A Framework for Testing Indoor Positioning Systems

Project assignment TBA4560

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Abstract

During this project a software framework for testing the quality of indoor positions has developed. The system, named IndoorPos, provides automatic gathering and storage of positioning data for later analysis. The framework is designed to be extensible and reusable for future projects, and has currently been equipped to acquire position information from the NTNU/Wireless Trondheim WiFi positioning system with storage in a PostGIS database.

The IndoorPos system has been tested in practice by performing a large scale experiment capturing reported positioning information from a large number of reference points in a building at NTNU. By analysing this data, conclusions about the WiFi positioning system are drawn and recommendations for future improvement are made. Finally, some consideration is given to the performance and reliability of the IndoorPos system and ideas for future use and development are formed.
Preface

This project was carried out as the main assignment in the course TBA4560 at the division of Geomatics at NTNU, with Alexander Nossum as the main supervisor and Terje Midtbø as the course lead and assisting supervisor.

In the course of this project I have learned a lot about indoor positioning systems and the diverse challenges they involve. Beyond that, I have learned a lot about planning and executing a major project and solving all the challenges that may arise. Some mistaken assumptions and other difficulties proved to be a source of frustration, but in conquering them I have learned many valuable lessons.

I would like to thank Alexander Nossum for steadfast guidance and advice regarding the project, Andreas Landmark for practical help at MTFS, Gunnar Rangøy of Wireless Trondheim for his willingness to help me with my sometimes difficult demands at all hours of the day, and Kyrre Liaaen of NTNU IT for all the time he devoted to investigating issues connected to the WiFi positioning system. I would also like to thank Thomas Jelle and John Krogstie for their contributions.

Last, but definitely not least, I would like to thank my beloved Christina for taking care of me, reminding me (and sometimes forcing me) to take breaks and in general making sure I kept my sanity through the most hectic periods of the project!

Trondheim, February 6, 2012

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1 Background

1.1 Indoor Positioning Systems

After the NAVSTAR GPS system was opened for unrestricted public use, the question of accurate positioning in an outdoor environment could be said to be more or less settled. GPS has become a ubiquitous technology, affording accurate positioning at low cost, often built into small and portable consumer devices.[1]

However, due to the design of the NAVSTAR system, it and comparable GNSS systems like GLONASS and Galileo[2] have poor signal penetration indoors[3], and therefore do not give accurate positioning indoors. In the last ten to fifteen years research in indoor positioning systems has been gaining in popularity, and many new products for indoor positioning have been developed. [4] These systems utilize a variety of different techniques for determining location, each with its own distinct advantages and disadvantages. Table 1.1 summarizes these, and the following subsections describe them in greater detail.

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Table 1.1: Table of indoor positioning technologies

1.1.1 WiFi-based

WiFi-based systems use existing wireless infrastructure to triangulate a transmitter’s position by estimating signal strength. The device being tracked can be a purpose made tag or any consumer device with WiFi capabilities. The great advantage to this system is that it can be used with WiFi infrastructure that normally is deployed in any building to provide wireless networking, and that it can be used to track any device. The main disadvantage is potentially limited accuracy compared to other positioning systems, where accuracy is believed to be dependent on if the system uses radio frequency fingerprinting or not. The trade-off is between higher accuracy and workload in setting up the system.
NTNU has deployed a positioning system from Cisco using these methods [5, 6], detailed in subsection 1.2, and this report aims to investigate issues related to it.

1.1.2 RFID-based

RFID chips are small, low-cost radio transmitters that can be either active (battery-powered) or passive (powered by incoming electromagnetic waves). They typically have a short range, and RFID based location systems work by sensing when a chip comes within range of a known receiver. [7] With passive systems the sensors are typically placed at choke points such as doorways to enable room-scale positioning. The major disadvantages are the need for dedicated infrastructure and client-side software which is not commercial off-the-shelf software, and the unsuitability for positioning within large open spaces.

1.1.3 Ultrasound-based

A ultrasound based system works by transmitting ultrasound waves from tags, which are frequency modulated for identification and are picked up by dedicated receivers. Since ultrasound does not readily pass through walls, a receiver is needed in every room intended to be covered by the system. [8] As such, the location is not determined by triangulation but by which receiver is picking up the (strongest) ultrasound signal. The advantages of this system include accurate determination of which room a device is in, while disadvantages, much like RFID positioning, include the need for dedicated infrastructure and poor accuracy in large, open spaces.

1.1.4 Infrared-based

Early research into indoor positioning looked at using beacons transmitting infrared signals to receivers for positioning. [9] This is a fairly effective method, but has the same requirement for infrastructure as ultrasound, and is further hampered by requiring a line of sight from the beacon to the receiver. [10]

1.1.5 GPS Infrastructure Improvement

One approach to indoor positioning is to simply attempt to negate the flaws of traditional GNSS systems. Some research has focused on attempting to improve the receiver and signal processing in order to extract more viable positioning information in challenging environments.[11] While this approach yields better results, effectively extending the range of the GPS signals, it doesn’t provide complete coverage. Another disadvantage is that custom receivers are required, so it will
not work with consumer devices.

Other venues of research have been to set up GPS transmitters in known locations inside the building, so called pseudolites. This gives high precision but is expensive to set up because of the dedicated infrastructure. [12, 13] Also, while off the shelf GPS receivers can be used they must have their settings modified, which precludes the system from being effortless for the casual user.

1.1.6 Cellular Phone Triangulation

It is possible to triangulate the position of a GSM device such as a mobile phone by comparing signal strength readings to known positions of cell towers, and since the wavelength of GSM/UMTS signals is suitable for penetrating buildings one will have positioning coverage indoors that is comparable to what is achievable outdoors. One advantage to this method is that it requires no additional investments in infrastructure and can work with any GSM device, however the accuracy is not very good. Positioning based on calculating Time Advanced (TA), that is the time it takes for a signal to reach from a tower to the receiver and back again, has an accuracy of 100 meters at best.[14]

Research has been carried out in which one has achieved indoor positioning accuracy broadly comparable to WiFi through the use of radio frequency fingerprinting methods.[15] On the other hand, this requires a lot of work to set up and requires alterations to the devices being positioned.

1.1.7 Hybrids & Other Systems

Other systems exist, such as Bluetooth (operates in a fashion similar to a hybrid of WiFi and RFID), UHF radio tags and ultra wide band (UWB) radio tags.[16]. Furthermore, the aforementioned methods can be combined in any number of ways, for example WiFi and ultrasound which combines both absolute positioning and room-based positioning for greater accuracy.[17]

1.2 Details of NTNU & Wireless Trondheim’s WiFi Positioning System

NTNU has a WiFi positioning system from Cisco, the Cisco Mobility Services Engine (MSE). The MSE is connected to the system of wireless access points that provides WiFi coverage to students and employees. Position is determined by signal triangulation from the access points to the device. (All access points have relative positions plotted on a map/floor plan of each floor that is covered by the
1 Background

WiFi system.) Internally, one can through the Wireless Control System (WCS) track any device connected to the network, while externally an API is exposed through the GeoPos system. With a user account and appropriate cryptographic certificates, one can use the GeoPos system to track the position of devices with known MAC addresses. (Which mainly limits the devices one can track to devices in one’s possession.) This system is illustrated in figure 1.1. Wireless Trondheim have the same type of Cisco MSE system providing positioning coverage for the centre of Trondheim, and GeoPos interfaces with it in the same way. This means GeoPos is a unified portal for positioning services in large parts of Trondheim if you have the correct access rights, and it is used as the underlying positioning service for Campusguiden, Wireless Trondheim’s smartphone application for navigation in NTNU facilities.[6, 18]

Specifically, through the WCS one can access the relative position for a device within a floor on a per-floor basis, while the GeoPos system uses web services to connect to the WCS in order to extract that information. GeoPos then adds value to that information by translating the relative coordinates to absolute coordinates. (WGS84 longitude and latitude and UTM 32 coordinates are returned along with information about building and floor.) Neither the GeoPos system nor the MSE/WCS system have any facility for remembering previous positions of a device, and will only deliver the current known position of a device. (Or an error message if the device is not currently in range.) Both because of the more controlled access and the usefulness of the value-added data, all the experiments in this report are carried out using the GeoPos system.

1.2.1 Previous Research at NTNU

Research into WiFi positioning at NTNU and Wireless Trondheim has so far looked at positioning performance through MSE in an outdoor environment[19, 20, 21], and at positioning performance indoors without MSE/WCS.[22] The indoor experiments revealed that it was possible to achieve an accuracy in line with a calibrated Cisco system [5, 22], but required extensive work collecting data and custom software, and therefore it was not superior to the Cisco system. The outdoor experiments were all performed using Aeroscout tags as the devices being tracked, since they were angled towards equipment tracking scenarios. Aeroscout tags are small, portable WiFi tags designed to have a long battery life and to not cause network traffic by only operating on the WiFi link layer.[23]

The outdoor experiments demonstrated that since the MSE/WCS system is designed for indoor use, it has serious weaknesses in outdoor positioning, espe-
Figure 1.1: Illustration of the NTNU/Wireless Trondheim positioning system, from [19]
1 Background

icularly when no calibration has been performed. Outdoor positioning performance could not compete with GPS positioning, even in urban environments with suboptimal GPS conditions and a relatively large concentration of WiFi access points. However, they did serve to prove that the GeoPos system of position delivery was sound.

1.3 The IndoorPos System

This project introduces a new system for gathering indoor positioning information over time from existing systems and storing them for later retrieval and analysis, which has been named the IndoorPos System. It does not introduce any new positioning functionality or accuracy improvements, but seeks to enable and simplify research on indoor positioning systems. It is expressly designed to be of use not only for this project, but also for possible future projects in the same research area.

