.2.1 Evaluation with smoke divers

The smoke divers were asked questions about how the use of FireTracker affected their performance. Their answers were that it had no impact on how they behaved, because they were so focused on their tasks that they forgot they had the phones on their helmet. They also said that using a few seconds to start the tracking before entering the building did not matter in this setting, but in the future it should already attached to their bodies before arriving the location. They already have other equipment that is attached and activated in the car en route to the exercise.

They were also asked about how the system could be used during their evaluation of an exercise. To this they answered that the current version of the visualizations are too cluttered with all the incorrect lines, but they think the system has potential to become useful. They also stated that they wanted a higher level of precision on the tracking. Instead of all points and lines showing up at once in the visualization, they would prefer to have the graph drawn stepwise as they step through each visited location.

Figure 8.6 shows the smoke divers' scores on the SUS questionnaire. Both of the smoke divers scored below 68, which is the lower limit for what Brooke (2013) considers a good score. This means that the smoke divers found the system hard to use or they did not think they would use the system.

8.2.2 Evaluation with instructors

The instructors were asked questions about how it was to use the system, both about the user interface, and the physical setup and use. Both instructors agreed that the system was easy set up and use. They thought it was user friendly and easy to understand. One of them also said that if they were to use FireTracker in real exercises they would attach and activate the tracking devices before they left the fire station or in the car on the way to the exercise

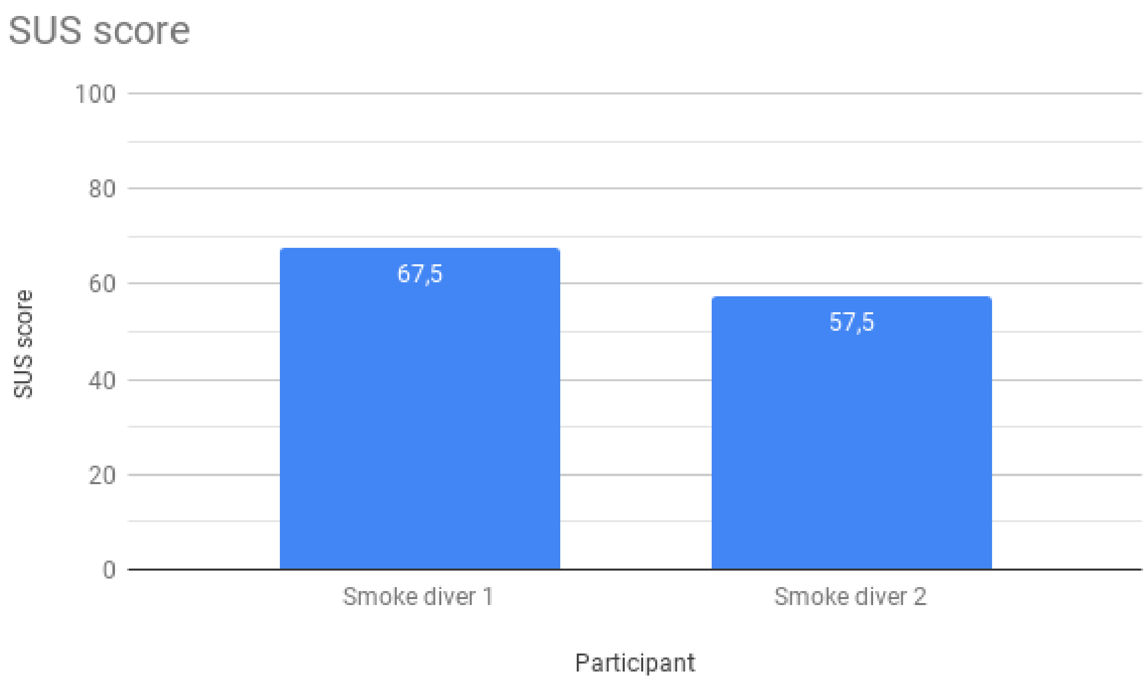


Figure 8.6: SUS score for the smoke divers

location, as they do with other equipment. It was also mentioned that the helmet might not be the ideal placement of the phones, as it is a very exposed position.

They were also asked about the data the system provided, and how it contributed to the exercise evaluation. Both of the instructors thought the data collected was relevant, but in the current version the data was not good enough because it showed the user as being somewhere else than they actually were at times. They were also positive to the visualization of time usage, as it can show if a smoke diver hesitates somewhere he should not be hesitating, or at what part of the exercise a smoke diver spends most time. This can be used in their discussions after the exercise, and it could be used to understand what the individual smoke divers need to exercise more of in the future. One of them also said that it could be interesting to combine the tracking with video footage from a camera attached to the smoke diver. It was suggested to use beacons with a very short range to track if a specific object, such as a bed, had been searched.

Figure 8.7 shows the instructors' scores on the SUS questionnaire. Both of the instructors scored above 68, which is the limit for what is considered a good score (Brooke, 2013). This means that the instructors thought the system was easy to use, and that they would like to use the system often.

