Tracking and Visualizing Hospital Equipment in a Web Based GIS

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Abstract

The hospital in Gävle has been fined multiple times due to improper placement of hospital beds in the hallways; so far they have been fined 20 times for a total of 570 000kr (Löfving, 2013). A solution to this problem was requested by the hospital in the form of an indoor positioning system to track hospital equipment.

Therefore, this study was performed and it was focused on three main research questions:

- How will tracking equipment indoor with the fingerprint method perform under different circumstances? (Moving between floors, running, walking, under a bed, hidden by electronic equipment etc.)
- How can the positions be visualized in a web-based GIS?
- What problems can be solved by visualizing the movement of equipment in a GIS?

The research questions were answered by performing studies on previous research in the fields of Indoor Positioning Systems (IPS) and visualization techniques. To test how the system performs a case study was performed in a testing environment on floors 7 and 8 of building 38 of Gävle Hospital. The data collected in the case study was then used to simulate moving hospital beds and from there create visualizations based on the research on previous studies.

Because the hospital wanted the system to use the already existing infrastructure of the building an IPS was found that use the already existing Wi-Fi network. By combining this positioning system with the web-based Geographic Information System (GIS) called CRISP a powerful analysis tool emerged that not only had the ability to track equipment but also perform analysis of statistics for workflow and the movement of the equipment, among others.

The precision of 3 m was found to be on par with other positioning systems using Wi-Fi. This gives the system described and tested in this thesis great potential to expand in to other fields, where there is need for high accuracy combined with a powerful analysis tool to help make the business as efficient as possible.
# Table of contents

1. Introduction .......................................................................................................................... 1
   1.1 Background ....................................................................................................................... 1
   1.2 Research focus .................................................................................................................. 1

2. Previous research .................................................................................................................. 3
   2.1 Visualization .................................................................................................................... 3
      2.1.1 Visualization Techniques ......................................................................................... 4
      2.1.2 Visualizing temporal data ....................................................................................... 12
      2.1.3 Designing an easy to interpret visualization ............................................................. 14
   2.2 Indoor positioning systems .............................................................................................. 15
      2.2.1 The different solutions to IPS .................................................................................. 15

3. Method .................................................................................................................................... 19
   3.1 The previous research ...................................................................................................... 20
   3.2 Site surveying .................................................................................................................. 20
   3.3 Evaluating the positioning performance ......................................................................... 22
   3.4 Visualizing positions in the web-based GIS .................................................................. 23

4. Result ...................................................................................................................................... 25
   4.1 Evaluation of positioning performance .......................................................................... 25
   4.2 Visualizing positions in the web-based GIS .................................................................. 28

5. Discussion and conclusion .................................................................................................... 31
   5.1 Evaluation of positioning performance .......................................................................... 31
   5.2 Visualization of positions in the web-based GIS ............................................................. 32
   5.3 Conclusion ....................................................................................................................... 34

6. Acknowledgements ............................................................................................................... 35

References ................................................................................................................................ 36

Appendix 1 ................................................................................................................................ 38
1. Introduction

1.1 Background

The hospital in Gävle has been fined multiple times due to improper placement of hospital beds in the hallways; so far they have been fined 20 times for a total of 570 000kr (Löfving, 2013). A solution to this problem was requested by the hospital in the form of an indoor positioning system to track hospital equipment.

Since Global Positioning Systems (GPS) needs line-of-sight to satellites orbiting the Earth (Schutzberg, 2013) it will lose precision indoors to the point that it is unusable. Therefore, another solution has to be found that delivers precision high enough to distinguish if equipment is situated in the hallway or the room on the other side of the wall.

After conducting a literature review it became obvious that research on IPS (Indoor Positioning System) has not come as far as outdoor positioning. There is no defined standard and a lot of different solutions exist such as Bluetooth, Wi-Fi, RFID (Radio-Frequency IDentification) or IR (Infrared) (Ngan et al., 2012).

One request from the hospital was that the system should use the building’s existing infrastructure and therefore this research was focused on a solution based on Wi-Fi. It was found that there is some research performed on how indoor positioning systems work but that there is a significant lack of on how IPS performs in the continuous tracking of equipment in a large building complex.

1.2 Research focus

The focus of this research will be the evaluation of an IPS that use Wi-Fi with the fingerprint method in order to find out how it performs in tracking equipment in a large scale building complex. It will also focus on how moving equipment can be visualized in a web-based Geographic Information System (GIS) and what analyses can be performed by using data from the positioning system.
The three main research questions are:

- How will tracking equipment indoor with the fingerprint method perform under different circumstances? (Moving between floors, running, walking, under a bed, hidden by electronic equipment etc.)
- How can the positions be visualized in a web-based GIS?
- What problems can be solved by visualizing the movement of equipment in a GIS?

The first question will be answered in chapter 4.1 Evaluation of positioning performance, based on results from the case study performed on floors 7 and 8 in building 38 of the Gävle county hospital.

The second and third question will be answered in chapter 4.2 Visualizing positions in the web-based GIS, based on the study on previous research performed in the visualization section of chapter 2.

Should this system prove to be effective the hospital would not only save money by avoiding fines, but queues for treatment are expected to be reduced since the system makes it easier for nurses to manage the hospital’s resources more efficiently. The web-based GIS provide a powerful tool with an interface that is very light and user friendly, this opens up possibilities for a constant development of solutions to problems that might emerge, without the need to contact GIS-specialists.

Since the initial literature review showed that there is some research done on how indoor positioning systems work but no research was found on how IPS performs in the continuous tracking of equipment in a large building complex this research was conducted in two parts. First, a study of previous research was done to find out what types of IPS there are and how they work as well as explore different ways of visualizing statistical quantitative data and temporal data in order to visualize the movement of hospital equipment. Secondly, a case study was performed in order to evaluate how the system performs in the hospital environment.
2. Previous research

2.1 Visualization

Large amount of data can be hard to comprehend if presented to the user in its raw form, such as in attribute tables, especially if the data is collected with the purpose of solving a specific problem that requires a view of the bigger picture. Before the computer-era of cartography this was something that only trained cartographers could do. This changed in the 1980s when the development of on-screen maps combined with a database that allowed user to query information began (Kraak & Ormeling, 2010). This was the start of GIS.