In this project it will be used for gathering of position information from known reference points in order to estimate characteristics of the NTNU WiFi positioning system in a single building. Other uses envisaged for the system include observation of movement patterns, for example for inventory items such as wheelchairs in a hospital environment, or direct side by side by side comparisons of different indoor positioning technologies.

1.3.1 Contributing Parties

The project is headed up by the division of Geomatics at NTNU, with significant support from Wireless Trondheim and NTNU IT. Originally it was conceived as a strong cooperation with the COSTT project, but unfortunate circumstances led to that aspect being reduced despite invaluable support from COSTT. The potential for future cooperation with COSTT, however, remains strong.

1.3.2 Project Motivation

The motivation for this project is to explore aspects of indoor positioning and to develop a system that facilitates this exploration. A concrete wish from the COSTT project has been to explore the possibilities for tracking equipment in a hospital environment with the help of WiFi tags, and therefore it is of great interest to ascertain what kind of accuracy and precision can be expected. In addition to this, knowledge of potential flaws in the positioning system and how they may be discovered and avoided is also desirable. In order to make informed decisions about this, solid statistical data is needed.
1.3.3 Privacy Concerns

A question which arises quite often when working with tracking technologies such as the WiFi indoor positioning system at NTNU, is that of privacy. (Those legally responsible for such systems tend to raise them particularly often!) Accurate tracking of the whereabouts of a electronic device is of some concern if that device was to be carried on someone’s person, as that essentially constitutes personally identifiable information about the person’s movements and habits. Any such scientific research falls under the jurisdiction of some rather stringent rules and regulations designed to protect the privacy of the individual.[24] This project has avoided any questions of privacy by strictly limiting the devices tracked to devices in the possession of the author, and only collecting data from them in controlled test scenarios.

That being said, the software developed does not have any particular anonymization features and could easily be used to collect completely identifiable data. It is the responsibility of the user to make sure that no privacy transgressions are made.

1.3.4 Project Outline & Desired Outcome

The project is divided into three major stages:

- Design and develop a test framework for collecting indoor positions, which can be used for the next stage and in possible future projects.

- Use the test framework to perform a series of real-world positioning tests on the NTNU wireless positioning infrastructure in a selected building.

- Analyse the collected data using statistical methods to determine the accuracy and precision of the positioning results for the selected building.

At the project’s close, the hope is to have the completed IndoorPos system ready, to have tested it in practice and to have used the information gathered to derive some knowledge of the performance of the WiFi positioning system at NTNU.
2 Application Architecture

2.1 Goals

For the implementation of the IndoorPos software system, it was desirable to achieve the following goals:

- Use of the GeoPos service as a data source.
- Availability of historical positioning data.
- Availability of current positioning data.
- Easy access for the end user.
- Safe storage of data for future use.
- Modularity and extensibility for future development.

Naturally these goals must shape the selection of technologies used to build the system, and the mode in which they are deployed. In order to satisfy these goals, it was decided to split the application in two. The central part is the server-side application, which takes care of the positioning data and exposes an API to clients. The client can access the server data in a stateless fashion, and does not need to be running all the time. Since the client is decoupled from the server, it can exist in any number of forms but has for the purposes of this project been implemented as a browser-based application.

2.2 Server-side Implementation

2.2.1 Server

The server environment used for deployment is a Linux-based server belonging to the division of Geomatics, running Ubuntu 10.10. This server also runs instances of Geoserver and PostGIS which are useful for this project. See Appendix C for more information on the specifics of the server.

2.2.2 Language Considerations

For the development of the server software Java was chosen as the programming language, for several reasons:

Familiarity Java is along with C# one of the most familiar languages for the author of this report, since it is the chosen language for a large number of courses at NTNU.
Server support  The division of Geomatics server has a Java runtime installed for use with Geoserver, but does not have a Mono runtime as would be required for running applications based on C# code. With the main hard drive partition of the server being rather resource-constrained, installing more frameworks was not desirable without good reason. It was also felt that one might be able to glean a marginally reduced server overhead by running major applications on the same runtime.

Availability of libraries  Java is seen as an enterprise-ready language with many professional and well-supported libraries, well suited for development of applications using web services. [25] The server application utilizes a large number of external libraries with open source licences, see appendix F for details on the libraries and their licences.

Reuse of existing code  Previously developed client code for communicating with the GeoPos service was obtained from Wireless Trondheim, which was written in Java.[6] (Client code written in PHP was also obtained but was not used.)

In addition, another advantage of using Java which did not directly influence the decision to employ it is cross-platform support, which means that the program should be able to run on for example Microsoft Windows with little extra work.

2.2.3 Structure

The system is designed to be modular and flexible, both with regards to the needs of the current experimentation and to any possible future development. As seen in figure 2.1, the classes have been designed to be highly orthogonal, so that future development and maintenance will be as easy as possible.[26] Areas of responsibility have been divided up and interaction between the components is defined by a number of interfaces that may be cleanly implemented without any knowledge of the module calling them.

As a result of this, the back-end components are swappable and new ones can easily be added to the program. At program start, which back-ends are loaded in and used can be easily changed by modifying the settings file as detailed in appendix D. This is useful during development and debugging because one can substitute dummy components for live ones in order to avoid unnecessary load on databases and positioning systems, and it is useful for any future development if one for example should wish to use a different kind of database.

The following is a short description of the main classes of the server application:
Figure 2.1: **Class diagram showing the internal relationships in the server software.**
IndoorPosServer This is the central core of the program that manages the interaction between the other components, and the timing mechanism that periodically calls upon the position delivery system.

ClientHttpServer This component is the only one that has a two-way coupling with the core, and manages a HTTP server that accepts external web service requests. The requests are then passed on to the core to be processed.

TextFileSettingsLoader This component reads in the program settings at start-up and equips the IndoorPosServer class with the correct delivery and storage back-ends, managing things such as user names and passwords for databases. This component is the only one that has explicit knowledge about what kind of back-ends exist, while the central core makes no distinction between back-ends.

GeoPosPositionDelivery This component queries the GeoPos service for positions with the help of the supplied code for GeoPos communication. [6]

PostGISPositionStorage This component stores and retrieves positioning data from a PostGIS database. Connection details such as address, user name and password are loaded dynamically via the SettingsLoader class. PostGIS was chosen for the primary database back-end because it has good support for spatial data and is robust and proven in production[27], as well as that the Geomatics server already had a running instance.

2.2.4 Running as a System Service
In order to maintain high availability, the server process has been set up to run as a system service (a daemon in UNIX terminology) using the Apache Commons Daemon utilities. [28] This allows the process to run in the background without any user terminal open, and is set up to automatically restart the process if it should crash for some reason. Again, this is cross platform and therefore the server should be able to function as a system service in a Windows environment.

2.2.5 Exposed Web Services
The server exposes three web services for clients to access, through an API based on JSON (JavaScript Object Notation) and HTTP POST. The HyperText Transfer Protocol defines a POST method that clients can use to send text content to a server[29], and in this case that text is encoded as JSON. JSON is a standard for data interchange based on the object notation in JavaScript[30], and is in common use as an interchange format on the Internet with support in most programming languages.[31] In this case the JSON in the call will include the MAC address you
are looking for and between zero and two time stamps, depending on the function being called. When the request has been processed by the server, the results are returned by the server as text, also encoded as JSON. This JSON represents the data structure used for representing indoor positions in the server application and the storage back-end. If the request was not understood or there were no results, an error message is returned instead.

There are three services that are exposed, where each service is accessed by querying a specific address:

<server address>::2011/indoorpos/newestpos This is the simplest query, where the client sends a MAC and is returned the last recorded position of that MAC, regardless of age.

<server address>::2011/indoorpos/findattime Here the client sends a MAC and a time stamp, and the client returns the recorded position that is closest to that point in time.

<server address>::2011/indoorpos/findbetweentimes The client sends a MAC and two time stamps, and the server returns a list of all recorded positions between those two times.

A typical request for the newestpos service might look like this:

```
{"MAC":"3C:F7:2A:57:B3:66"}
```

The corresponding response might look like this:

```
{"internal_x":33.217104000000006,
 "internal_y":112.84610400000001,
 "wgs84Point":{"x":10.406364143823856,
 "y":63.41477129181068,
 "z":0.0,
 "m":0.0,
 "dimension":2,
 "haveMeasure":false,
 "type":1,
 "srid":4326},
 "MAC":"3C:F7:2A:57:B3:66",
 "targetDescription":"Tag number 1",
 "targetTag":"Demonstration tests"}
```
The data returned from these services should be sufficient for any client to create needed visualisations, statistics or other derivate data.

### 2.2.6 Security Considerations

If one knows the MAC address of a device, one is able to track its position in any area covered by the GeoPos system. (All NTNU areas and all areas with coverage from Wireless Trondheim.) This raises obvious questions about information security and possible surveillance that need to be addressed. The GeoPos system has been secured by requiring that all connections to it authenticate themselves with a user name and password, coupled with a cryptographic key. User names and cryptographic keys are assigned to users after vetting and are distributed only through secure means like encrypted email.[6]

The IndoorPos server uses these user names and passwords to authenticate to the GeoPos server, but will only fetch, store and deliver positions for a specific list of targets which may only be set by authenticated users on the Geomatics server. The only targets set in this projects have been devices used for testing and experimentation. Therefore it is of no consequence that the web services exposed from the IndoorPos server require no authentication, because they will only give out information deemed to be harmless.

### 2.3 Client-side Implementation

As previously mentioned, it is possible to build multiple types of client due to the client-agnostic nature of the server APIs, but for this project a basic browser-based implementation has been decided upon. The language chosen is JavaScript, as that is the most common language for creating interactive web pages, with support across all major browsers.[32] The implementation relies heavily on OpenLayers, a popular JavaScript mapping library[33], for map rendering and navigation. Certain other libraries are also used, which are detailed in appendix F.