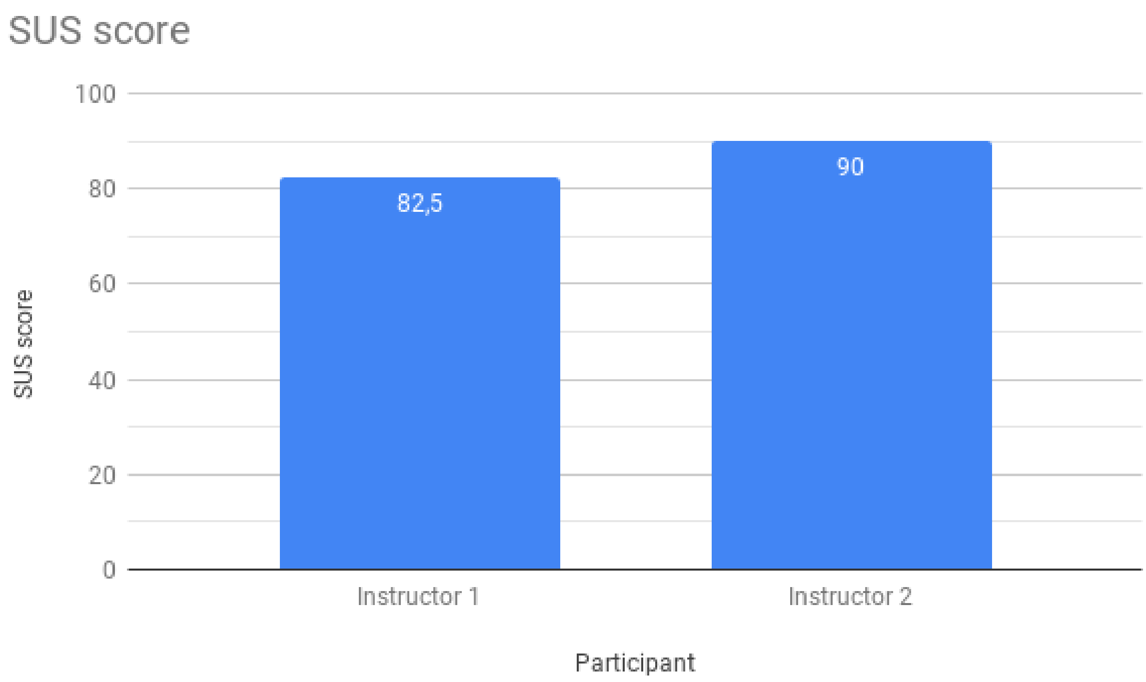


Figure 8.7: SUS score for the instructors

8.3 Summary

This chapter described the evaluation of the FireTracker system that was performed as a field trial in a real-life cold smoke diving exercise with Øygarden Fire and Rescue, and followed up by interviews and SUS questionnaires.

Chapter 9

Discussion

This chapter discusses and critically reflects upon the research methods used in this project and answers the research questions.

9.1 Design Science Research

Throughout this research the Design Science research methodology was used by following the seven guidelines: *design as an artifact*, *problem relevance*, *design evaluation*, *research contributions*, *research rigor*, *design as a search process*, and *communication of research* (Hevner et al., 2004).

Design as an artifact means that the research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation (Hevner et al., 2004). This research has produced the FireTracker system, with its three components, as the main artifact.

Problem relevance means that the purpose of the research should be to develop technology-based solutions to solve relevant and important problems for businesses and organizations (Hevner et al., 2004). This research has satisfied this guideline by creating a system which can help firefighters get more and better feedback from their smoke diving training.

Design evaluation means that the utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods (Hevner et al., 2004). In this research the design evaluation was fulfilled by the evaluation of the final prototype which was described in Chapter 8.

Research contributions means that the research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies (Hevner et al., 2004). This research provides the FireTracker system as its main artifact, and it has contributed in the field of learning analytics and as there is little existing research on the use of BLE in this situation it can also be considered as a design foundation.

Research rigor means that the research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact (Hevner et al., 2004). The artifact has been developed as a high-fidelity prototype that was evaluated using experiments, semi-structured interviews, and SUS questionnaires.

Design as a search process means that the search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment (Hevner et al., 2004). This research project went through an iterative development with testing and evaluation after each iteration, and the results from the testing was used to improve the prototype in the next iteration.

Communication of research means that the research must be presented effectively both to technology-oriented as well as management-oriented audiences (Hevner et al., 2004). The artifact created in this research has been presented to smoke divers, instructors and the fire chief at Øygarden Fire and Rescue. A presentation of the research were also made, in the form of a poster, at the LASI-Nordic 2018 symposium in Copenhagen, Denmark. This poster is included in Appendix F.

9.2 Semi-structured Interviews

Semi-structured interviews were used to establish requirements in the first iteration, evaluate and get feedback on the first prototype in iteration two, and to evaluate the final prototype. Using semi-structured interviews gave the researchers answers to the predefined questions, while also giving the firefighters and instructors freedom to comment other aspects of the system, suggest new ideas or improvements. This was very important when establishing requirements in the first iteration as the researchers had little prior knowledge on how the firefighter training is executed and what needs the fire department had. Using semi-structured interviews in the evaluation provided feedback on the developed system, but also on how it could be developed further, and other use cases for the system.

9.3 System Usability Scale

System Usability Scale questionnaires were used, in addition to interviews, in the evaluation of the final prototype. It provided quantitative data on how the smoke divers and instructors perceived the usability of the FireTracker system. The sixth question which is: *"6. I thought there was too much inconsistency in this system."* was confusing for all of the respondents, and they did not immediately know how to answer it. The researchers explained that it was probably more applicable to larger systems with more functionality, but for this evaluation they could have the design of the app and the exercise management tool in mind when answering it.

The smoke divers would normally only be exposed to the visualizations after the exercise, and not the setup of a session or the Android application. In this evaluation the entire system was presented to them, in addition to the instructors, but they did not test it. This could be the reason for the lower SUS scores from the smoke divers.

9.4 Technical tests

The technical tests done in iteration 3 were done as experiments in a controlled environment outside the smoke diving site. Those test showed that there were some issues with the Bluetooth Low Energy beacons, which affected the precision and usability of the FireTracker system. If time had allowed it more technical testing should have been done to find a way to reduce the signal strength from the beacons, or to get enough statistics about the beacon signal strength so it could be handled in the software.

9.5 Research Questions

This research provided two research questions in Chapter 1. To answer those questions the FireTracker system was developed and evaluated.

Research Question 1: *How can indoor position data from BLE beacons be used to support firefighter movement tracking under smoke diving training?*

This research shows that Bluetooth Low Energy beacons have potential for being used for tracking firefighters. Using them for precision tracking in a temporary location, such as those used by Øygarden Fire and Rescue, seems unrealistic at the moment. To get precision tracking one would need a system such as the one described by Takahashi and Kondo (2016) (*cf.* Chapter 2.2.2), which is not a solution that can be moved around. For a permanent setup a solution like that could be used.

Using BLE beacons for proximity tracking, as is shown in this research, seems like the most viable solution for tracking firefighters during smoke diving training, when the location of the exercises changes often. Currently there are some technical difficulties with the BLE beacons, but if beacons that transmit using lower signal strength become available, the current version of FireTracker could work well.

Research Question 2: *Do the beacons provide high enough quality of data to be used for useful feedback?*

As earlier mentioned the currently available Bluetooth Low Energy beacons are not precise and consistent enough to provide an accurate tracking of the firefighters' movements. Therefore the information presented in the FireTracker system only gives the users an idea of their movements and time usage. This could be somewhat useful when exercising in a smoke filled building, as the instructor cannot see what the smoke divers are doing, but in general the current version of the system does not provide good enough information for useful feedback.

Chapter 10

Conclusion

This chapter presents a summary of the research presented in this thesis, limitations of the research project, and suggestions on what could be done in the future.

10.1 Summary

Design Science Research was used to develop FireTracker, a system for tracking firefighters while exercising smoke diving. The system was developed through three iterations, and the prototype created during those iterations was evaluated. This prototype consisted of three components: an Android application for collecting data; a back-end for processing data; and an exercise management tool for creating and presenting data. The two first components are presented in this thesis[1], but all of them are interrelated and were evaluated together.

In the first iteration the requirements for the system were established. A wireframe for the Android application was created, together with a visual demonstration of how the app could work. This was presented to the fire department, and their feedback, and ideas were combined with observations made during a smoke dive exercise were used to establish requirements for the system.