Ware, C. (2013) stated that “The perception of a pattern can often be the basis of a new insight”, this is the essence of geospatial visualization. By using a GIS the user can combine different datasets and apply an appropriate visualization technique to attributes that are of interest so that the relation between different events can be made more obvious, e.g. combining data of air pollution with locations for factories. Visualizing different attributes in the form of points, lines, polygons or symbols on a map allows for an easier interpretation and a more in-depth analysis of the problem at hand, it becomes easier to see the whole picture and how the different aspects of the data affect the outcome.

When given a set of spatial data there are a number of different ways it can be visualized, but which technique is best suitable for which type of data? This section will list some of the existing techniques for visualizing data and explain what type of data it is most suited for as well as to find out the best way of visualizing temporal data.

Since this paper concerns tracking the positions of hospital equipment and how this can be visualized in a way that users can quickly understand, this study will be focused mostly on visualizing univariate and bivariate (Spence, 2001), since visualization of data with attributes more than that quickly gets complicated and hard to interpret. Univariate data is data where entities have one attribute and bivariate data is data where entities have two attributes.
2.1.1 Visualization Techniques

In the following sections we will introduce the different visualization methods and give examples of what usage is most appropriate for each technique. Most of the techniques shown here will be visualizations of spatial data on a map, but since statistical data derived from the location data also should be visualized some statistical visualization of quantitative data will also be explored.

Statistical visualization of quantitative data

Data is classified depending on the number of associated attributes. This affects what type of visualization technique that should be used (Spence, 2001).

Univariate data

Data with only one attribute, such as a list of cars with the attribute price, is called univariate data. Such low dimensional data can in its simplest form be visualized through tables, but if a table consists of several hundreds of rows gaining an understanding of the data distribution can be difficult (Slocum, McMaster, Kessler & Howard, 2010).

Instead of a table with raw data a group-frequency table can be used. The data is classified in different intervals and then displayed in a table that shows the number of observations of values within each class. This gives a table with a significantly smaller amount of rows, and it is easier to interpret the distribution of values along the different classes.

Univariate data can also be plotted as points on a scale (also called a point graph), where one point corresponds to one value in the attribute table, which makes it easier to see the distribution of the data.

Points on a scale can be simplified even more by using a Tukey Box Plot (Spence, 2001), this method groups the values in the range 25% - 75% in a box with lines reaching to 10% and 90% of all the values, leaving the top and bottom values still shown on the scale. See figure 1 for a comparison between the regular point plot and the Tukey Box Plot visualization of house prices.

![Figure 1. Point plot (left) and Tukey box plot (right) representation of house prices.](image)
Histograms classify the data into different ranges in order to get less classes, the data is then visualized by one bar for each class with a height relative to the frequency of observations (Slocum et al., 2010).

**Bivariate data**

Bivariate data is data with two attributes. For instance, this can be a list of houses with the attributes price and number of bedrooms. The task of finding a relation between two attributes using a table can be difficult (Slocum et al., 2010), but is made easier to understand if the data from both attributes are divided into classes just as with the group-frequency table. By creating a matrix of the results, with one attribute per axes, a relation between the attributes is easier to distinguish (Slocum et al., 2010).

The bivariate data can be plotted using a scatterplot. This works essentially the same as a point graph but with the points plotted in two dimensions (x- and y-axis) instead of one (Spence, 2001). If the scatterplot contains too many observations the view becomes cluttered, this can be solved by using a hexagon bin plot, which is created by overlaying the scatterplot with a hexagon grid and then creating filled hexagon cells with size proportionate to the number of dots inside them (Slocum et al., 2010).

By using two adjacent histograms two variables can easily be compared (Spence, 2001), this can be further enhanced by adding a slider underneath the histograms to dynamically adjust what selected attributes are to be highlighted in each histogram (see figure 2).

Trivariate data and Hypervariate data

Since Spence (2001) claims that it is appropriate to use visualization techniques meant for hypervariate data when visualizing trivariate data these two will be explained in the same paragraph.

Trivariate data is associated with three attributes, and hypervariate data is any data with more than three attributes (Spence, 2001).

Data with this amount of attributes is difficult to visualize in a way that a user without prior knowledge of how the different visualization techniques work can see relations between the attributes. Since the data can be three (or more) dimensional, the greatest challenge is to plot a three dimensional space onto a two dimensional view. There are, however, a few ways of doing this.

By creating a scatterplot matrix three or more attributes can be visualized in relation to each other (Slocum et al., 2010). The matrix consists of the attributes lined up diagonally and all attribute relations plotted on each side of the line (see figure 3).

The parallel coordinate plot is another way of visualizing data with many attributes; this technique is mostly suitable for hypervariate data but can also be used for trivariate data (Slocum et al., 2010). A parallel coordinate plot is created by assigning each attribute to a vertical line and placing these lines parallel to each other along one axis, connecting each observation with lines (see Figure 4). This creates an intricate web of lines that is, unless the user is specially trained, hard to interpret.

![Parallel coordinate plot, Fisher’s Iris data](http://en.wikipedia.org/wiki/Parallel_coordinates)


**Table lens visualization**

The table lens visualization (Rao & Card, 1994) allows the user to gain a graphical view of an attribute table by turning every column of the table into a histogram. Since all the columns are represented by histograms it makes for an easier interpreted table.

Ordering the data by a specific attribute can reveal patterns that would have been difficult to find when looking at the table as letters and numbers. The table lens visualization is used for attribute tables containing large amount of data. This method has the ability of allowing the user to select certain parts of the histograms which looks interesting and zooming in on it so that values can be more easily viewed.
Attributes can also be combined in order to create one separate histogram depicting the relation between the two values chosen. Figure 5 is an example of a table lens visualization where the column “Avg” has been created by dividing values from “Hits” with the “At Bats” column. By using this type of analysis it is easier to identify interesting features in the dataset.


**Mosaic display**

When visualizing data in a mosaic display the data is organized in cells whose height and width represent the attributes value, this creates a mosaic of tiles for each combination of attributes where the area of the tile is proportionate to the frequency (Friendly, 2002).