The client has been designed in a simple fashion, with only one purpose in mind: To facilitate the reliability tests detailed in section 3.6. The user interface
is very basic and presents a lot of information that is only useful for this particular scenario, therefore it can by no means be called a general-purpose client for later use. Should one wish to build up a different kind of research system around the IndoorPos server, it would be natural to design a new client from scratch.

As seen in figure 2.2, positions are rendered as dots on the map, with lines connecting recorded positions chronologically. When multiple tags are being tracked, different colours are used. The client also calculates and displays a number of values based on the data, which are explained in section 3.6 on reliability tests. Position data is fetched from the IndoorPos server through the exposed web services, and the client is completely stateless. Any refresh of the page or fetching of new position data will remove the displayed data. (But this is inconsequential as the data can be retrieved from the server at any time.)

2.3.1 Map Data

All the map data utilized by the client is served by the Geoserver instance on the Geomatics server. Five layers are available, of which two are floor plans for the Lerkendal building which have been georeferenced as detailed in section 3.3. The third layer, mainly used for testing in areas outside the Lerkendal building, is a simplified version of OpenStreetMap data for Trondheim highlighting NTNU buildings which was produced as a part of an earlier project in the course TBA4250. The last two layers are floor plans for the MTFS building which were used when testing the eligibility of the building.
Indoor Positions

This is a simple client to visualize tracked positions.

Figure 2.2: Screenshot of the client in use.
3 Experimental Design

3.1 Equipment

The original plan was to use an Aeroscout tag as the device to be tracked, like previous studies at NTNU have done. This was both because the tags were suited to a inventory tracking scenario like COSTT is interested in, and because Wireless Trondheim has a supply of them left over from previous testing. Sadly, it turned out that in the time period elapsed since [19, 20, 21], Cisco published a system update that required WiFi tags such as Aeroscout to interact with WCS in a different way than before. As the new system was not installed and GeoPos was not updated to handle this new situation[6, 34], it was not feasible to use Aeroscout tags for this project.

As a result of this, it was decided to use a WiFi-enabled mobile phone instead. For practical reasons, a phone belonging to the division of Geomatics was chosen: a HTC Desire HD running the Android operating system. While it is not suitable for use as a tracking tag due to price, size and battery life, that should not affect how effectively the positioning system is able to locate it provided it has a WiFi connection in active use.

3.1.1 Other Equipment

Apart from the mobile phone, there was little other equipment needed:

- The server detailed in appendix C.
- A laptop computer to use the browser-based client.
- An office chair with wheels.
- A professional measuring tape, 50 metres.
- Masking tape for marking positions.

3.2 Location

Originally, it was hoped to do the experiments at the MTFS building due to this building having an interesting combination of small and large rooms and some multi-story open areas, as well as housing the COSTT project’s usability laboratory. Since the laboratory has a Sonitor ultrasound positioning system[35, 36] installed, it would have been interesting to collect data from that system simultaneously and compare the results with the WiFi system. Sadly it turned out that
the geographic referencing of access points in the building was severely incomplete and that one in fact did not even know where all the access points were. Therefore the MTFS building had to be abandoned.

The alternate building, which in the end was selected, was the Lerkendal building. The building has several strengths: It has a mix of small and large rooms (although more school-like in structure than hospital-like) and calibration of the wireless model for the building had been completed. Finally, it is also where the division of Geomatics is located, which eased the process of gaining access to every room at all hours of the day.

3.3 Georeferencing of Floor Plans

In order to establish reference points for location control (as detailed in section 3.4) and to provide a visual backdrop for the client application, a map of the interior of the Lerkendal building was needed. Since no map existed, simple indoor maps were made by georeferencing architectural floor plans obtained from NTNU’s Lydia service. The georeferencing was done using Quantum GIS 1.7.1 with the Georeferencer plugin.

Using architectural floor plans directly as maps is not ideal, because they contain a lot of unnecessary detail that makes them harder to read. For example, knowing the swing direction and radius of a particular door does not help a user navigate through the building and can safely be omitted on a proper map. Another potential challenge in using architectural plans instead of surveying the building as one might to create a map from the ground up is that architectural plans are "as planned" but what a map needs to be is "as built". Changes to the building in subsequent renovations are often not reflected in the original floor plans, as is observable in some rooms near the north-western corner of the Lerkendal building.

However, the quality of the floor plan maps is good enough to allow finding reference points, easy understanding of which room a point is in, and to assist in the test planning process. Therefore it was good enough for the purposes of this project.

3.4 Location Control

One important aspect of testing a positioning system is verifying the accuracy and precision of location information, where accuracy refers to how close to the real position the mean value of position estimates is and precision refers to how tightly
grouped the returned positions are. (As illustrated in figure 3.1.) Through this we get a good idea of how reliable the positioning results are, and how to best make use of them in practice.

The natural way to determine both accuracy and precision is to place the devices in a known location, and compare the reported position values to the actual position. Typically one gives the device enough time in each location to make sure the positioning process has ”settled” and will report positions with as little dithering as possible.

Previous projects at NTNU[19, 20] have controlled the positioning accuracy of the GeoPos service by comparing positioning results to the positions recorded by a hand-held GPS device. However, as this project aims at investigating indoor positioning GPS is not suitable due to GPS signals having very poor penetration of buildings.[3]
Because of the limitations of GPS, the location control testing in this project utilizes a mix of high-tech and low-tech methods. As discussed, digital floor plans for the building have been obtained and georeferenced, which provide references for measuring distances from. Typically, one measures from a corner with a known position along a wall, and then at a straight angle out from the wall. The required distances are determined by examining the digitised floor plans in Quantum GIS. All distances are measured with a tape measure, which it has been decided that will give good enough accuracy given the expected levels of accuracy provided by the positioning system. [5] When the known locations have been found, they are marked with a cross made of masking tape with details of the point written on it for future reference. Figure 3.2 demonstrates this.

Figure 3.2: Two of the most closely spaced reference points, marked on the floor.

3.5 Calibration

One way to improve the positioning reliability of the Cisco MSE system is to calibrate it through a process known as fingerprinting.[40, 5] In an ideal world, one
could easily triangulate WiFi devices by assuming a circular distribution of radio waves of uniform intensity emanating from the device. In practice, however, the signals are blocked and disturbed by any number of hindrances such as walls, people and other electronic devices. [41] Fingerprinting is so named because it makes a "fingerprint" of the received signal strengths to or from a device that is placed in a known location. Having gathered enough of these fingerprints from a suitably distributed number of positions, one can run them through a statistical analysis [42] that will produce a map of WiFi signal distortions. Using this information, the MSE can compensate for signal variances and compute a more reliable position estimate.

Since the experimentation is being performed in a building which has already been calibrated, we can gain valuable insights into the positioning performance with calibration turned on and off. (Switching calibration on and off is a simple setting in the Cisco Wireless Control System.[6]) Therefore all positioning tests are performed twice, once with calibration turned on and once with it turned off. That way we can examine discrepancies between the two states and determine if the calibration has had a significant effect compared to the standard signal propagation model, “Cubes and small offices”.

## 3.6 Reliability Tests

### 3.6.1 Test Platform

In order to simulate the tracking of a device placed on a piece of equipment like a wheelchair, the device was placed on a wheeled office chair so that it is a constant height above floor level. The height is a realistic height for a equipment tracking device as they would not normally be placed as close to the floor as possible, both for convenience and practical reasons. (One would not want to attach a device to the underside of a wheelchair’s footplate, for instance.) This also facilitates predictable movement and placement of the tracking devices because they are not carried around and placed by hand, which might have caused pendular motion.

The device was mounted on the central axis of the chair, as seen in figure 3.3, so that one could position it using the central intersection of chair legs. The chair height was set to the maximum, which is 56 cm over the floor when measured from the seat. The phone was mounted in its case, so that the phone could easily be retrieved from the case and stored in a safe location between tests while still securing reproducibility because the case was in a fixed position, as seen in figure 3.4.
Figure 3.3: Chair used for mounting device.
Figure 3.4: Mounting of the device on the chair.
3.6.2 Stationary Positioning Accuracy & Dithering

These tests are primarily meant to gather information about how reliable the absolute positioning is, and secondarily how successful the system is at placing devices in the correct room and floor. They are executed by placing the test platform in a known position, activating a ping program and leaving it there for a period of time (in these experiments five minutes) in order to allow the position estimate to settle, and then collecting position estimates for that time period. (A ping program periodically sends requests to a server and times the responses. In this case we are not interested in response times, but rather keeping the internet connection active by periodically generating traffic in a fashion akin to a tracking tag.) The average position for that time period is calculated and compared to the known position to give an indication of accuracy, and maximum and average position dithering is calculated to give an indication of precision. The calculations are performed by the browser-based user interface, and all results are manually transferred to a spreadsheet for future reference.

Selected Positions  Ten stationary positions were selected, which represent a varied selection of environments from small rooms to larger multi-story open areas. As such, they were expected to provide some challenging scenarios for the positioning system, which may or may not affect the positioning accuracy. The points are listed in table 3.1, illustrated in figure 3.5, and are recorded in a shapefile. (See appendix B.)

In addition to the specifically selected stationary points, every way-point for mobile positioning (shown in figure 3.6) will be measured as a static position. These larger volumes of more similar points should help to improve the statistical accuracy of the conclusions regarding accuracy in general.