The second iteration started with the development of the first functional prototype of the system. In this iteration most of the tracking functionality was implemented in the Android application. The back-end was developed with web-server functionality and the first version of the localization algorithm. At the end of this iteration the system was demonstrated for, and tested by, a smoke diving instructor at Øygarden Fire and Rescue.

[1] The third presented in Bjørgen (2018)

In the third iteration the feedback from iteration two was used to improve the prototype. The localization algorithm in the back-end was improved, and the Android app got a visual overhaul. During this iteration technical tests of the system and the BLE beacons were performed, and the results were used in the development of the final prototype.

The system was evaluated by testing it in a smoke diving exercise together with ØFR. Two instructors and two smoke divers participated in the testing. After the tests the two instructors and smoke divers were interviewed using semi-structured interviews, and they answered a System Usability Scale Questionnaire.

10.2 Results and Limitations

This research shows that Bluetooth Low Energy Beacons have potential to be used for tracking firefighters during smoke diving, but there are still some issues with the technology that needs to be resolved before a reliable system can be created and used. And in its current state the data gathered from the beacons are not precise enough to be used as feedback in a smoke diving training setting.

10.3 Future Work

If more work is to be done on this project in the future, or on similar projects, the research should focus on either finding ways to restrict the beacon's signal strength or develop a new localization algorithm that handles this problem better. When these issues are resolved the possibility for the instructor to see the tracking in real-time would be a desired feature from the fire department. Research on how to track firefighters in a real-life emergency situation would be interesting both for use in training, and if the tracking is in real-time, it could be used to enhance the safety of the firefighters.

References

Apple (2014). Getting Started with iBeacon. Technical report.

Assistant Secretary for Public Affairs (2013, sep). System Usability Scale (SUS). https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html.

Babich, N. (2017). Prototyping 101: The Difference between Low-Fidelity and High-Fidelity Prototypes and When to Use Each | Adobe Blog. https://theblog.adobe.com/prototyping-difference-low-fidelity-high-fidelity-prototypes-use/.

Bjørgen, E. P. (2018). *FireTracker: Using beacons and indoor positioning to enhance fire-fighter's training exercise scenarios.* Masters thesis, University of Bergen.

Bluetooth Special Interest Group (2017). How it works | Bluetooth Technology Website. https://www.bluetooth.com/what-is-bluetooth-technology/how-it-works.

Bluetooth Special Interest Group (2018). Radio Versions | Bluetooth Technology Website. https://www.bluetooth.com/bluetooth-technology/radio-versions.

Brooke, J. (2013). SUS: A Retrospective. Technical report.

Buckingham Shum, S. and R. Ferguson (2012). Social Learning Analytics. *Journal of Educational Technology & Society 15*.

Chang, N., R. Rashidzadeh, and M. Ahmadi (2010). Robust indoor positioning using differential Wi-Fi access points. *IEEE Transactions on Consumer Electronics 56*(3).

Chawathe, S. S. (2008). Beacon Placement for Indoor Localization using Bluetooth. Technical report.

Correa, A., M. Barcelo, A. Morell, and J. L. Vicario (2017, aug). A Review of Pedestrian Indoor Positioning Systems for Mass Market Applications. *Sensors 17*(8), 1927.

Curran, K., E. Furey, T. Lunney, J. Santos, D. Woods, and A. McCaughey (2011, jun). An evaluation of indoor location determination technologies. *Journal of Location Based Services 5*(2), 61–78.

DiCicco-Bloom, B. and B. F. Crabtree (2006, apr). The qualitative research interview. *Medical Education 40*(4), 314–321.

Dijkstra, E. (1970). Notes On Structured Programming.

Direktoratet for samfunnssikkerhet og beredskap (1994). Veiledning om røyk- og kjemikaliedykking.

Echeverria, V., R. Martinez-Maldonado, T. Power, C. Hayes, and S. B. Shum (2018, jun). Where Is the Nurse? Towards Automatically Visualising Meaningful Team Movement in Healthcare Education. pp. 74–78. Springer, Cham.

Estimote (2017). Intro to Estimote APIs - Estimote Developer. https://developer.estimote.com/.

Estimote Inc. (2018). Estimote SDK | iBeacon & Eddystone Bluetooth Beacons | Proximity + Location For Apps. https://estimote.com/products/.

Facebook Inc. (2014). A JavaScript library for building user interfaces | React. https://reactjs.org/.

Feese, S., B. Arnrich, G. Tröster, M. Burtscher, B. Meyer, and K. Jonas (2013). CoenoFire: Monitoring Performance Indicators of Firefighters in Real-world Missions using Smartphones.

Flanagan, D. (2011). *JavaScript: The Definitive Guide* (6 ed.). O'Reilly Media.

Google (2018a). Application Fundamentals | Android Developers. https://developer.android.com/guide/components/fundamentals.

Google (2018b). The Go Project - The Go Programming Language. https://golang.org/project/.

Gosling, J., B. Joy, G. Steele, G. Bracha, A. Buckley, and D. Smith (2018). The Java ® Language Specification Java SE 10 Edition.

Greenrobot (2016). EventBus: Events for Android - Open Source by greenrobot. http://greenrobot.org/eventbus/.

Hellevik, O. (2002). *Forskningsmetode i sosiologi og statsvitenskap* (7th ed.). Universitetsforlaget.

Hevner, A. R., S. T. March, J. Park, and S. Ram (2004). Design science in information systems research. *MIS quarterly 28*(1), 75–105.

Hipp, D. R. (2015). About SQLite. https://www.sqlite.org/about.html.

Information and Analysis Center for Positioning Navigation and Timing (2018a). GLONASS history. https://www.glonass-iac.ru/en/guide/index.php.

Information and Analysis Center for Positioning Navigation and Timing (2018b). Information analytical centre of GLONASS and GPS controlling. https://www.glonass-iac.ru/en/.

International Data Corporation (2018). Smartphone OS Market Share, 2017 Q1. http://www.idc.com/promo/smartphone-market-share/os.

Jean-Paul Zanlucchi de Sousa Tavares, J., R. Hiroshi Murofushi, L. Henriques Silva, and G. Rezende Silva (2017). Petri Net Inside RFID Database Integrated with RFID Indoor Positioning System for Mobile Robots Position Control. Technical report.

JInzhu Zhang (2018). GORM - The fantastic ORM library for Golang, aims to be developer friendly. http://gorm.io/.

Jones, B., A. Tang, C. Neustaedter, A. N. Antle, and E.-S. McLaren (2018). Designing a Tangible Interface for Manager Awareness in Wilderness Search and Rescue. In *Companion of the 2018 ACM Conference on Computer Supported Cooperative Work and Social Computing - CSCW '18*, New York, New York, USA, pp. 161–164. ACM Press.