This type of visualization can be used to visualize bivariate data by assigning one attribute to height and one attribute to width, e.g. using height to visualize eye colour and width to visualize hair colour. It can be expanded with more attributes by subdividing the tiles so that the attributes eye colour, hair colour and sex are visualized at the same time. See figure 6 for a comparison of bivariate data and trivariate data visualized in a mosaic display.
When visualizing hypervariate data the mosaic display can be hard to interpret, this can be countered by increasing the spacing between the tiles to differentiate the tiles from each other (Friendly, 2002).

Network map

Network data such as data on telephone calls between people is best visualized through a node-link map (Spence, 2001). In the example of the telephone calls the map visualizes the people as nodes and the relation between them as links. To show a certain frequency of an attribute e.g. number of calls made, the links can be made thicker proportionate to the chosen attribute.

By separating the network into sub networks it becomes more evident what parts of the network communicate with each other and between what parts no communication took place at all, something that would have been much harder to see if the data was represented in an attribute table alone.

Isopleth map

An isopleth map is created by interpolating the values of isolines, created by connecting points of equal value, to create a smooth surface (Slocum et al., 2010) where concentrations of values are easily distinguished.

This type of visualization is appropriate when the data changes gradually over an area, e.g. the concentration of hospital beds are not restricted by bounded areas but can be continuously mapped over the whole floor. This would create a map where the
attributes of the isolines are defined by the density of points, specified to be considered a group if they are within a specific distance of each other.

**Dot mapping**

Dot maps are used for visualizing occurrences of a phenomenon in order to distinguish underlying patterns that would not otherwise be visible (Slocum et al., 2010). By assigning a set value of an attribute to the dots it is easier to identify specific patterns of how the data is distributed. This technique can be used for example when visualizing population, by assigning one dot per person it is easy to distinguish which areas have the largest population density.

Since datasets can have large amount of data that is to be visualized through a dot map it is not the purpose of dot maps to show the actual count of occurrences but rather to make it easier to distinguish patterns, e.g. which areas have the largest concentration of population (Kraak & Ormeling, 2010).

**Proportional symbol map**

Proportional symbol maps are similar to dot maps but differ in the way that the points in a proportional symbol map are assigned different sizes depending on the amount of data that occurs at the point location (Slocum et al., 2010) (see figure 7). The data visualized with the proportional symbol method is raw data values in opposite to choropleth maps where the data has to be standardized before it can be used.

This makes proportional symbol maps most useful when visualizing raw totals of an attribute in an area where the purpose is to show the magnitude of occurrences, in order to easily compare the different magnitudes of occurrences (Kraak & Ormeling, 2010), and pattern recognition is not of the essence.

![Proportional Symbol Map of Internet Users in 2004 Europe](http://www.geog.ucsb.edu/~jeff/gis/proportional_symbols.html)
**Choropleth map**

When visualizing values collected for whole areas with set boundaries the choropleth map is most suitable (Slocum et al., 2010), it is created by classifying the data into appropriate class ranges and applying those colours to the area. There are, however, choropleth maps with boundaries generated from the occurrences of values called a dasymetric map (Kraak & Ormeling, 2010).

It is important to remember that the choropleth map does not depict variations of data within the area but is often a display of a ratio between attributes, such as the ratio between population and area. Such data standardization has to be made in order to visualize a fair comparison between areas, independent of size (Slocum et al., 2010).
2.1.2 Visualizing temporal data

Traditionally when visualizing data to identify certain patterns by relating data attributes to each other the data considered is only collected at a snapshot in time, this is called static representations (Duckham & Worboy, 2004). Since data can change over time certain patterns may be impossible to see if only viewed from one point in time. This is where introducing a new variable, time, is needed to get a deeper understanding of the phenomenon and how it develops.

The first example of visualization of temporal data dates back to 1869, when Charles Joseph Minard visualized Napoleon’s march towards and back from Moscow (see figure 8). This map is still considered to be one of the best (Kraak & Ormeling, 2010) visualization of temporal data. By using the thickness of the line Minard visualizes the size of the army, the colours of the line shows the heading (grey shows the movements towards Moscow, black shows the retreat). Included is also a representation of temperatures during retreat, showing a clear connection between low temperatures and loss of men. This type of temporal visualization is called a single static map (Menno-Jan, 2003).

![Figure 8. Minard's visualization of Napoleon's march towards and back from Moscow Reprinted from “Cartography Visualization of Spatial Data” by Kraak, M.J., Ormeling, F. (2010). Harlow: Pearson Education Limited. Reprinted with permission.](image-url)
There are two additional ways of visualizing temporal data: small multiple maps and animation (Menno-Jan, 2003). Mapping time by the use of small multiple maps is done by using a sequence of static maps, each showing the progression of the phenomenon that is to be visualized.

The advantage of using small multiple maps is that the user is not overwhelmed by seeing data from all points in time simultaneously (Menno-Jan, 2003), as is the case with a single static map. The small multiple maps technique is limited in its ability to display longer sequences of pictures since it is difficult to comprehend any patterns if the amount of pictures is too large (Kraak & Ormeling, 2010).

By animating the temporal data, change can be visualized over a longer period of time and by adding interactivity, such as allowing the user to pause, play, rewind and fast-forward patterns are easier to recognize (Slocum et al., 2010), e.g. recognizing that traffic along a road increases during weekends or weekdays.

Cartographic animation can be divided in two groups: temporal animations and non-temporal animations (Kraak & Ormeling, 2010). Temporal animations have a direct connection between world time and display time e.g. visualizing the change of a coastline from the dark ages to the present time while non-temporal animations do not have a connection between display time and world time. Non-temporal animations can consist of an animation of a choropleth map where different areas are highlighted to display the highest and lowest values respectively.

Animations of change can be done in different ways (Slocum et al., 2010), if the purpose of the animation is to visualize change in position over time a point can be used that moves through the map as time progresses. For animating change in attributes a choropleth map can be used where colours gradually change as you move further through the animation.