<table>
<thead>
<tr>
<th>Point ID</th>
<th>Description</th>
<th>Known E (UTM32)</th>
<th>Known N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Centre of medium office</td>
<td>570212.935</td>
<td>7032575.085</td>
</tr>
<tr>
<td>2</td>
<td>Close to corner outside walls, glass</td>
<td>570192.742</td>
<td>7032587.135</td>
</tr>
<tr>
<td>3</td>
<td>Large open room, two stories</td>
<td>570202.747</td>
<td>7032599.989</td>
</tr>
<tr>
<td>4</td>
<td>Large Open room, one story</td>
<td>570216.988</td>
<td>7032607.073</td>
</tr>
<tr>
<td>5</td>
<td>Centre of elevator</td>
<td>570210.598</td>
<td>7032591.846</td>
</tr>
<tr>
<td>6</td>
<td>Semi-enclosed corridor</td>
<td>570210.306</td>
<td>7032582.607</td>
</tr>
<tr>
<td>7</td>
<td>Long corridor</td>
<td>570238.313</td>
<td>7032570.721</td>
</tr>
<tr>
<td>8</td>
<td>Lobby area; staircases</td>
<td>570267.781</td>
<td>7032566.449</td>
</tr>
<tr>
<td>9</td>
<td>Medium-large room, close to central air-well</td>
<td>570223.999</td>
<td>7032594.493</td>
</tr>
<tr>
<td>10</td>
<td>Small room</td>
<td>570212.278</td>
<td>7032588.139</td>
</tr>
</tbody>
</table>
3.6.3 Mobile Positioning Accuracy & Dithering

These tests are meant to gather information about how well the positioning performs when the device is in motion and positioning estimates have not had time to settle. Furthermore it is meant to reveal whether one with a fixed signalling interval can gather enough information to be able to discern which route was taken between two points. In order to do this, a number of known positions are measured for use as start, stop and way-point positions which the test platform is then moved in straight lines between. (With the ping program running.) The calculated position at the start and end points is compared to the known position to give an indication of accuracy. Because the positioning intervals may not match up with the time taken to move between way-points, the intermediary positioning results are not comparable with the way-points. A visual inspection of the displayed route is performed to compare it with the actual route and determine how well it placed the route in the correct rooms. Again, all the data is collected in a spreadsheet.
Selected Routes  Five routes have been selected, where two of them have identical way-point coordinates but are executed on different floors of the building. The routes represent a varied selection of environments, from navigating tight spaces to larger multi-story open areas. The routes are listed in table 3.2, illustrated in figure 3.6, and are recorded in a shapefile. (See appendix B.)

<table>
<thead>
<tr>
<th>Route ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 1</td>
<td>Long hallway, ground floor</td>
</tr>
<tr>
<td>R 2</td>
<td>Rectangle in large room</td>
</tr>
<tr>
<td>R 3</td>
<td>Lobby-like area</td>
</tr>
<tr>
<td>R 4</td>
<td>Complex transitions between rooms/hallways</td>
</tr>
<tr>
<td>R 5</td>
<td>Identical to R1, first floor basement</td>
</tr>
</tbody>
</table>

Table 3.2: List of mobile test routes

Figure 3.6: Waypoints for mobile accuracy test routes
4 Results

The tests were carried out at various points in time during the second week of December 2011, largely at hours of the day without a lot of activity in the building. This was done mainly to minimise impracticalities relating to measurements being taken in rooms with a lot of traffic, but may also perceivably have reduced signal interference due to fewer devices broadcasting on the 2.4 GHz band. (This is merely conjecture as there have not been undertaken similar experiments during high-traffic periods for comparison.)

In total, 33 points were statically measured first with calibration turned on and thereafter turned off, resulting in a total of 66 observations. Similarly, movement along the five routes was also measured twice, resulting in ten observations.

One fact that became clear rather early in the observations was that the positioning system currently is exceedingly conservative about adjusting a position. Normally, during a period of observation for a point the reported position would not change at all. (In a few cases it would fluctuate a bit, but once settling on a position it would not change again.) Moreover, this conservatism also comes into play when the device has been physically relocated. Quite often when one had measured in one point and moved on to the adjacent point, the system would report the position as unchanged.

As a result of this, the order of testing for positions was readjusted to try to maximise the physical distance between points tested in sequence. (Within constraints of time and practicality.) All the same, some measurements still became duplicates of previous position estimates. Since situations like this might arise in real-world use of the positioning system, these measurements were kept instead of attempting to remeasure them. In the section on statistical examination, section 4.3, statistics are calculated both with and without these obviously errant values in order to give an idea about real-world results versus theoretical results. (Note: The calibrated and uncalibrated tests were not all performed in the same order, so there are differences in which points became duplicates in each test run.)

Furthermore, while one originally considered doing doing twice the amount of stationary tests by doing one run with a high sampling frequency (0.3 Hz) and another with lower sampling frequency (0.03 Hz), it turned out to be unnecessary due to the aforementioned conservatism in positioning estimates. (A higher frequency would simply mean more identical position estimates.) In the end, all the mobile tests were performed with a sampling frequency of 0.3 Hz and all the stationary tests were performed with a sampling frequency of 0.03 Hz.
4.1 Calibration Switched Off

These test runs were performed with the standard signal propagation model, "Cubes and small offices". The complete test results are listed in appendix A, while the following tables show the most important results, namely the positioning errors and notes on perceived correctness. For clarity the results have been rounded down to the nearest centimetre, as both the accuracy of the positioning system and the placement of the reference points does not support using sub-centimetre accuracy in the results.

4.1.1 Stationary Positioning Accuracy

As one can see in table 4.1 and figure 4.1, there appears to be a systematic bias towards the south-east in the positioning results for this building, possible reasons for which will be enumerated in section 5.1.1. The expected errors based on the sample with and without all duplicates removed are presented in table 4.2, rounded to the nearest centimetre. (The mean distance error is calculated as the mean of all the distance errors, not the trigonometric distance of the mean N/E errors.) As one might expect, the calculated errors are smaller when duplicate positions are removed. In order to see if this assumption is true a statistical test can be performed on the samples, with duplicate points removed.
<table>
<thead>
<tr>
<th>Point Name</th>
<th>Error E</th>
<th>Error N</th>
<th>Trig. distance error</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP 1</td>
<td>-1.26</td>
<td>0.35</td>
<td>1.31</td>
<td>Correct room</td>
</tr>
<tr>
<td>SP 2</td>
<td>11.82</td>
<td>0.81</td>
<td>11.85</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 3</td>
<td>11.28</td>
<td>-11.72</td>
<td>16.27</td>
<td>Wrong floor</td>
</tr>
<tr>
<td>SP 4</td>
<td>5.82</td>
<td>-5.38</td>
<td>7.93</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 5</td>
<td>9.77</td>
<td>3.42</td>
<td>10.35</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 6</td>
<td>-2.74</td>
<td>2.63</td>
<td>3.80</td>
<td>Wrong floor</td>
</tr>
<tr>
<td>SP 7</td>
<td>12.42</td>
<td>-2.43</td>
<td>12.66</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 8</td>
<td>-2.08</td>
<td>-6.89</td>
<td>7.20</td>
<td></td>
</tr>
<tr>
<td>SP 9</td>
<td>-5.17</td>
<td>8.94</td>
<td>10.33</td>
<td></td>
</tr>
<tr>
<td>SP 10</td>
<td>-7.71</td>
<td>-0.19</td>
<td>7.72</td>
<td>Duplicate of SP2</td>
</tr>
<tr>
<td>MP 1</td>
<td>0.46</td>
<td>-4.38</td>
<td>4.40</td>
<td></td>
</tr>
<tr>
<td>MP 2</td>
<td>3.50</td>
<td>-2.56</td>
<td>4.34</td>
<td>Wrong room.</td>
</tr>
<tr>
<td>MP 3</td>
<td>16.22</td>
<td>3.78</td>
<td>16.65</td>
<td>Duplicate of MP2.</td>
</tr>
<tr>
<td>MP 4</td>
<td>12.23</td>
<td>5.34</td>
<td>13.34</td>
<td></td>
</tr>
<tr>
<td>MP 5</td>
<td>5.77</td>
<td>-9.01</td>
<td>10.70</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 7</td>
<td>14.29</td>
<td>-7.43</td>
<td>16.10</td>
<td></td>
</tr>
<tr>
<td>MP 8</td>
<td>6.67</td>
<td>0.69</td>
<td>6.71</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 9</td>
<td>4.33</td>
<td>-2.08</td>
<td>4.80</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 10</td>
<td>7.81</td>
<td>-10.53</td>
<td>13.11</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 11</td>
<td>15.45</td>
<td>-8.44</td>
<td>17.60</td>
<td>Placed outside</td>
</tr>
<tr>
<td>MP 12</td>
<td>19.90</td>
<td>-15.54</td>
<td>25.25</td>
<td>Duplicate of MP11</td>
</tr>
<tr>
<td>MP 13</td>
<td>10.67</td>
<td>5.00</td>
<td>11.78</td>
<td>Placed outside</td>
</tr>
<tr>
<td>MP 14</td>
<td>28.28</td>
<td>-31.32</td>
<td>42.20</td>
<td>Duplicate of MP11</td>
</tr>
<tr>
<td>MP 15</td>
<td>6.95</td>
<td>6.30</td>
<td>9.38</td>
<td>Placed outside</td>
</tr>
<tr>
<td>MP 18</td>
<td>5.44</td>
<td>-5.16</td>
<td>7.50</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 19</td>
<td>9.11</td>
<td>15.08</td>
<td>17.62</td>
<td>Duplicate of MP8.</td>
</tr>
<tr>
<td>MP 20</td>
<td>-13.53</td>
<td>5.80</td>
<td>14.72</td>
<td></td>
</tr>
<tr>
<td>MP 21</td>
<td>-0.02</td>
<td>-3.61</td>
<td>3.61</td>
<td></td>
</tr>
<tr>
<td>MP 22</td>
<td>3.63</td>
<td>-6.07</td>
<td>7.07</td>
<td>Wrong floor</td>
</tr>
<tr>
<td>MP 23</td>
<td>8.23</td>
<td>-3.71</td>
<td>9.03</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 24</td>
<td>12.36</td>
<td>-1.91</td>
<td>12.51</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 25</td>
<td>17.61</td>
<td>0.03</td>
<td>17.64</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 26</td>
<td>4.96</td>
<td>-9.83</td>
<td>11.01</td>
<td>Wrong room</td>
</tr>
</tbody>
</table>