Lacerda, D. P., J. A. V. Antunes, and A. Dresch (2015). *Design Science Research: A Method for Science and Technology Advancement.* Springer.

Mackensen, E., M. Lai, and T. M. Wendt (2012, oct). Bluetooth Low Energy (BLE) based wireless sensors. In *2012 IEEE Sensors*, pp. 1–4. IEEE.

March, S. T. and G. F. Smith (1995). Design and natural science research on information technology. *Decision support systems 15*(4), 251–266.

Martínez-Almeida, M. (2017). Gin Web Framework. https://gin-gonic.github.io/gin/.

Morrill, D. (2008). Android Developers Blog: Announcing the Android 1.0 SDK, release 1. https://android-developers.googleblog.com/2008/09/announcing-android-10-sdk-release-1.html.

Netscape (1995). NETSCAPE AND SUN ANNOUNCE JAVASCRIPT, THE OPEN, CROSS-PLATFORM OBJECT SCRIPTING LANGUAGE FOR ENTERPRISE NETWORKS AND THE INTERNET. https://web.archive.org/web/20070916144913/http://wp.netscape.com/newsref/pr/newsrelease67.html.

Netteland, G., B. Wasson, C. Hansen, and M. Hirnstein (2016). Learning analytics and open learning modelling for professional competence development.

Nilsson, J.-O., J. Rantakokko, P. Handel, I. Skog, M. Ohlsson, and K. V. S. Hari (2014, may). Accurate indoor positioning of firefighters using dual foot-mounted inertial sensors and inter-agent ranging. In *2014 IEEE/ION Position, Location and Navigation Symposium - PLANS 2014*, pp. 631–636. IEEE.

Oates, B. J. (2005). *Researching Information Systems and Computing.* SAGE Publications.

Oosterlinck, D., D. F. Benoit, P. Baecke, and N. Van de Weghe (2017, jan). Bluetooth tracking of humans in an indoor environment: An application to shopping mall visits. *Applied Geography 78*, 55–65.

Pike, R. (2012). Go at Google: Language Design in the Service of Software Engineering. https://talks.golang.org/2012/splash.article.

Pozyx (2017). Pozyx - centimeter positioning for arduino. https://www.pozyx.io/.

Preece, J., Y. Rogers, and H. Sharp (2011). *Interaction design : beyond human-computer interaction* (4 ed.).

Radius Network (2015). Android Beacon Library. https://altbeacon.github.io/android-beacon-library/.

Russian system of differential correction and monitoring (2018). Precision of GLONASS navigation definitions. http://www.sdcm.ru/smglo/st_glo?version=eng&repdate&site=extern.

Saab, S. S. and Z. S. Nakad (2011, may). A Standalone RFID Indoor Positioning System Using Passive Tags. *IEEE Transactions on Industrial Electronics 58*(5), 1961–1970.

Sætre, K. A. S. (2017). *Bluetooth Low Energy Beacon Performance and Utility in a Car Location Memory Aid Setting.* Ph. D. thesis, University Of Bergen.

Samat, S. (2018). Android 9 Pie: Powered by AI for a smarter, simpler experience that adapts to you. https://www.blog.google/products/android/introducing-android-9-pie/.

Schweinzer, H. and G. Kaniak (2010). Ultrasonic device localization and its potential for wireless sensor network security. *Control Engineering Practice 18*(8), 852–862.

Siemens, G. and D. Gasevic (2012). Guest Editorial-Learning and Knowledge Analytics. Technical report.

Spikol, D., K. Avramides, M. Cukurova, B. Vogel, R. Luckin, E. Ruffaldi, and M. Mavrikis (2016). Exploring the interplay between human and machine annotated multimodal learning analytics in hands-on STEM activities. In *Proceedings of the Sixth International Conference on Learning Analytics & Knowledge - LAK '16*, New York, New York, USA, pp. 522–523. ACM Press.

Square Inc. (2017). Retrofit. http://square.github.io/retrofit/.

Sun Microsystems (1996). JAVASOFT SHIPS JAVA 1.0. https://web.archive.org/web/20070310235103/http://www.sun.com/smi/Press/sunflash/1996-01/sunflash.960123.10561.xml.

Takahashi, C. and K. Kondo (2016, oct). Accuracy evaluation of an indoor positioning method using iBeacons. In *2016 IEEE 5th Global Conference on Consumer Electronics*, pp. 1–2. IEEE.

United States Department of Defence (2008). Global Positioning System Standard Positioning Service Performance Standard 4th Edition. Technical report.

Venners, B. (2000). *Inside the Java Virtual Machine* (2nd ed.). Computing McGraw-Hill.

Wake, J. D., F. V. Heimsæter, E. P. Bjørgen, B. Wasson, and C. Hansen (2018). FireTracker: Indoor Positioning for Firefighter Training.

Wharton, J. (2018). Butter Knife. http://jakewharton.github.io/butterknife/.

Worsley, M., D. Abrahamson, P. Blikstein, S. Grover, B. Schneider, and M. Tissenbaum (2016, jan). Situating multimodal learning analytics.

Worsley, M. and P. Blikstein (2010). Toward the Development of Learning Analytics: Student Speech as an Automatic and Natural Form of Assessment. Technical report.

Xiaohan, L. I. U., H. Makino, and M. Kenichi (2010). Improved indoor location estimation using fluorescent light communication system with a nine-channel receiver. *IEICE transactions on communications 93*(11), 2936–2944.

Zandbergen, P. A. and S. J. Barbeau (2011, jul). Positional Accuracy of Assisted GPS Data from High-Sensitivity GPS-enabled Mobile Phones. *Journal of Navigation 64*(03), 381–399.

Appendix A

Interview guide first iteration

Generelt

1. Har dere utstyr som kan påvirke radiosignaler ? (egne komm. radioer osv., måleinstrumenter)
2. Røyken påvirker signaler?
3. Hvilken informasjon ønsker dere å få fra et slikt system? Nøyaktig posisjon? Sti på kart? Tidsbruk i rom/øvelse?
4. Hvilke forberedelser i forkant av øvelse? Hvordan kan dette implementeres i et reelt øvelsesscenario?
5. Hvilken informasjon har røykdykkere om øvelsesbygning?
6. Hvor kan mottaker (telefon) være på kropp?
7. Hvor mange personer er inne på øving samtidig?

Visualisering

1. Hva slags informasjon kan denne type data gi?
2. Hvordan burde dataen presenteres?
3. Hvordan kan dette komme til nytte?
4. Kunne dette ha noen negative konsekvenser for opplæring/vurdering/tilbakemelding?

Vurdering

5. Kunne dette ha blitt brukt i vurderingssammenheng? Hvis ja, hva ville ha vært mer gunstig: “Realtime” eller oversikt etter øvelsen?