Kraak & Ormeling (2010) also mentions two alternative ways of visualizing temporal data, the space-time cube (see figure 9) and a travel cartogram (see figure 10). The space-time cube represents both time space and geographical space by allowing the bottom of the cube to represent the geographical space while time space is visualized as a path moving up along the time axis. The travel cartogram has distorted the geographical space and placed all areas in relation to a specified point where distance between the areas and the point is based on the travel time.
Even though the space-time cube and the travel cartogram visualize the time space they lack in readability and change is not easily perceived.

**2.1.3 Designing an easy to interpret visualization**

When designing an interface for users, Ware (2013) claims that the graphic representation of data should be designed in a way that takes into account the capabilities of the human mind so that important patterns and data elements are easily distinguished.

If confronted with a large set of data, visualized by points, it can easily become overwhelming to the user. This can be solved by making data that is more important to the specific analysis performed more visually distinct, if the data sought is a relatively small quantity of the entire data set this data can be made more visible by using motion or marking the point with a blinking light (Ware, 2013).

Ware (2013) also claims that, in theory, using grayscale sequences should make it easier to distinguish forms but studies have shown that using a colour sequence results in lower values of erroneous readings of values from the key. A colour sequence using distinctive set steps makes it easier to interpret separate values than a smooth colour sequence.
When using symbols to mark some specific phenomena it is important to make them distinct from the background and from other symbols present in the view. To make the symbols stand out even more a visualization of that symbol should be used that is unique, e.g. it can be the only thing coloured on a map that is black and white.

Kraak & Ormeling (2010) describes three parts of designing an interface that helps in making the data exploration process easier for the user. When confronted with the dataset for the first time the visualization should start with a basic overview, where all parts of the data is visible. By then allowing the user to zoom and filter the attributes in a specific area of interest the user gets a better view of the phenomenon. First now the user is allowed to get details about the data on demand by clicking on them.

2.2 Indoor positioning systems

The ability to navigate with the help of Global Positioning System (GPS) is very useful for finding your position or navigating to places that are unknown to you, which is easily done in an outdoor environment. When faced with an indoor environment, GPS cannot be used since it needs the receiver to be in line-of-sight from the satellites. This is because roofs and walls scatter the signals which results in a precision that is too low for a useful positioning (Schutzberg, 2013).

This is where other solutions to indoor positioning have to be explored, such as Bluetooth, Wi-Fi, RFID or IR (Ngan et al., 2012). All of these solutions are widely available and since the solution should have as little impact as possible on the existing infrastructure of the building this study was focused mostly on indoor positioning systems (from here on referred to as IPS) involving Wi-Fi since this is present in almost every public building.

The purpose of this section is to explore the different solutions for tracking the spatial location of hospital equipment by the use of IPS. Different solutions to IPS will be presented and advantages and disadvantages of those will be explored in order to find a solution that is easy to deploy without a too significant impact on the existing infrastructure.

2.2.1 The different solutions to IPS

Sensor-based IPS

Sensor based IPS involve a large number of sensors which have to be deployed at a lot of places to be able to get correct positions of the tags. A proximity based positioning is
used which is based around tags coming in close range of the sensors, and then the position of the tag is mapped to that location. The precision of this type of IPS depends on the density of sensors, which means that the number of sensors used correlates to higher precision (Vera, Ochoa & Aldunate, 2010).

There are three types of sensor-based IPS; Infrared, RFID (Remote Field Identifier) and Bluetooth. Infrared is the oldest one and it requires the tags to be in line-of-sight and close proximity to the sensor to be read (Ngan et al., 2012). Since both RFID and Bluetooth use radio waves instead of light they do not have to be in line-of-sight and the distance to the sensor can be greater.

**Vision analysis**

Vision analysis use cameras deployed in the human visible area to identify and track objects (Vera et al., 2010). Tracking positions with a video-based system can be done in two ways (Schiller & Voisard, 2004): with cameras placed in the building or with a camera positioned on the object that is to be positioned. By using tags with a specified pattern of colours the cameras can easily recognize them and since the size of the tag is known the system can then calculate the distance from the camera by looking at the size of the tag. When the tag is seen by two cameras at the same time the angles from the cameras to the tag can be determined and the position of the tag can be triangulated.

The other way of tracking positions with a video-based system is to put the camera on the object that is to be positioned. The camera then searches for the same type of tags used in the other method, only this time they are placed on the walls and have a known position. When the camera detects two tags it can calculate the objects position.

**Ultrasonic-based**

The ultrasonic-based IPS uses both radio waves and ultrasonic waves. It uses the difference in speed of the radio frequency and ultrasonic signals to calculate the position of the object (Woo et al., 2010). This positioning system, similar to the video-based positioning, can also be achieved in two ways (Schiller & Voisard, 2004), with the transmitter either positioned on the object to be tracked or positioned in the building.

A system that has the transmitters positioned on the object is called the Active Bat, the object to be tracked is equipped with a badge that sends an ultrasound pulse when told to do so by the server via radio. The receivers are positioned in a raster grid of 1,2m in the ceiling and when they receive a signal from the badge they send the information to a server that calculates its position.
Transmitters can also be positioned in the building, sending ultrasound pulses to a receiver placed on the object that is to be positioned. The transmitters also send out a radio signal that allows the receiver to calculate its position directly without the need for a server. This type of system is known as the Cricket system.

**Wi-Fi-based**

There are a number of Wi-Fi-based solutions (see figure 11) and they are either based on calculating the distance to the receiver by using the RSS (Received Signal Strength) as a location tag or using the fact that signals travel at a fixed speed to calculate the distance to the access point (hereon referred to as AP).

Determining the location of the receiver can be done in several ways. Cell-ID matches the target with the AP it is connected to and gives a rough estimate of where the receiver is. It is the simplest technique but it has the lowest precision (Woo et al., 2010). This technique does not use the RSS but simply states that it is in the vicinity of an AP.
Another technique that also disregards the RSS values is the Time Of Arrival (TOA) technique, it measures the time it takes for the receiver to receive a signal from an AP and calculates the distance. In order to get a position it triangulates the position of the receiver by the use of three APs. (Woo et al., 2010). A development of TOA is the Time Difference of Arrival (TDOA) technique. It functions similarly to TOA but is measures the time difference between two signals and uses that information to calculate a position.