Table 4.1: Stationary test results (in metres), uncalibrated, concise version
Figure 4.1: Scatter plot of errors in $E$ and $N$ direction for uncalibrated tests, with duplicate positions removed.
4 Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Error E</th>
<th>Error N</th>
<th>Distance Error</th>
<th>Variance E</th>
<th>Variance N</th>
</tr>
</thead>
<tbody>
<tr>
<td>With duplicates</td>
<td>7.04</td>
<td>-2.73</td>
<td>11.71</td>
<td>70.61</td>
<td>68.88</td>
</tr>
<tr>
<td>Without duplicates</td>
<td>5.95</td>
<td>-2.21</td>
<td>9.89</td>
<td>48.29</td>
<td>31.45</td>
</tr>
</tbody>
</table>

**Table 4.2:** Mean error (in metres) for uncalibrated positioning sample.

In these tests, first for the easterly errors and then for the northerly errors, we assume that random variations in the positioning error will be normally distributed. From this it follows that the expected mean of errors will be close to zero, with a variance allowing for values on both sides of the mean. The aim of the statistical test is to establish whether the mean calculated from the sample is close enough to zero that we cannot reject the possibility of it actually being zero, something that depends on the size and variance of the sample. The test being used is the Student’s t-test.[43]

For Easterly error:

Hypothesis $H_0 : \mu_E = \mu_0 = 0$

Hypothesis $H_1 : \mu_E \neq \mu_0$

Mean calculated from sample: $\bar{x}_E = 5.9523$

Sample variance: $s^2_E = 48.2913$

Sample size: $n = 28$

Student’s t-test statistic: $t_E = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}} = \frac{5.9523 - 0}{\sqrt{48.2913} / \sqrt{28}} = 4.532$

t-value for $n - 1 = 27, \alpha = 0.05 : t_c = 2.052$

$-t_c < t_c < t_E \Rightarrow H_0$ has been disproved.

For Northerly error:

Hypothesis $H_0 : \mu_N = \mu_0 = 0$

Hypothesis $H_1 : \mu_N \neq \mu_0$

Mean calculated from sample: $\bar{x}_N = -2.2078$

Sample variance: $s^2_N = 31.4500$

Sample size: $n = 28$
4 Results

Student's t-test statistic: \( t_N = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}} = \frac{-2.2078 - 0}{\frac{\sqrt{31.4500}}{\sqrt{28}}} = -2.0832 \)

\( t \)-value for \( n - 1 = 27, \alpha = 0.05 : t_c = 2.052 \)

\( t_N < -t_c < t_c \Rightarrow H_0 \) has been disproved.

Thus, we have proven with 95% confidence that there is a statistically significant difference between the assumption that the errors are randomly distributed around zero and the observed results, lending credence to our assumption that there is a systematic bias in the positioning results. This is true in both northerly and easterly directions.

On another note the subjective accuracy was not great, with the reported position being in the wrong room in most cases. While this does not have any influence on formal accuracy and precision, it does have an effect on the experienced accuracy and precision for the user, and the usefulness of the positioning for indoor navigation.

4.1.2 Mobile Positioning Accuracy

The tests of mobile positioning accuracy seem to have suffered greatly from the conservativeness of the positioning system. Out of five routes measured, there was only one case where the positioning system actually registered any movement during the time period that the movement lasted. That was route 1, which is a long hallway with fire doors enclosing separate sections and an access point positioned on the wall in each section. This probably contributed to the system being able to resolve a sufficient difference in received signal strength to warrant a shift in position.

As can be seen in figure 4.2, the results were still not that good. The movement that the system recorded was a great deal shorter than the movement actually performed, where the first registered point was 4.40 metres away from the real start, and the last recorded position was 19.28 metres away from the actual end position. Since none of the other routes returned any usable results, there is not a lot more to say about uncalibrated mobile positioning accuracy.
Figure 4.2: Visualization of captured points for route 1, uncalibrated. (Green is planned route, blue is recorded.)
4.2 Calibration Switched On

4.2.1 Stationary Positioning Accuracy

<table>
<thead>
<tr>
<th>Point Name</th>
<th>Error E</th>
<th>Error N</th>
<th>Trig. distance error</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP 1</td>
<td>5.13</td>
<td>-1.14</td>
<td>5.26</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 2</td>
<td>19.38</td>
<td>-0.49</td>
<td>19.39</td>
<td>Wrong floor</td>
</tr>
<tr>
<td>SP 3</td>
<td>9.72</td>
<td>-2.20</td>
<td>9.97</td>
<td>Wrong floor</td>
</tr>
<tr>
<td>SP 4</td>
<td>6.00</td>
<td>-9.07</td>
<td>10.87</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 5</td>
<td>5.36</td>
<td>2.31</td>
<td>5.84</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 6</td>
<td>7.24</td>
<td>-3.55</td>
<td>8.07</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 7</td>
<td>2.47</td>
<td>-4.06</td>
<td>4.75</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 8</td>
<td>-1.40</td>
<td>5.21</td>
<td>5.39</td>
<td></td>
</tr>
<tr>
<td>SP 9</td>
<td>1.89</td>
<td>5.12</td>
<td>5.46</td>
<td>Wrong room</td>
</tr>
<tr>
<td>SP 10</td>
<td>4.43</td>
<td>3.51</td>
<td>5.65</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 1</td>
<td>0.23</td>
<td>-5.87</td>
<td>5.87</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 2</td>
<td>2.64</td>
<td>-3.69</td>
<td>4.54</td>
<td></td>
</tr>
<tr>
<td>MP 3</td>
<td>21.91</td>
<td>4.85</td>
<td>22.44</td>
<td>Duplicate of MP1</td>
</tr>
<tr>
<td>MP 4</td>
<td>8.58</td>
<td>-9.21</td>
<td>12.59</td>
<td></td>
</tr>
<tr>
<td>MP 5</td>
<td>15.48</td>
<td>-5.12</td>
<td>16.31</td>
<td></td>
</tr>
<tr>
<td>MP 7</td>
<td>9.34</td>
<td>-10.45</td>
<td>14.02</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 8</td>
<td>7.73</td>
<td>-5.65</td>
<td>9.58</td>
<td></td>
</tr>
<tr>
<td>MP 9</td>
<td>2.73</td>
<td>-8.97</td>
<td>9.38</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 10</td>
<td>0.82</td>
<td>-21.20</td>
<td>21.21</td>
<td>Duplicate of MP5</td>
</tr>
<tr>
<td>MP 11</td>
<td>-7.01</td>
<td>19.46</td>
<td>20.68</td>
<td>Duplicate of SP8</td>
</tr>
<tr>
<td>MP 12</td>
<td>-3.21</td>
<td>12.69</td>
<td>13.09</td>
<td>Duplicate of SP8</td>
</tr>
<tr>
<td>MP 13</td>
<td>0.88</td>
<td>4.90</td>
<td>4.98</td>
<td></td>
</tr>
<tr>
<td>MP 14</td>
<td>4.41</td>
<td>0.39</td>
<td>4.43</td>
<td></td>
</tr>
<tr>
<td>MP 15</td>
<td>7.59</td>
<td>-5.81</td>
<td>9.56</td>
<td></td>
</tr>
<tr>
<td>MP 18</td>
<td>8.69</td>
<td>-9.07</td>
<td>12.56</td>
<td>Duplicate of MP7</td>
</tr>
<tr>
<td>MP 19</td>
<td>12.52</td>
<td>9.27</td>
<td>15.58</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 20</td>
<td>6.99</td>
<td>-5.06</td>
<td>8.63</td>
<td></td>
</tr>
<tr>
<td>MP 21</td>
<td>2.48</td>
<td>0.63</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>MP 22</td>
<td>-22.30</td>
<td>-22.15</td>
<td>31.43</td>
<td>Extreme outlier</td>
</tr>
<tr>
<td>MP 23</td>
<td>0.87</td>
<td>-8.27</td>
<td>8.31</td>
<td>Wrong room</td>
</tr>
<tr>
<td>MP 24</td>
<td>8.15</td>
<td>-6.94</td>
<td>10.70</td>
<td>Placed outside</td>
</tr>
<tr>
<td>MP 25</td>
<td>22.25</td>
<td>2.16</td>
<td>22.35</td>
<td>Duplicate of MP24</td>
</tr>
<tr>
<td>MP 26</td>
<td>7.77</td>
<td>-7.66</td>
<td>10.91</td>
<td>Wrong room</td>
</tr>
</tbody>
</table>

Table 4.3: Stationary test results (in metres), calibrated, concise version

Again, the values in table 4.3 and figure 4.3, seem to indicate a systematic bias
Figure 4.3: Scatter plot of errors in E and N direction for calibrated tests, with duplicate positions but not the statistical outlier removed.
towards the south-east, as evidenced by table 4.4. (The extreme outlier in MP22 has also been removed from the sample, as it is probably the result of some sort of positioning duplication of a position that was recorded while in transit from one point to another.)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Error E</th>
<th>Error N</th>
<th>Distance Error</th>
<th>Variance E</th>
<th>Variance N</th>
</tr>
</thead>
<tbody>
<tr>
<td>With duplicates</td>
<td>5.45</td>
<td>-2.58</td>
<td>11.28</td>
<td>67.67</td>
<td>71.40</td>
</tr>
<tr>
<td>Without duplicates</td>
<td>5.89</td>
<td>-3.38</td>
<td>8.31</td>
<td>22.14</td>
<td>24.67</td>
</tr>
</tbody>
</table>

Table 4.4: Mean error (in metres) for calibrated positioning sample.