Tilbakemelding

6. Ville et system som gir oversikt og kart over brannkonstablene sine tilstedeværelser og tidsbruk i ettertid?
7. Kunne dette ha gitt brannkonstablene bedre tilbakemelding i ettertid?
8. Hvordan kan dette gi brannkonstablene bedre tilbakemelding på øvelsen?

Opplæring

9. Ville det ha vært gunstig å bruke dette ifm. opplæring?
10. Kunne dette systemet eller dataene bli brukt i videre opplæring av brannkonstabler?
11. Ville det ha vært best å se brannkonstablene i “realtime”? Og dette ifm. med opplæring?

Appendix B

Interview guide second iteration

Praktisk

1. Hvordan var det å sette opp en session? (oppretting av informasjon og plassering av beacons)

Brukergrensesnitt

1. Var det deler av systemet som var vanskelig å forstå eller å bruke?
   (a) Viss ja, hva kan gjøres enklere / forklares bedre.
2. Gir systemet (app+web) nok informasjon om hvordan det skal brukes?
   (a) Viss ikke, hvor mangler det informasjon?

Visualisering

1. Hvordan var navigeringen til visualiseringen?
2. Fikk dere nok informasjon om session'en?
3. Var det noe i grafen og kartet som var utydelig?
4. Hva kan visualiseringen i nåværende tilstand bli brukt til?

5. Kunne det vært interessant med varslinger/meldinger der en brannkonstabel har stått i ro lenge eller lignende?
   (a) Hvordan burde et slikt varsel se ut? (I selve visualiseringen eller i listen over punkter?)

Data

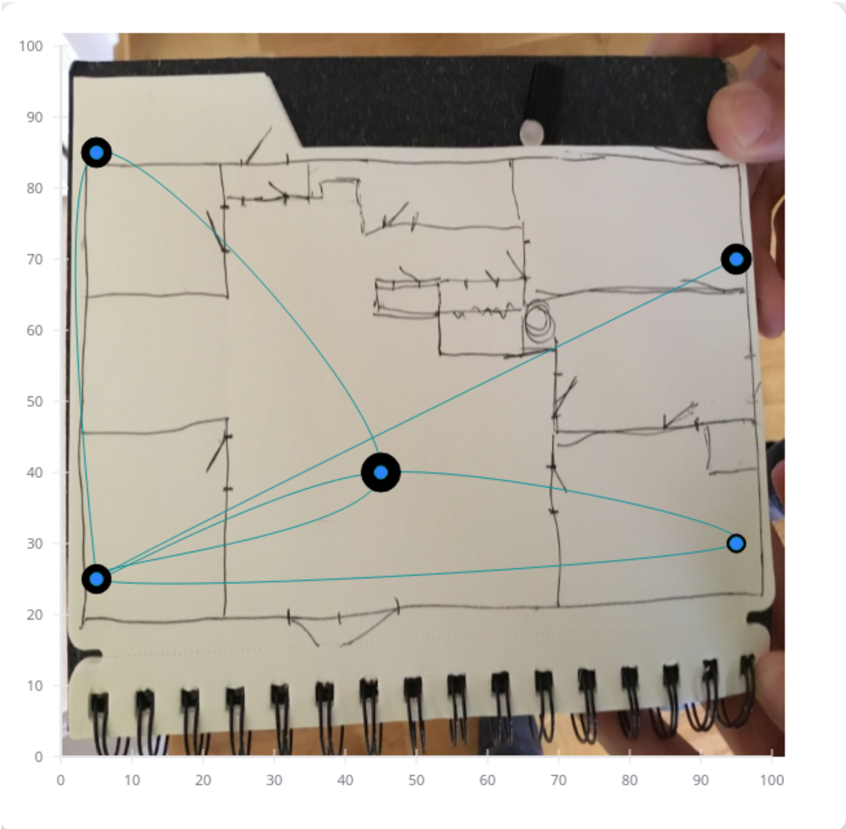
1. Hva tenker dere om å bruke informasjon om hodebevegelser for å si noe om hvor aktiv en røykdykker er?
2. Vi bruker skritteller for å se om en røykdykker beveger seg innenfor området til en beacon. Er dette informasjon som er interessant?
   (a) Ville det ha vært interessant å vise skritt/distanse?