A position can also be calculated by using the angle to the receiver from the transmitter, this technique is called Angle of Arrival (AOA). To get a position estimate this technique needs at least two directions from fixed points (Schiller & Voisard, 2004). This method has problems with precision when the receiver is located far from the transmitter (Vera et al., 2010).

By using the RSS values from all available APs in a building the fingerprint method can calculate a position. The fingerprint method is divided in an offline- and an online phase. Since the strength of the signal decays as it gets further away from the AP (Jan, Hsu & Tsai, 2010), unique patterns of RSS values are created that can be interpolated and plotted in a raster map (see figure 12). This is done during the offline phase where sample points, called fingerprints, are measured throughout the room and saved in a database entry containing the coordinates and RSS from different APs (Kjærgaard, 2010).

In the online phase the user creates their own fingerprint, which is then compared to the fingerprints in the database. By the use of a matching algorithm the most similar set in the database is used to extrapolate the user’s position (Jan et al., 2010). According to research done by Schiller & Voisard (2004) an IPS using the fingerprint method can reach a precision of up to 3 m, this precision is reached by measuring every point in four different directions in order to get a large amount of data for every point.
3. Method

In order to develop an indoor positioning system that tracks hospital equipment and visualizes their positions in a web-based GIS system, a study of previous research was performed exploring the different techniques there are for positioning indoors as well as different ways of visualizing spatial and statistical data. A case study was then performed on two floors in the IT-department of the hospital in Gävle with the purpose of evaluating the precision of positioning during different scenarios.

By using the positions recorded by the IPS in a web-based GIS, different visualizations were created with inspiration from the study on previous research, such as how to design the view in order to make it easier for the user to comprehend large data sets (Kraak & Ormeling, 2010; Ware, 2013). This was done with the purpose of exploring what problems can be solved by visualizing the data using different techniques.

When the study on previous research was completed it was decided that an indoor positioning system based on the fingerprint method was most suitable for the hospital environment. A company called SenionLab AB was contacted that supplied an easy to use application, called SLIndoorLocation, which works with any android smartphone containing the required sensors (Wi-Fi, accelerometer and magnetometer). This positioning application cannot be used by any iPhone or Windows phone since they do not allow users to develop applications that scan Wi-Fi channels. This application was used to perform the site survey as well as the actual positioning.

The application developed by SenionLab AB use a technique called sensor fusion (D. Törnqvist, personal communication, May 15, 2013) which use all available sensors in a smartphone and combine their readings to improve positioning precision. In this case study the smartphone Samsung Galaxy S3 was used and the sensors available were: magnetometer, accelerometer, gyroscope, pressure sensor and Wi-Fi. The magnetometer and accelerometer are used to provide a direction and a velocity, the gyroscope is used in combination with the magnetometer to increase the direction precision and the pressure sensor is used to detect when the user changes floor.

When the positioning was done a web-based GIS system called CRISP, developed by Invotech Solutions, was used to visualize the positions and to test different ways of visualizing the statistical data extrapolated from the positions and timestamps recorded.
3.1 The previous research

The literature used in the study of previous research consisted of books, scientific articles and journals found via the library database “Discovery” available at the University of Gävle. The study on visualization techniques was used as a basis to answer the research question: “What problems can be solved by visualizing the movement of equipment in a web-based GIS?”.

3.2 Site surveying

Before deploying the positioning system in a large scale for the entire hospital facility, the precision had to be tested in a small laboratory environment. In order for the indoor positioning to work the fingerprints had to be collected for the area that is to be used for testing the positioning system. For this purpose floors 7 and 8 of building 38 were chosen since this is the IT department’s headquarters.

Before the actual surveying could take place CAD drawings of the floors were obtained from the county hospital real estate register. These drawings were then imported in ArcGIS and georeferenced, in order to ease the implementation of the positions recorded by the system into the web-based GIS since WGS84 coordinates are universal. The positioning can be done by using only a local coordinate system but this can cause problems when visualizing the positions recorded by the system in a third party application. Since the position of origo (0,0) can be hard to match exactly in both systems a faulty placement can cause position displacement.

With the georeferencing completed the maps were put on an ArcGIS server connected to CRISP. This allowed the CRISP platform to visualize the drawings of building 38 in its correct position in a Google Maps view. The maps were also sent to SenionLab AB that implemented them in their positioning application, called SLIndoorLocation, adding routes used for the surveying of fingerprints (see figure 13).
The surveying was performed by choosing each subpath in order from 1 to 6 and following the route presented by the app while holding the smartphone at hip height and walking in a normal walking pace. To ensure that the data collected could be properly processed all routes were surveyed twice.

After walking the routes the survey could be ranked from “Very Poor” to “Very Well”. This was chosen based on how well the route was followed, since SenionLab did not know how furniture was positioned when they created the routes it might have been necessary to deviate from the course sometimes. When a rank had been chosen additional comments could be entered to explain why it had been graded that way, e.g. if you took a wrong turn somewhere and had deviated from the route the route would have gotten a lower grade. This happened the first time surveying when the change of floor from floor 7 to floor 8 was not detected, causing the subpath of floor 8 to contain data from floor 7. By using the ranking system and comments the developers at SenionLab could be made aware of this flaw and therefore skip the processing of that particular survey.

The survey process had to be done two times. This was because after the data had been processed for the first survey and the positioning was tested it had too low precision as well as it jumped between floors. The reason for this was supposedly because data from the erroneous survey, when floor 8 was surveyed on the floor 7 subpath, was mistakenly taken in to account when processing the data. After doing a second survey, this time making sure that all the subpaths were logged correctly, the positioning improved drastically.
3.3 Evaluating the positioning performance

When data from the survey had been processed by SenionLab, the application was updated with the ability to navigate through floors 7 and 8. All the rooms were not included in the survey since SenionLab did not feel it was necessary to use more than two rooms on floor 7 and the hallways on both floors to get an accurate assumption of the precision. See figure 14 for an example of three routes on floor 7.

![Figure 14. Three routes on floor 7. The route to follow is the red line that begins at the blue circle and ends at the big red dot. The areas inside the building have been coloured white to enhance where the route is.](image)

To test how the system performs a number of tests were done where performance was measured while walking at a normal pace, running and placing the smartphone on a scooter (to simulate a moving hospital bed). Under these three different circumstances tests were made as to how the system handles changing of rooms, changing floors and moving through the hallway.