We will make the same assumptions as last time, removing all duplicates and also the extreme outlier, and test if there is evidence of a systematic bias in this sample.

For Easterly error:

Hypothesis $H_0 : \mu_E = \mu_0 = 0$

Hypothesis $H_1 : \mu_E \neq \mu_0$

Mean calculated from sample: $\bar{x}_E = 5.8882$

Sample variance: $s^2_E = 22.1376$

Sample size: $n = 25$

Student’s t-test statistic: $t_E = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}} = \frac{5.8882 - 0}{\frac{\sqrt{22.1376}}{\sqrt{25}}} = 6.2573$

t-value for $n - 1 = 24, \alpha = 0.20 : t_c = 2.064$

$-t_c < t_c < t_E \Rightarrow H_0$ has been disproved.

For Northerly error:

Hypothesis $H_0 : \mu_N = \mu_0 = 0$

Hypothesis $H_1 : \mu_N \neq \mu_0$

Mean calculated from sample: $\bar{x}_N = -3.3769$

Sample variance: $s^2_N = 24.6658$

Sample size: $n = 25$

Student’s t-test statistic: $t_N = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}} = \frac{-3.3769 - 0}{\frac{\sqrt{24.6658}}{\sqrt{25}}} = -3.3997$
t-value for $n - 1 = 24, \alpha = 0.20 : t_c = 2.064$

$t_N < -t_c < t_c \Rightarrow H_0$ has been disproved.

Again, we can claim with 95% confidence that there is a systematic positioning bias in both the northerly and easterly directions.

4.2.2 Mobile Positioning Accuracy

The mobile tests went slightly, but not much better for the calibrated model than for the uncalibrated one. Out of five tested routes, one had to be discarded because it only displayed a single point, and two had to be discarded because the first point recorded was fixed to the position of the last point being tested. (These cases again caused by the conservative nature of the positioning system.)

However, in the two acceptable routes there were still severe shortcomings caused by the conservative nature of the positioning, in the same way as the one successful uncalibrated run. As one can see in figure 4.4, both the first and the last points in route 1 were quite far short of the actual position. Route 2 followed quite closely along the axis of the hallway, but did very poorly along the opposite axis, as can be seen in figure 4.5. It seems that an advantageous distribution of access points is important for the system to be able to resolve movement properly.

In total, the calibrated model seems to have slightly more success recognising movement than the uncalibrated one. This claim is however merely conjecture, as a much larger sample size is needed if it is to be verified.

4.3 Statistical Comparison of Calibration On and Off

Having presented the expected errors for the uncalibrated and calibrated models, it is of interest to see if the calibrated and uncalibrated samples actually represent a statistically significant difference in expected accuracy and precision. As the reader will recall, in both the uncalibrated and the calibrated model there is non-zero expected error due to a systematic bias. Therefore there is room for doubt whether the investment of effort in calibrating the model is actually worthwhile. These suspicions can be checked by performing two types of statistical test.

In these tests we again assume that random variations in the positioning error will be normally distributed. The aim of the first statistical test is to establish whether the mean calculated from the uncalibrated sample is close enough to the mean calculated from the calibrated sample that we cannot reject the possibility of the two means being the same, something that again depends on the size and
Figure 4.4: Visualization of captured points for route 1, calibrated. (Green is planned route, blue is recorded.)
Figure 4.5: Visualization of captured points for route 2, calibrated. (Green is planned route, blue is recorded.)
Results

For Easterly error:

Hypothesis $H_0 : d_0 = \mu_{uc} - \mu_c = 0$

Hypothesis $H_1 : d_0 = \mu_{uc} - \mu_c \neq 0$

Mean calculated from uncalibrated sample: $\bar{x}_{uc} = 5.9523$

Mean calculated from calibrated sample: $\bar{x}_c = 5.8882$

Uncalibrated Sample Variance: $s_{uc}^2 = 48.2913$

Calibrated Sample Variance: $s_c^2 = 22.1376$

Uncalibrated sample size: $n_{uc} = 28$

Calibrated sample size: $n_c = 25$

Student’s t-test statistic: $t' = \frac{(\bar{x}_{uc} - \bar{x}_c) - d_0}{\sqrt{s_{uc}^2/n_{uc} + s_c^2/n_c}} = \frac{(5.9523 - 5.8882) - 0}{\sqrt{48.2913/28 + 22.1376/25}} = 0.9685$

Approximate degrees of freedom: $v = \frac{(s_{uc}^2/n_{uc})^2}{(s_{uc}^2/n_{uc})^2 + (s_c^2/n_c)^2} = \frac{(48.2913/28)^2}{(48.2913/28)^2 + (22.1376/25)^2} = 47.6974$

$t$-value from table: $t_c = t_{0.025, 47.6974} = 2.0105$

$-t_c < t' < t_c \Rightarrow H_0$ has not been disproved.

For Northerly error:

Hypothesis $H_0 : d_0 = \mu_{uc} - \mu_c = 0$

Hypothesis $H_1 : d_0 = \mu_{uc} - \mu_c \neq 0$

Mean calculated from uncalibrated sample: $\bar{x}_{uc} = -2.2078$

Mean calculated from calibrated sample: $\bar{x}_c = -3.3769$

Uncalibrated Sample Variance: $s_{uc}^2 = 31.4500$

Calibrated Sample Variance: $s_c^2 = 24.6658$

Uncalibrated sample size: $n_{uc} = 28$

Calibrated sample size: $n_c = 25$
Student’s t-test statistic: 
\[ t' = \left( \bar{x}_{uc} - \bar{x}_c \right) - d_0 \]
\[ \sqrt{\frac{s^2_{uc}}{n_{uc}} + \frac{s^2_c}{n_c}} = \sqrt{\frac{31.4500}{28} + \frac{24.6658}{25}} \]
\[ = 0.4246 \]

Approximate degrees of freedom: 
\[ v = \frac{(\frac{s^2_{uc}}{n_{uc}} + \frac{s^2_c}{n_c})}{\frac{(s^2_{uc})^2}{n_{uc} - 1} + \frac{(s^2_c)^2}{n_c - 1}} = \frac{(31.4500)^2}{28 - 1} + \frac{(24.6658)^2}{25 - 1} = 50.9982 \]
\[ t\text{-value from table}: t_c = t_{0.025,50} = 2.0105 \]

\[ -t_c < t' < t_c \Rightarrow H_0 \text{ has not been disproved.} \]

Through this we have established that there is no statistically significant difference (at 95% confidence) between the mean of the two samples. This means that there cannot be said do be any difference in expected error, and therefore accuracy, between the two. However, the precision can still be different, which makes a difference in practical usage. We suspect that the calibrated model gives a lower variance, and therefore we perform a second test to establish whether there is a significant difference in variance. Here we will use the f-value test to compare variances, again assuming the samples are from a normal population.[43]

For Easterly error:

Hypothesis \( H_0 : \sigma_{uc} = \sigma_c \)

Hypothesis \( H_1 : \sigma_{uc} \neq \sigma_c \)

Significance value: \( \alpha = 0.05 \)

Uncalibrated Sample Variance: \( s^2_{uc} = 48.2913 \)

Calibrated Sample Variance: \( s^2_c = 22.1376 \)

Uncalibrated sample size: \( n_{uc} = 28 \)

Calibrated sample size: \( n_c = 25 \)

f-value test statistic: 
\[ f = \frac{s^2_{uc}}{s^2_c} = \frac{48.2913}{22.1376} = 2.1814 \]

f-value from table: \( f_{0.05}(27,24) = 1.96, f_{0.95}(27,24) = \frac{1}{f_{0.05}(27,24)} = \frac{1}{1.96} = 0.5102 \)

\[ f_{0.95}(27,24) < f_{0.05}(27,24) < f \Rightarrow H_0 \text{ has been disproved.} \]

For Northerly error:
Hypothesis $H_0 : \sigma_{uc} = \sigma_c$

Hypothesis $H_1 : \sigma_{uc} \neq \sigma_c$

Significance value: $\alpha = 0.05$

Uncalibrated Sample Variance: $s^2_{uc} = 31.4500$

Calibrated Sample Variance: $s^2_c = 24.6658$

Uncalibrated sample size: $n_{uc} = 28$

Calibrated sample size: $n_c = 25$

f-value test statistic: $f = \frac{s^2_{uc}}{s^2_c} = \frac{31.4500}{24.6658} = 1.2750$

f-value from table: $f_{0.05}(27, 24) = 1.96, f_{0.95}(27, 24) = \frac{1}{f_{0.05}(27, 24)} = \frac{1}{1.96} = 0.5102$

$f_{0.95}(27, 24) < f < f_{0.05}(27, 24) \Rightarrow H_0$ has not been disproved.

These tests prove that the variance in easterly position errors is significantly smaller, while the same cannot be confidently claimed for the northerly errors. All the same, this still gives credence to the assumption that the calibrated model has superior (smaller) variance and therefore has higher precision than the uncalibrated one.
5 Conclusions

5.1 Testing of the WiFi positioning system at NTNU

5.1.1 Regarding Accuracy and Positioning Bias

The results show that both with and without calibration there is a systematic bias in returned positioning results of around six metres to the east and three metres to the south, meaning that the accuracy of the system as it is deployed in the test building is not perfect. (The positioning results are not hitting the middle of the bullseye, as it were.) However, they are still fairly good compared to for example GSM positioning indoors, which is the only other option for indoor positioning without any special user devices.

There are several reasons why the positioning may be biased, which are mainly speculated on without thorough investigation:

Building layout & construction The layout of the building and the materials and methods used to construct it might adversely affect the signal propagation in a way that is hard to understand for the positioning system. For example, the central air-well in the building could perceivably confuse some positioning attempts.