Annet

1. Har dere andre kommentarer eller innspill?

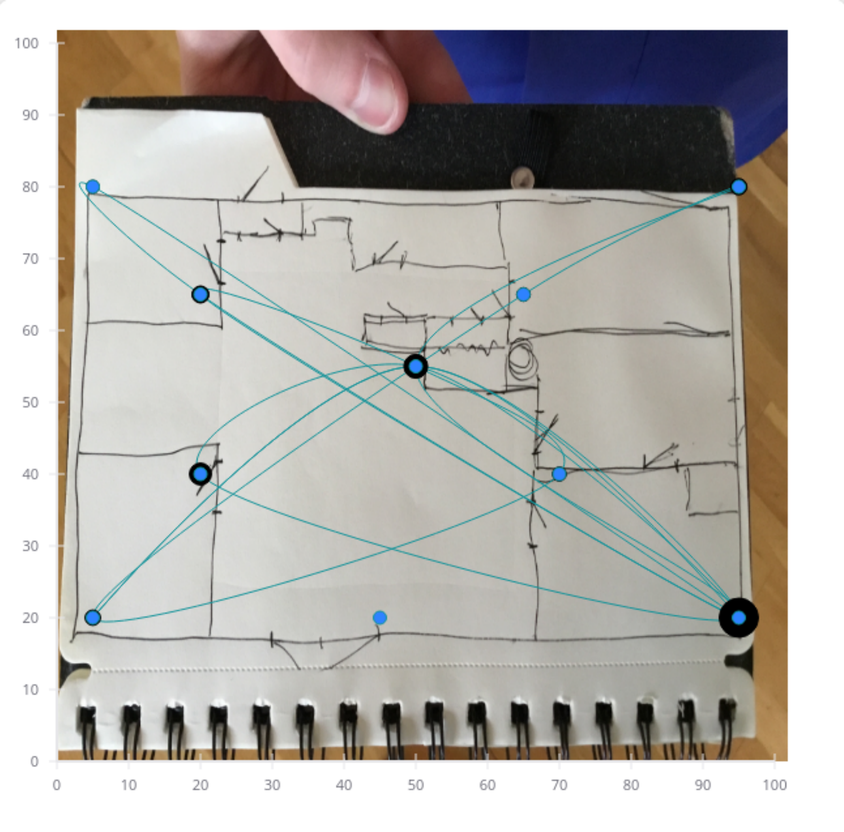
Appendix C

Visualizations from the final evaluation

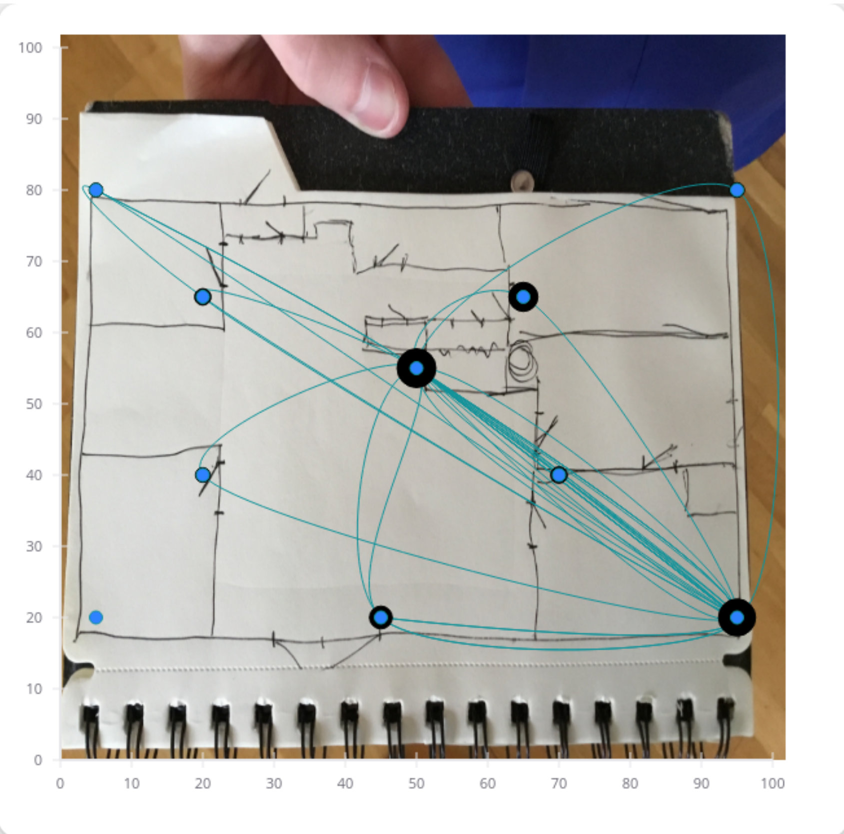


(a) Smoke diver 1

Figure C.1: Visualization from exercise 1

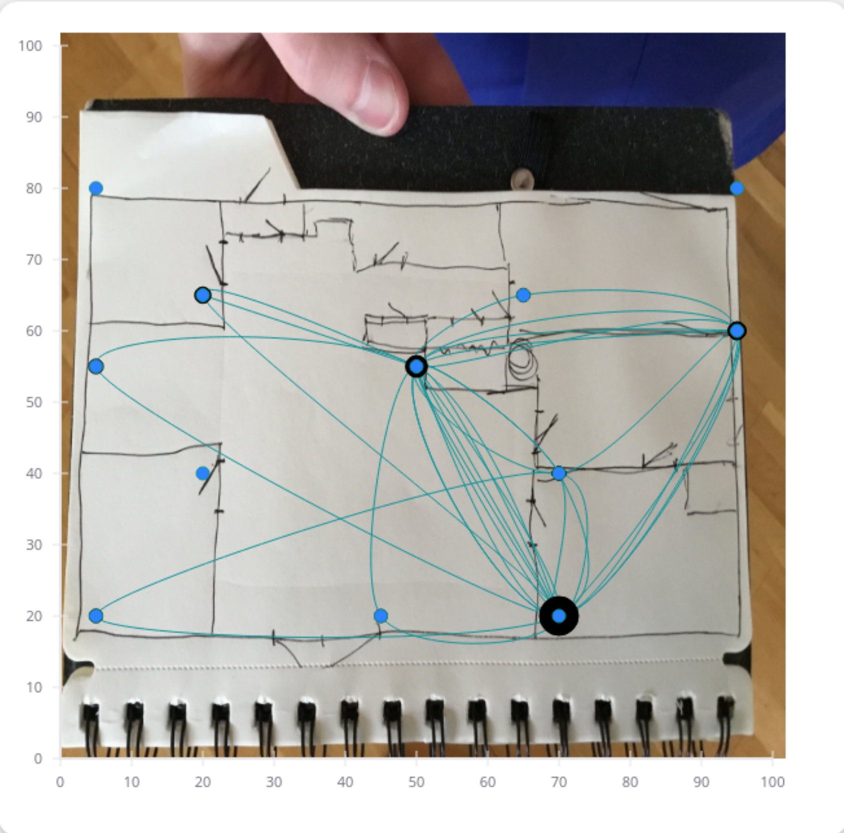


(a) Smoke diver 1

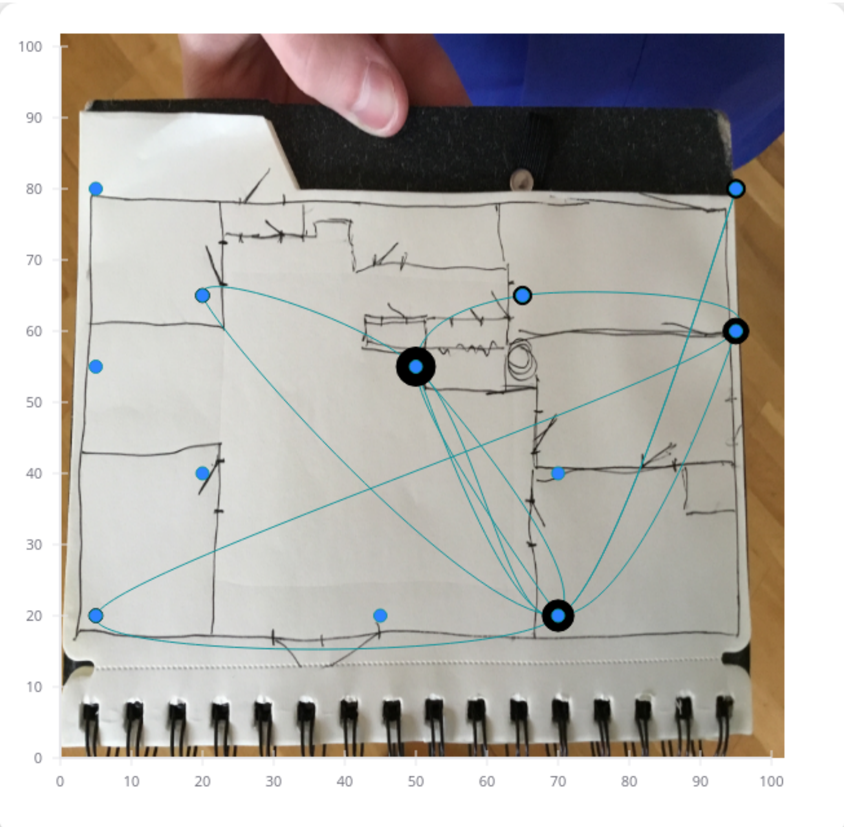


(b) Smoke diver 2

Figure C.2: Visualizations from exercise 2

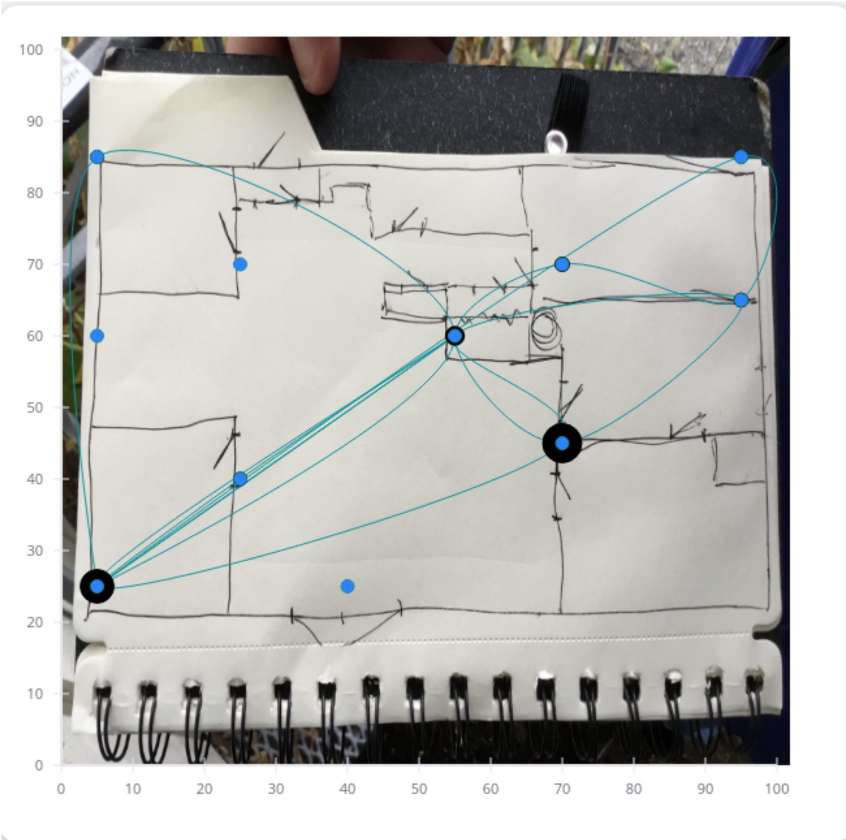


(a) Smoke diver 1

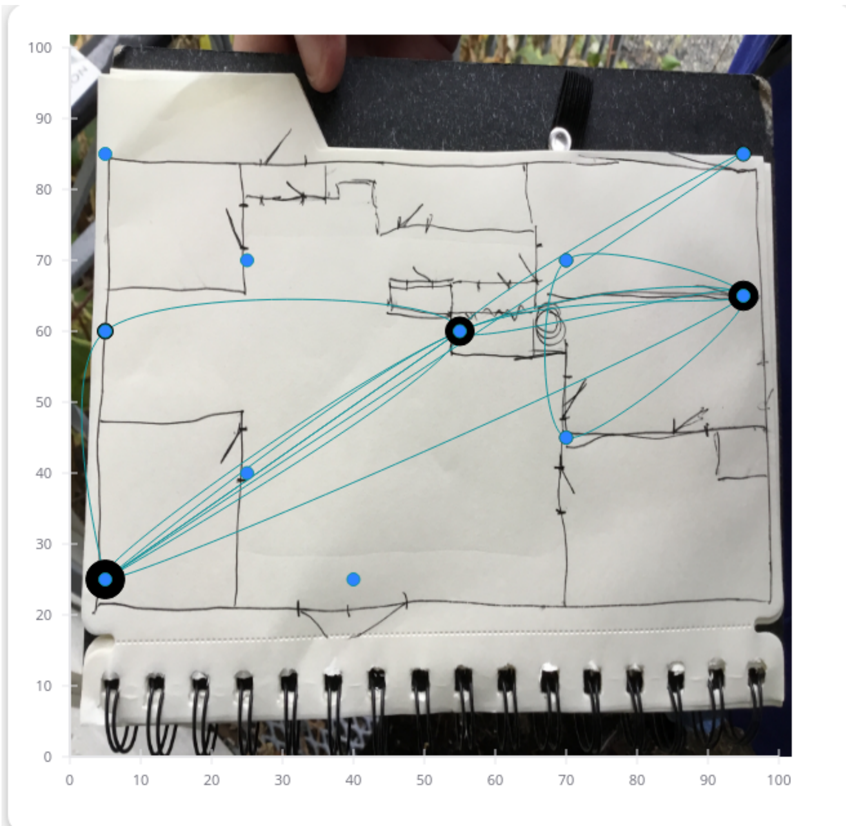


(b) Smoke diver 2

Figure C.3: Visualizations from exercise 3



(a) Smoke diver



(b) Instructor

Figure C.4: Visualizations from exercise 4

Appendix D

Interview guide final evaluation

Instruktører

UI og UX

- Hvordan var bruken av systemet i forhold til brukergrensesnittet?
  - Hvordan påvirket det gjennomgangen av øktene under internevalueringen?
    - (Var det enkelt å vise frem visualiseringen under evalueringen?)
- Under opprettelsen av økten, var det noe i brukergrensesnittet som gjorde det vanskelig eller uklart?

Data og visualisering

- Var dataene relevante?
  - Hva bidro de enkelte dataene med, typ tid, plassering, og bevegelse?
  - Hvordan bidro det til evalueringen?
  - Var det noe nytt man kunne gi tilbakemelding på med disse dataene?
    - Hvis ja, hvordan gjorde datavisualiseringene evalueringen annerledes enn før?
- Ville dette verktøyet ha hjulpet i opplæring av nye røykdykkere? Hvordan?
- Hva tenker du om presisjonen på sporingen?

  - Hadde dere hatt større utbytte av en mer nøyaktig sporing?
  - Ser du noen fordeler ved å ha sporingen slik den er nå sammenlignet med å ha centimeterpresisjon?

Fysisk bruk av utstyr

- Hvordan gikk det å sette opp beaconene?
  - Var det problemer knyttet til dette?
  - Er det noe som kunne vært gjort enklere?
- Hvordan gikk det å feste og starte sporingen på røykdykkerne?
  - Var det problemer knyttet til dette?
  - Er det noe som kunne vært gjort enklere?
  - Påvirket det øvelsen på noen måte å måtte stoppe opp for å gjøre dette?
- Ser du noen utfordringer som kan oppstå ved bruk av dette utstyret?