One initial test was performed where the smartphone was positioned at different heights; near ground, waist height and close to the ceiling. This proved to make no significant difference in positioning precision; therefore the tests recorded in this study are all made at the same height.

The performance was measured as how well the position given by the application correlated with the actual position of the smartphone. To get a better view of this the actual position was drawn on a map while a screenshot of the application was taken and saved on the phone. These points were then digitized and compared in ArcMap, since it
is difficult to know exactly which point in CRISP belongs to which point on the paper map.

The performance of the positioning while the smartphone was placed on a scooter could not be measured by taking notes of positions on a paper map since the screen could not be seen while on the scooter. Instead, the performance was measured by how the route looked when visualized in the web-based GIS. Since the accelerometer did not give any measurements while on the scooter, because the smartphone remained vertically still during the whole measurement, the readings from that test were based only on the fingerprinting positioning.

To test how the system performs in case one of the APs breaks down some tests were also conducted when one of the APs was shut down. When the AP was offline the positioning was tested while walking from “Start” to “End” and back again.

3.4 Visualizing positions in the web-based GIS

The positions recorded by the SLIndoorLocation application was automatically uploaded to the CRISP server and visualized as points on the georeferenced CAD drawings of building 38.

The CRISP platform is a highly customizable tool that allows the user to create its own dashboards where content easily can be drawn on to the view and configured according to the demands and needs of the user. Figure 15 shows what an empty dashboard looks like, notice the small buttons at the top left of the picture, these are the different “Gadgets” the user can put on the dashboard. These gadgets can be configured by the user to display whatever parts of the dataset is required, such as choosing to display only the positions containing the attribute value “7” of the attribute “Plan” in the dashboard for floor 7.
The CRISP system has many users from different parts of the world so therefore all dashboards created related to the indoor positioning project were placed in the same workgroup, called PositionLG. This allowed for the displaying of data for one floor in several different views on one dashboard, and data for another floor or statistics for the whole building on another dashboard. See figure 16 for an example of a view of different dashboards and how easy it is to switch between them to get information about different floors, this is an administrative view; the dashboard list shown to the left is not seen by regular users.

Dashboards can be filled with as many gadgets as needed, and they can all display different kinds of data such as positions on maps, animations, statistical visualizations and attribute tables. By using these visualizations three different dashboards were created; two containing information for floor 7 and 8 respectively, and one for displaying a summary of the positions of the equipment to allow the user to easily choose the correct map when searching for a specific bed.

The positioning data used to represent the different beds, as seen in the table of Figure 16, was the data collected during the performance testing. The collected data was split up in eight different segments and given an attribute called “Enhet”, each segment was then given the attribute 1, 2, 3 etc., to make eight different routes corresponding to eight different beds. This was done to make it easier to experiment with the views and make the visualizations as close as possible to a real life situation where more beds than one would be used.
4. Result

The result section will be divided in two parts. The first part will answer the research question of how the tracking of hospital equipment with the fingerprint method performs. The results are based on the case study performed on floors 7 and 8 of building 38, hospital of Gävle.

The second part will answer the research questions; “How can the positions of hospital beds be visualized in a web-based GIS”, the results are based on the study on visualization techniques. The research question: “What problems can be solved by visualizing the movement of equipment in a web-based GIS?” will be answered as a part of the discussion where different applications of this kind of system will be discussed.

4.1 Evaluation of positioning performance

In order to measure the precision of the system, screen captures of the application were made at specific positions and at the same time the actual positions were drawn on paper maps. These points were then digitized in ArcMap where the measuring tool was used to measure the distance between the actual position and the position recorded by the application.

Table 1 shows the precision measured in ArcMap and the points of measurement number 1-9 are visualized in figure 17, the rest of the points are available in appendix 1. For each point there are two symbols, a circle for the actual position and a square for the position recorded by the application. The positions “Start”, “End” and “Common room” are also shown on the map to better explain where some of the tests were taken place.

<table>
<thead>
<tr>
<th>Measurements taken on point</th>
<th>Specific activity</th>
<th>Floor</th>
<th>Approximate precision (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stood still</td>
<td>7</td>
<td>1,5</td>
</tr>
<tr>
<td>2</td>
<td>Stood still</td>
<td>7</td>
<td>28,5</td>
</tr>
<tr>
<td>3</td>
<td>Ran from Start -&gt; End -&gt; point 3</td>
<td>7</td>
<td>2,3</td>
</tr>
<tr>
<td>4</td>
<td>Ran from point 1 -&gt; point 4</td>
<td>7</td>
<td>3,2</td>
</tr>
<tr>
<td>5</td>
<td>Walked from point 1 -&gt; point 5</td>
<td>7</td>
<td>1,2</td>
</tr>
<tr>
<td>6</td>
<td>Walked from point 5 -&gt; point 6</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Ran from Start -&gt; through the common room -&gt; End -&gt; point 7</td>
<td>7</td>
<td>3,2</td>
</tr>
<tr>
<td>8</td>
<td>Stood still</td>
<td>7</td>
<td>2,5</td>
</tr>
<tr>
<td>9</td>
<td>Stood still in middle of staircase</td>
<td>Staircase</td>
<td>6,6</td>
</tr>
<tr>
<td>10</td>
<td>Stood still right after changing floor</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>Stood still</td>
<td>8</td>
<td>8,2</td>
</tr>
<tr>
<td>12</td>
<td>Walked from Start -&gt; common room</td>
<td>8</td>
<td>0,9</td>
</tr>
<tr>
<td>13</td>
<td>Ran from common room -&gt; End</td>
<td>8</td>
<td>0,5</td>
</tr>
<tr>
<td>14</td>
<td>Walked from End</td>
<td>8</td>
<td>5,25</td>
</tr>
</tbody>
</table>

Average precision 5,13
Average precision when disregarding point 2 3,3
The first point was measured when standing still in the middle of the hallway and allowing the application to get as good position as possible, since the smartphone takes 4 seconds to scan all available Wi-Fi channels it took 8 seconds for two scans to get a good positioning.