Access point layout The physical layout of the access points is important, since the geometry of sending and receiving antennas will presumably affect the positioning estimate in much the same way it affects GPS systems[3]. The mobile positioning tests indicated that where all the access points were lined up, movement resolution was better along that axis than perpendicular to it.

Map adjustment The map corner coordinates entered into the Cisco WCS system may not be entirely correct, which would easily induce a systematic bias in positioning results. This potential source of errors can be eliminated by a thorough revision of entered coordinates.

Access point map referencing All the access points have to be properly referenced on a map for the Cisco MSE/WCS system to be able to resolve positions. If this is lacking then the positioning results will be adversely affected. As mentioned in section 3.2, the original choice of candidate building had to be abandoned because the access points were not referenced at all. An examination of a screenshot of the access point positions recorded in the WCS reveals that not all the access points are recorded in exactly the correct position. As figure 5.1 demonstrates, the difference can often be
measured in metres. There is no doubt that this particular issue must have affected the positioning estimates. (As one can assume that the deployment and registering of WiFi access points across NTNU was performed with a similar level of precision, it is probable that a systematic positioning error exists in other buildings as well.)

There is no doubt that the key element to gaining high accuracy in positioning and avoiding systematic bias is to be very thorough and conscientious in setting up all the parameters that the system relies on for determining positions. While some issues, like the physical building layout and access point positions are in whole or in part impossible to influence, correct metadata about the building and the access points is easily verifiable. This in turn directly influences the accuracy of the result. The systematic bias of positioning in the tested building could have been reduced in whole or at least in part by the acquisition of better system metadata.

5.1.2 Regarding Precision

The question of precision is a difficult one, and the answer depends somewhat on how one chooses to interpret the results. On a point-by-point basis, as the system reports it, the precision is extremely high since the system reports zero position dithering over time when the device is sitting still. The reported position may not be correct (a matter of accuracy), but the clustering of reported positions is perfect. This is obviously because of the way the Cisco positioning system treats deviations in calculated signal strengths rather than the signal strengths being completely constant over time. Presumably the system has some sort of threshold for reporting a deviation in position, the components of which are calculated in some proprietary way. Whether this threshold is overridable by the user is something the author of this report has not been able to ascertain.

When considering the "big picture" precision, namely the variance in collected positions, one can see that the precision must necessarily be less than perfect. This indicates that the positioning system must also experience similar variations but that they are suppressed. Quite possibly the system adjusts the reported position according to predetermined statistical parameters based on testing during design of the system, and then locks it in place. In practice we must assume that the variance in positioning, and therefore also the precision of the WiFi positioning system as a whole, must be similar to the variance of the collected samples.

To sum up: The WiFi positioning system reports results with near infinite precision, when it in reality is subject to a variance of around twenty metres when
Figure 5.1: Difference between access point positions recorded in WCS (crosshair) and actual positions (red dot).
5 Conclusions

5.1.3 Regarding Usefulness of Calibration

Calibration of a floor is a non-negligible investment of time, and an obvious question is whether that investment of time is worthwhile. As it stands, the results indicate that calibrating does not give a significant improvement in accuracy. As concluded in section 5.1.1, the system probably suffers from systematic bias due to poor system metadata and from that we can infer that a calibration is not able to correct this type of error. (Calibration measurements are probably not given enough weight by the system to overrule the given positions of access points.)

However, one can reasonably claim that the purpose of calibrating is not to improve accuracy, but to improve precision. This is because if a system was unbiased, both calibrated and uncalibrated errors should average out to zero, which would mean there was no difference in accuracy. When measuring precision by way of comparing sample variance, it becomes apparent that the calibrated system has lower variance and therefore higher precision. For a user this is important, as lower variance means that the position is more often experienced as being close to the correct one, and also that the user’s impression over time is that the system does not return grossly incorrect results.

To sum up: Calibrating the system does not compensate for systematic errors, but increases precision and provides greater user satisfaction.

5.1.4 Implications for Real-time Navigation

For a subjective user experience such as real-time navigation, there are two important factors: Positioning accuracy and frequent position updates. Currently the WiFi positioning system at NTNU has certain challenges in both regards. As previously discussed, the test building revealed a systematic bias in positioning results. These could easily frustrate a user since a user would expect to be positioned in the correct room, while the systematic error would often mean that the position was reported to be in a different room. Being presented with positions and route calculations based on the incorrect room can easily be a confusing and frustrating experience. Furthermore, the extremely conservative approach to changes in position makes turn-by-turn navigation difficult, as a navigation system would be unable to realise that the user was moving before a sudden large jump in positions was registered.
In total, the system as it stands today does not effectively support real-time navigation.

5.1.5 Implications for Inventory Control

When tracking pieces of inventory that move only intermittently and normally are stationary, the question of positioning bias is more important than movement conservatism. This is because one would most often be looking for an item while it is standing still and therefore the risk of the positioning information being obsolete is smaller, but looking in the right room is still important. One unresolved question is how long time the system will continue to report the same position for a device without re-evaluating it, because if a position was acquired while the item was in transit it might be retained when the item reaches the final destination, thus creating an effective positioning error.

In conclusion, the system would strongly benefit from a revision to eliminate systematic positioning bias, but should otherwise support a inventory control scenario.

5.2 Performance of the IndoorPos system

All of the testing was carried out and logged using the IndoorPos system, with information extracted via the browser-based client. The system performed as expected, with high reliability on the server side. Once deployed, the server application did not crash hard a single time during testing, despite running for several weeks during the various phases of examination of candidate buildings, development of the browser client and experimentation. It also gracefully handled fault situations that arose when the GeoPos positioning server went down and when WiFi infrastructure faults caused unexpected situations. In total 116719 position records were entered into the database during this period, with the entire database requiring 32 megabytes of space. At an average of 274 bytes per record, that is a fairly economic use of space. 5255 position records, or a bit over 43 hours of positioning data for a device at a 0.03 Hz sampling rate, would fit on to a single floppy disk, which is by today’s standards an extremely small amount of storage. As discussed in section 6.2, there are also ways of reducing the storage and bandwidth footprints even further.

The browser-based client was functional and allowed the collection of all relevant samples, which were then used as the basis for a number of statistical cal-
Conclusions

All the underlying data behind the calculations is still safely stored in the database in case it should be desirable to apply any new transformation and analysis to the collected data.

The IndoorPos indoor positioning test system allowed the gathering of large amounts of test data from which statistical analysis could be performed and important conclusions about the indoor positioning system at NTNU could be inferred. These conclusions are backed up with hard data and are reproducible, and can help stakeholders like Wireless Trondheim make informed decisions about their indoor positioning systems. As such, the stated goals for the IndoorPos system have been successfully achieved.
6 Future Work

There are several avenues of future work which may be pursued in relation to the subjects covered in this report, some of which are mentioned here.

6.1 NTNU’s Wireless Positioning System

The most obvious and immediate way of continuing work in this direction is to follow the conclusions set forth in this paper and revise the system’s metadata on the indoor map and access point positions. By doing that one can ascertain if the systematic bias truly is caused by these reasons, and also how much the accuracy and possibly also precision can be improved by the revisions.

Another avenue of inquiry would be to examine the actual and registered positions of access points on other buildings on the NTNU campus in order to reveal whether or not they suffer from the same inaccuracies as the building tested during this project, and then taking positioning samples to see if a systematic bias manifests itself. If so, the conclusions of this paper would be strengthened.

For a proper verification of the conclusions in this report, both avenues should probably be pursued. In other words, all buildings should undergo a revision of metadata once it has been proven to have an effect on the building tested in this report. Doing so would also almost certainly guarantee an improvement in accuracy and possibly precision for all buildings so examined.

6.2 The IndoorPos System

Since the IndoorPos system was designed to be modular and extensible, there are many possibilities for improving it and making it into a more valuable tool for future testing of indoor positioning accuracy. Some of the potential points of improvement are listed here.

Decoupling of data structures Currently, the internal data structure of IndoorPos is rather tightly modelled on the data received from a GeoPos service. (The coupling is not one to one, due to several unnecessary or erroneous properties of the GeoPos data being amalgamated, changed or removed for better data consistency.) In the future it would be wise to research criteria for a data structure that can accommodate all types of data sources without prejudice, thereby ensuring proper independence of data sources.

Improved installation/packaging Setting up the system is still somewhat complex, and could be streamlined further to make it easier. Providing a turnkey
solution to position quality testing could potentially be useful for others in the future.

**Elimination of duplicate positions** Currently, the PostGIS back-end both stores and retrieves every single position recorded, even though it may be one in a long series of identical positions due to a device being stationary. This uses up space in the database and requires more transmission bandwidth when sending to clients. If one was to use the IndoorPos server as a basis for a large scale or user-oriented test of some kind, one might not be interested in all these duplicates. This could be remedied by sub-classing the database back-end and adding checks to see if the position is significantly different from the previous either when storing or retrieving data. (Depending on whether the priority is on storage requirements or bandwidth requirements.) Then it would merely by a question of changing the configuration to load the appropriate back-end.

**Rigorous testing of server** While the server has proven to be stable over time, it has never been tested under extreme load, and no serious attempts at security circumvention have been attempted. In order to make the server "production ready" one would want to conduct rigorous tests designed to uncover potential flaws and repair them.

**Improved client** The browser-based client used for this project was very basic, giving access to the data needed for analysis but not much more. A improved client (either browser-based or native) could facilitate a lot of the analytic functions that in this project were accomplished through manual use of a spreadsheet program. Furthermore, it could provide better visualisations and stateful operation to make the user experience better.

Implementing these suggestions would help make IndoorPos a truly universal testing framework that could be of use in future research, not just at NTNU but also elsewhere should the need be.
References


References


[34] R. Nordan and K. Liaaen, “Email exchange regarding positioning at ntnu and geopos,” September 2011.