Røykdykkerne

- Gjorde dere noe annerledes under øvelsen nå som dere visste at bevegelsene deres ble logget? Påvirket det gjennomføringen?
- Påvirket det å ha en mobil festet til hjelmen/tanken dere fysisk?
  - Hindret det arbeidsoppgaver?
  - Påvirket det mobilitet?
- Påvirket det øvelsen at dere måtte stoppe opp for å feste og sette i gang telefonene?
  - Hvis ja: hvordan?
- Sammenlignet med tidligere, hva synes dere dette systemet bidro i forbindelse med den interne evalueringen?
  - Hva er annerledes?
  - Føler dere at dere har mer innsikt i øvelsen nå enn før?

  - Ser dere noe forskjell på deres egen og den andres (andre røykdykkeren) sine bevegelser?
  - (Hvis noe er litt utenom det vanlige, typ at de har stått i ro over lengre tid på en posisjon:) Husker du/dere hvorfor det ble brukt så lang tid på denne posisjonen?

- Hva tenker dere om presisjonen på sporingen?
  - Hadde dere hatt større utbytte av en mer nøyaktig sporing?
  - Ser dere noen fordeler ved å ha sporingen slik den er nå sammenlignet med å ha centimeterpresisjon?
- Er det noe som mangler eller kunne vært annerledes?

Ikke-røykdykkende brannkonstabler

- Hjalp visualiseringene dere til å få mer innsikt i øvelsen, selv om dere ikke var inne i bygget?
- Kan dere bruke denne innsikten til noe nyttig?
  - Hvis ja, hva er forskjellen i forhold til før?
- Hva tenker dere om presisjonen på sporingen?
  - Hadde dere hatt større utbytte av en mer nøyaktig sporing?
  - Ser dere noen fordeler ved å ha sporingen slik den er nå sammenlignet med å ha centimeterpresisjon?
- Er det noe som mangler eller kunne vært annerledes?

Appendix E

System Usability Scale

E.1 SUS Questions

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.

E.2 Norwegian Translation of SUS Questions

1. Jeg tror at jeg ville ha brukt dette systemet ofte.
2. Jeg synes at systemet var unødvendig vanskelig.
3. Jeg synes systemet var enkelt å bruke.
4. Jeg tror at jeg ville ha trengt støtte fra en teknisk person i bruken av dette systemet.
5. Jeg synes at funksjonene i systemet var godt integrerte.
6. Jeg synes systemet var lite konsekvent.
7. Jeg tror at de fleste ville ha lært seg å bruke systemet veldig fort.
8. Jeg synes systemet var veldig tungvint å bruke.
9. Jeg følte meg selvsikker i bruken av systemet.
10. Jeg måtte ha lært meg mange ting før jeg kunne ha tatt systemet skikkelig i bruk.

Appendix F

Poster from LASI-Nordic 2018

On the following page is the poster for this project presented at the LASI-Nordic 2018 symposium in Copenhagen, Denmark (Wake et al., 2018).

FireTracker: Indoor Positioning for Firefighter Training

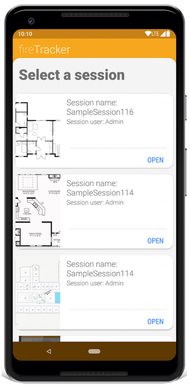
FIRETRACKER USES BLUETOOTH LOW ENERGY TO DETECT AND CREATE VISUALIZATIONS OF A SMOKE DIVER'S MOVEMENT PATTERN DURING INDOOR, COLD SMOKE DIVING EXERCISES. BASED ON A STUDY OF HOW FIREFIGHTERS TRAIN FOR SMOKE DIVING, THE APPLICATION IS AIMED AT IMPROVING THE TRAINING, BY PROVIDING THE FIREFIGHTERS AND THEIR INSTRUCTORS VISUALIZATIONS OF THE MOVEMENT WHICH CAN THEN SERVE TO MEDIATE THE EVALUATION POST TRAINING EXERCISE.

Overview

This poster describes the development of data driven ICT-support for firefighter training. As a study within the iComPAss project, the goal is to combine different sensor data to create visualisations of the indoor training activity of smoke diving. As a first step we have developed a system for providing a track of the firefighters movement in a house during smoke diving training exercises.

The iComPAss project

The iComPAss project – Inquire Competence for better Practice and Assessment – studies data based decision making in workplace learning settings by looking at how digital tools that use competence modeling, learning analysis, and visualizations, can support decision making about training needs, strategic management, opportunities for identifying and assessing competencies, identification of training needs, and competency development, at the right time.

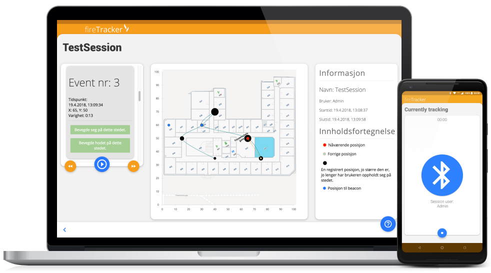


FireTracker

FireTracker visualises sensor-based data from smoke diving training activities. Currently, the sensors include Bluetooth Low Energy (BLE), gyroscope, and clock. BLE determines location, and gyroscope indicates physical activity level. In use, several Bluetooth Beacons are placed around the smoke diving exercise site, and a mobile phone is placed on the helmet or oxygen tank of the smoke diver. When the firefighters search the building, the phone collects data from the beacons and the gyroscope to produce a track of the exercise, including stops and activity levels. The information presented on an iPad is used in retrospective evaluation of the exercise.

The development process

Iterative development is based on a close study of firefighter training excercises, to understand practical user needs. FireTracker is the current working prototype, developed during the first iteration. The next step is to present the prototype to the training leader of Sotra Brannvern, our collaboration partner. The feedback will be used to further develop and optimise the system before we test it during an actual smoke diving exercise.



Authors

Jo D. Wake, Uni Research Health & SLATE, UiB
Fredrik V. Heimsæter, SLATE, University of Bergen
Edvard P. Bjørgen, SLATE, University of Bergen
Barbara Wasson, SLATE, University of Bergen
Cecilie Hansen, Uni Research Health & SLATE, UiB

uni Research
SLATE Centre for the Science of Learning & Technology
UNIVERSITETET I BERGEN

Appendix G

Source Code

G.1 Android application

The source code of the Android application will be released as a open source project on Github in January 2019. The source code will be found at this page: https://github.com/Freheims/Master-project-app

G.2 Back-end

The source code of the Android back-end will be released as a open source project on Github in January 2019. The source code will be found at this page: https://github.com/Freheims/Master-project-backend