The second point was measured from the beginning of the hallway also this time standing still and allowing the application to perform several scans. The precision achieved was approximately 28.5m, the cause of this is probably that this is the starting position of the surveying route and therefore this point lacks unique values. If the user moves towards the position indicated by the application it quickly catches up and obtains a better position fix.

Point 3 was measured by running from “Start” to “End” and then to point 3, the positions visualized on the map was measured after the application was allowed to perform one Wi-Fi scan.

Point 4 was measured by running from point 1, also here allowing the application one scan before recording the position. Both point 5 and 6 were measured after walking a short distance. Point 7 was measured after running a longer distance as well as running a more complicated route, running in to the common room and turning around to run out from there again. Points 8-10 are all part of the changing floor sequence, this is why the precision of point 9 and 10 is low.
Point 11 also has low precision; probably due to the same reasons as point 2. The precision of point 12 and 13 is very high; the reason for this can be that signals from floors above and below as well as floor 8 are received very well right here. Point 14 was measured by walking from the end and then standing still to allow the application to scan several times, the precision measured was relatively low and this can be because there are a lot of walls and bathrooms obstructing the signal to this point.

Tests were also performed on how the positioning performed while placing the smartphone on a scooter. This was done to simulate a moving hospital bed. Since the smartphone was positioned on the scooter and the positions were logged while moving no notes could be taken on a paper map to compare the actual position with the position measured by the application. Instead, the route was logged and is available to view in the animation view of CRISP. Figure 18 shows the route recorded by the application, the route was recorded from the point “Start” to the point “End” and then back to “Start”.

Since the smartphone was placed on a scooter the accelerometer could provide no data, which resulted in the positioning application being forced to rely only on data from the Wi-Fi signals. As shown in figure 17 this resulted in a much lower precision where the southern hallway was completely ignored. This can be because the smartphone only scans Wi-Fi channels every 4 seconds, and the turn from “End” to back to “Start” was very quick, had the scooter been moving slower a greater precision could have been achieved.
When one of the APs was taken offline the precision did not change noticeably, this was probably because the system still had enough data from APs on the surrounding floors as well as it still had data on in which direction the user was moving and at what speed it was moving.

4.2 Visualizing positions in the web-based GIS

When designing the layout of the different dashboards the ideas of Kraak & Ormeling (2010) were used. They claimed that to make an interface easy to interpret the user should be confronted with a basic overview where all available data is shown.

Therefore, the system was designed so that the first view shown to the user is a list comprised of all available equipment and their whereabouts. Figure 19 shows the first view where a list displays the current positions for all equipment. This was done so that the user easily can find the equipment they are looking for and open the correct dashboard, when the system goes full scale it is not feasible for the user to check 14 different dashboards of floors in search of one hospital bed.

![Figure 19. The first view of positioning system. The user is shown a list of the tracked equipment and its position, from here it is easy to choose the correct dashboard for additional information on the movements of the unit of interest.](image)

When the equipment looked for is found the user can then easily choose the dashboard corresponding to that floor. The dashboards are all designed in the same way; four views show: the current whereabouts of every piece of equipment on that floor, the movements of the equipment on that floor the last 24 hours, a bar chart showing in which rooms the beds are located and a heat (isopleth) map to display the areas that have the highest concentration of beds over the last 24 hours.
Since Ware (2013) claimed that a user easily is overwhelmed if confronted with a large set of points, only the current positions of the equipment is shown in the first view. If the user then wants to know more about a specific bed's whereabouts over a period of time the animation view can be used to further explore the data.

The animation was chosen to represent the movement of the equipment instead of viewing all positions measured as point objects since this would overwhelm the user with too much data and make it hard to comprehend in which point in time the specific point was recorded. Since the animation is interactive i.e., allowing the user to move a slider to fast-forward, rewind, pause or play, it is easy for the user to see where the equipment has travelled and at what period in time it was at a specific position. Slocum et al. (2010) argues that by combining animated data with the ability to interactively move through it patterns are easier to recognize, therefore an interactive animation of the positions of the equipment was chosen. Figure 20 shows a snapshot from an animation of bed 6 where the position of the bed at a specific point in time is easily recognized.

![Figure 20](image-url) A snapshot from the animation of the movements of bed 6. Notice the slider which provides interactivity as well as the timestamp which allows the user to identify at which point in time the movement occurred.

The two bottom views (See figure 21) were designed to provide the user with useful statistics corresponding to the specific floor. By using a bar chart and a heat map the flow of beds through the floor can be analysed and this makes it easy to recognize which areas are used the most and which areas could be utilized more efficiently by routing some of the equipment there from the more occupied areas.
The bar chart view provides the opportunity to quickly get an overview of how the rooms of the floor are occupied. By using bars instead of numbers in a table the heights of the bars quickly provide a representative view of how the rooms are occupied in relation to each other, the optimal relation would be one where all bars have the same height e.g., all rooms have an equal amount of usage.

By combining the bar chart view with the heat map it opens up the possibilities for a powerful analysis tool where the flow to and from the rooms can be analysed. Conclusions can be drawn between why a specific room is occupied more often than other rooms, this might be a result from an abnormally high amount of traffic around that room causing nurses to prefer putting beds in that room than having to move through a high amount of traffic that occurs in the hallway at a particular point in time.

The statistical views allow the administrative staff to supervise the workflow and implement changes to make it more efficient. By supervising these two statistical views the administrators can identify a problem, issue a change and follow the effects of the change by looking at how the heat map and bar chart changes. See figure 21 for an example of the statistical views showing data on floor 7.

![Figure 21](image)

Figure 21. The statistical views where bar charts show the number of beds in each room and a heat map that shows the concentration of bed movements. In this example data from floor 8 is included in the bar chart. This is because the statistical visualisation system is not yet fully developed.
5. Discussion and conclusion

This section will be divided in three parts; the first part will discuss the results from the case study on the performance of the positioning system, the second part will be focused on the results of the visualization of positions in CRISP and the third part will consist of a conclusion of how the project went. Every section will end with a discussion of any need for future research and development. The discussion will compare the data collected in the study on previous research with the results of the case study and explanations will be given as to why the results ended up the way they did.