APPENDIX
A Complete Test Results

For greater ease of reading and more details, please consult the electronic versions of these tables, detailed in appendix B.

Table A.1: Stationary test results for stationary points, uncalibrated.

Table A.2: Stationary test results for mobile points, uncalibrated.
### Table A.4: Stationary test results for stationary points, calibrated.

<table>
<thead>
<tr>
<th>Run Tag</th>
<th>Description</th>
<th>E</th>
<th>Distance</th>
<th>Start Error</th>
<th>End Error</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP 1, 30 s</td>
<td>Route 1, long hall, ground floor</td>
<td>Oct 31</td>
<td>570242.05</td>
<td>701207.41</td>
<td>701207.46</td>
<td>Correct floor, wrong room</td>
</tr>
<tr>
<td>MP 2, 30 s</td>
<td>Route 1, long hall, ground floor</td>
<td>Oct 31</td>
<td>570242.05</td>
<td>701207.41</td>
<td>701207.46</td>
<td>Correct floor, wrong room</td>
</tr>
<tr>
<td>MP 3, 30 s</td>
<td>Route 1, long hall, ground floor</td>
<td>Oct 31</td>
<td>570242.05</td>
<td>701207.41</td>
<td>701207.46</td>
<td>Correct floor, wrong room</td>
</tr>
<tr>
<td>MP 4, 30 s</td>
<td>Route 1, long hall, ground floor</td>
<td>Oct 31</td>
<td>570242.05</td>
<td>701207.41</td>
<td>701207.46</td>
<td>Correct floor, wrong room</td>
</tr>
<tr>
<td>MP 5, 30 s</td>
<td>Route 1, long hall, ground floor</td>
<td>Oct 31</td>
<td>570242.05</td>
<td>701207.41</td>
<td>701207.46</td>
<td>Correct floor, wrong room</td>
</tr>
<tr>
<td>MP 6, 30 s</td>
<td>Route 1, long hall, ground floor</td>
<td>Oct 31</td>
<td>570242.05</td>
<td>701207.41</td>
<td>701207.46</td>
<td>Correct floor, wrong room</td>
</tr>
<tr>
<td>MP 7, 30 s</td>
<td>Route 1, long hall, ground floor</td>
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</tr>
</tbody>
</table>
B Attached Files

This is a list of the electronic files that are attached to the project report, consisting mainly of the supporting software used to gather data and the gathered data itself. For the printed version of the report, the files are included on a DVD that should be included with the report. For the electronic version of the report, the files are available from the author upon request. Certain files pertaining to GeoPos communication have been omitted due to their sensitive nature.

**IndoorPos browser client folder** Contains all the files for the browser-based client, to be used in accordance with appendix E.

**IndoorPos server binaries folder** Contains all the files to be uploaded to the server, in accordance with appendix D. The binary has had the GeoPos code removed, a binary with the GeoPos code is available upon request.

**IndoorPos server source code folder** Contains all the source code needed to modify and build the server binaries, with an Eclipse project file for easier use. (Has also had GeoPos code excised.)

**PostGIS scripts folder** This folder contains the script needed to set up a PostGIS table for use with the server application.

**Test results folder** This folder contains spreadsheets with all the data collected, and the statistical calculations done based on that data. Also included a number of screenshots made of client visualisations during testing.

**Testing points folder** This folder contains a Quantum GIS project file with all of the test points and referenced floor plans for the Lerkendal building.

**A Framework for Testing Indoor Positioning Systems.pdf file** The electronic version of this report. (On the DVD accompanying the printed version.)
C  Server Details

The Geomatics server that has been used for the testing has the following characteristics, and is a known good environment for the server-side application:

**CPU**  Intel® Pentium® 4 CPU 2.40GHz (32-bit)

**Memory**  1.5 GB

**Hard Disk**  16 GB system disk, 688 GB storage disk

**Operating System**  Ubuntu Server 10.10

**JVM**  OpenJDK Runtime Environment, Java version 1.6.0_20

**Map server**  Geoserver version 2.0.3 with native JAI & Image I/O

**Database**  PostgreSQL 8.4.9 with PostGIS

This machine has certainly yielded good enough performance to capture data from a small number of devices and serve it to a single client, like it has been utilised in the testing work for this report. Whether one might need a more powerful machine to serve multiple users or track a multitude of devices, like for example in the case of inventory control, has not been researched.
D Server Set-Up and Configuration

Setting up and using the server application is designed to be as straightforward as possible, but all the same a small amount of configuration is needed. This guide assumes you have a server with a similar set-up to the server detailed in appendix C.

D.1 Server Files

A number of files need to be copied to the server, which are attached electronically to this report. They are listed here:

The lib folder This folder contains all the libraries needed for the application to function, and are detailed in appendix F.

indoorpos_server.jar The actual application.

indoorpos.log The log file where all events are logged.

jsvc The Apache Daemon start-up program.

start_server.sh A convenience script for starting the server as system service.

stop_server.sh A convenience script for stopping the server system service.

change_tag.sh A convenience script for changing the identifier tag applied to all recorded observations. (Typically an experiment identifier.) Usage is like this:

    ./change_tag.sh New tag message

In addition, if using the GeoPos service as a data source, the GeoPos keystore file must reside in the same folder.

D.1.1 Compiling jsvc

Since the Apache Daemon start-up program jsvc is not distributed in binary form, it must be compiled on the platform on which it is to be used. Following the instructions from [28] one can download and compile the source code to the jsvc program, and then copy jsvc into the IndoorPos folder. (The source code and compilation files may then be removed if desirable.)
D.1.2 Database

If the PostGIS database back-end is to be used, one must have access to a PostGIS databases (not necessarily on the same machine as the application) with a custom indoorpositions table in addition to the customary PostGIS tables. (The SQL script for creating the table is listed in section B.) Also, rights must be set for a indoorpos_user (the exact name is configurable, see the next section) to modify the table, and potentially for a client user to be able to view the table.

D.2 Server Configuration Files

In addition to the previous files, there are three configuration files that the user needs to modify in order to use the server.

**log4j.xml** An xml file that configures the logging level of the application; i.e. ”debug”, ”info”, ”warn”.

**indoorpos.targets** This file defines which MAC addresses will be searched for, one target per line with the MAC first and then a description. An example of a line:

```
00:11:22:33:44:55 Test device nr. 1
```

**indoorpos.config** This files defines everything about the application, such as which modules to use, how often to poll and so on. An example of how the file is structured:

```
# Sets the server to get positions from, e.g. Dummy, GeoPos
PROVIDER: GeoPos

# Sets the storage backend, e.g. PostGIS w/ options, Dummy
STORAGE: PostGIS localhost:5432/indoorpostest user password

# Sets how often you poll for updates. (in ms) 10 s = 10000 ms
POLL_FREQUENCY: 10000

# Sets the tag to be applied to the run, e.g. Test1, Trial run 2
RUN_TAG: Experimental run 1
```

At the very least, the STORAGE setting needs to be changed to fit the current set-up.
E Client Set-up and Configuration

Set-up of the client software is in principle somewhat less complex than the server, but due to the client being developed for the very specific use case of testing in the context of this project there are a lot more parameters hard-coded in the source code that need to be changed. All the client files must be uploaded to a web server equipped with PHP Hypertext Processor (PHP) support which is accessible from wherever one wishes to use the browser client. Of these files, there are two in particular that need to be changed to fit local conditions.

E.1 index.html

If the client is to be used for any other buildings or areas than the MTFS building and the Lerkendal building as provided by the geomatics server, it will be necessary to manually edit the layer definitions to reflect this. Likewise the predefined routes for visual comparison will have to be changed.

Furthermore, one will have to edit the variables serveraddress_newest and serveraddress_historic to reflect the domain the file is hosted on and the domain the IndoorPos server is hosted on.

E.2 pos-proxy.php

This script manages the redirection of requests to the IndoorPos server in order to comply with the security restriction against cross-site requests[44] enforced by most major web browsers.[45] The field named $valid_url_regex must be changed to a regular expression matching the domain on which you host the IndoorPos server. (If it is the same domain you can effectively eliminate the use of pos-proxy.php by setting the address directly in index.html.)
F  External Libraries & licences

Both the server-side program and the client-side program make use of a number of open source libraries to provide needed functionality. This both reduces the development workload and increases the reliability of the programs by using tested and well-proven components. The libraries and their licences are listed in tables F.1 and F.2, and for more information on the licences see [46].

F.1  Server-side

<table>
<thead>
<tr>
<th>Name</th>
<th>Purpose</th>
<th>licence</th>
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<tbody>
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<td>Google GSON</td>
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<tr>
<td>PostgreSQL JDBC Driver</td>
<td>Database Connectivity</td>
<td>BSD licence</td>
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</table>

Table F.1: Table of libraries used in the server application

As a result of the licence propagation inherent in the GNU General Public licence (GPL), the server-side application is also licenced under the GPL. The licence requirements are met by distributing the source code along with the binaries, as detailed in appendix B. In addition, for the GeoPos connection to function a proprietary library from Wireless Trondheim is used. This is not distributed with the rest of the program, but is available upon request.

F.2  Client-side

<table>
<thead>
<tr>
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<th>licence</th>
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<tbody>
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<td>OpenLayers</td>
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<tr>
<td>jQuery</td>
<td>Web Service Communication</td>
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<td>Coordinate Reprojection</td>
<td>MIT licence</td>
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<td>Datejs</td>
<td>Date conversion</td>
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<tr>
<td>Simple PHP Proxy</td>
<td>Cross-domain Webservice Calls</td>
<td>MIT licence</td>
</tr>
</tbody>
</table>

Table F.2: Table of libraries used in the client application

The client side application is released under the 3-clause BSD licence, and is fully available.