5.1 Evaluation of positioning performance

When the evaluation of the positioning performance was complete it was clear that the precision of the system performed on par with the research conducted by Schiller & Voisard (2004), they showed that a Wi-Fi based IPS using the fingerprint method can reach a precision of 3 m. Since the system they describe in their book use a technique that is more time consuming, by measuring data for each point four times, the system used in this study is a more time efficient method. The sensor fusion technology allows for almost the same precision but with a considerably less training time, which makes the full scale deployment of the system much easier and less troublesome.

The digitizing of the points recorded by the application and the points drawn on the paper map revealed an anomaly in the data. Point number two showed a great deviation in precision compared to the other points recorded; this indicates that more surveys of that particular area are needed to gain an even performance over the whole floor. This is one of the greatest benefits of using the fingerprint method; if areas are found that does not provide high enough precision additional surveys can be done to improve the amount of data the matching algorithm has to work with, increasing the chance of getting a better location estimate.

Having a positioning system with this level of precision opens up for a lot of different usages and applications more than just knowing where the equipment is positioned. Since the positioning is more than just a rough estimate the system can be used to analyse workflow and time of treatments, which allows administrators to incorporate changes to improve efficiency and interactively see how those changes work out.

If the positioning system is to be applicable to the whole hospital where hundreds of beds needs to be tracked a smartphone is not a feasible way to track the equipment.
Instead some sort of tag needs to be developed, it has to have Wi-Fi capabilities and it can contain several different sensors, depending on what type of equipment it is designed to track.

If the tag is designed to track hospital beds, Wi-Fi and accelerometer could be the only necessary components. Since the tests on the scooter simulated how the positioning algorithm functions with only Wi-Fi signals to rely on this is something that is feasible, once the bed comes to a stop it will take only a couple of scans for the positioning precision to reach acceptable levels. The accelerometer itself would not be contributing to the positioning accuracy, since travel speed is useless without direction, but would instead be used to tell the tag when the bed is moving. This allows for the Wi-Fi to be switched off when the bed is stationary, saving a lot of battery. Tags with other sensor can also be designed, such as temperature sensors for tracking medicine carts.

If a tag is found that is relatively cheap and can be developed with different types of sensors the positioning system can be expanded to include other branches of business such as in storerooms where it is necessary to keep track of the inventory.

5.2 Visualization of positions in the web-based GIS

During the study on visualization techniques a lot of ideas on how to visualize the positions of the beds and the statistics belonging to that data were found. Even though designing of the interface was conducted in close contact with the development staff of the CRISP platform, the time it would take to implement the concepts found in the study on previous research proved to be out of the scope for the time given to complete the study.

Therefore, the already available tools of the CRISP platform were used; the regular map view, the animated view, the bar chart and the heat map. The design and layout of the system was created according to the ideas of Ware (2013) and Slocum et al. (2010) and their ideas proved to be of great value since the system records positions as points every second, resulting in a large amount of data that would overwhelm the user if not processed in the right way. By filtering the results and only showing the most recent position, as well as animating the movements to show a point moving around creating a line where it had been the positioning data became easier to grasp.

The idea of using several different views, where the user is first presented with an overview of the data and is then allowed to explore the data more in-depth came from
Kraak & Ormeling (2010). This resulted in a well-structured and easy to understand interface where the different views are easy to switch between.

By visualizing the positions of the equipment in different views a lot of different problems can be solved. Since the system has such a high level of precision it can be used to solve the problem of improper placement of hospital beds. Areas where beds are not allowed can be tagged in the system and an alarm function can be connected to that area, if the bed remains stationary in that area longer than a specific amount of time the system will send out a warning telling the staff to move the bed.

Treatment time can also be shortened e.g., if someone is admitted to the hospital with a broken foot, the hospital bed given to that patient can be tracked and abnormal waiting times can be identified and investigated. This technique of tracking patients as hospital beds in the system can be applied to tracking the spread of diseases inside the hospital. If it is known that one particular disease is spreading on floor 7, a cross check could be done to patients who came to the hospital the last week with these symptoms and then track their movement. By doing this flaws in the disease containment system could be corrected.

If the developers have had more time some other views would have been incorporated as well, based on the ideas found in the study on previous research. The Table lens visualization (Rao & Card, 1994) could have made the first view more interactive, if the system is brought up to a larger scale in the future this view will possibly contain several hundreds of posts and by applying the Table lens visualization technique some interesting analysis of the data could have been made; such as where the majority of the beds are situated throughout the hospital.

By combining the idea of animated maps with some of the more traditional statistical maps such as the choropleth map, the proportional symbol map and the isopleth map (Slocum et al., 2010; Kraak & Ormeling, 2010), changes could be made by the administrative department and then viewed as e.g., an animated heat map that spans from 48 hours before the change was implemented to 48 hours after the change was implemented. This would make it easier to see if the change really did have an effect on the workflow.

Proportional symbols could also have been incorporated in the animations, to emphasize when equipment remained stationary a point could have been shown at that position that grew relative to the time it remained there. This would allow the user to see the stops
the unit made even though the actual stops were missed because of the user fast-forwarding.

An application for smartphones could be developed that focuses on visitors of the hospital. By downloading an app incorporating the CRISP system and the positioning algorithm by SenionLab AB and scanning a Quick Response (QR) code i.e., a two dimensional barcode, the user could be shown the way to the room they are there to visit by the application. Finding your way inside hospital can be difficult sometimes and by supplying a navigation solution the staff does not have to act as guides and can focus more on their job.

5.3 Conclusion

The positioning system developed and deployed during the writing of this thesis is showing a lot of potential. By combining a precision that is on par with other Wi-Fi-based IPS with the powerful web-based GIS CRISP it creates an easy to use system that can be used purely as positioning software but also as an administrative tool. It can supply several ways of analysing workflow and improve the efficiency of a range of different branches of business.

The results shown in this thesis was done in 10 weeks where the development started with the hospital having no positioning system available at all and after that short period of time the hospital had a positioning system, for the testing floors 7 and 8 of building 38, that seamlessly rerouted the positions measured by the system to the CRISP with a precision that is on par with the other systems available. By deploying the system on a larger scale both CRISP and the positioning algorithm will be heavily tailored to function even better with the hospital environment and hopes are that this system will see implications in other fields in the near future.
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