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Indoor location tracking using Signal Strength Pinpoints

Master of Science Thesis

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published:	7/7/2010

Abstract:

There have been many research efforts on location awareness in an indoor environment. Most of them rely on specialized equipment or motion detectors. This research focuses on signal strengths from WiFi transmitters and uses these signal strengths to calibrate virtual pinpoints. A pinpoint is a collection of stored signal strengths over time on a predetermined location. These pinpoints can then be used to situate the surroundings of an environment and determine the current measurement its position by providing the necessary information needed to the tracking methods proposed in this paper.

The experiments of this research are set up with low-end routers in an actual indoor work environment to get the baseline results with less than perfect circumstances. The tracking methods used are based on different locating techniques. These techniques vary from converting signal strength to distance, or using signal strength as a ratio difference between distances, to using signal strength to get the average distance variation in an area. All these techniques allow us to calculate the distance to the locations of the signals. These distances are then converted into a position by calculating the radical centre of the corresponding circles.

The results of this research are satisfactory considering the conditions of the experiments. The precision of the tracking methods is good enough to locate the receiver in a small room for all methods. If the methods are combined the average precision is improved to a minimum distance of about one meter. For another testing purpose the signal strengths are also preset manually, this is done to proof that the tracking methods produce suitable positioning results. Which demonstrates that the methods would be capable of tracking throughout the environment.

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1 Introduction

With outdoor geolocation being widely used and researched, more demand started to rise for indoor localisation. The main difference between them is that outdoor geolocation mainly relies on the Global Positioning System (GPS), which cannot be used for indoor location. Indoor location is being able to located the position of a persons inside a building. With this aspect totally new problems arise with respect to outdoor geolocation.

This paper is part of a larger research, this research is using the IEEE 802.11 standard [3] and its signal strength to find the indoor location of a Wireless Networking capable device. Because most people already have a mobile phone with Wireless Networking abilities, the used device can even be their phone, meaning they do not have to carry around an extra device. This research is done with projects like smart houses for all (sm4all)[19] in mind.

The IEEE 802.11 standard has already been used before and is proven to be capable of finding the distance from an access point in a perfect environment [1,2]. This research on the other hand is going to test it in an actual work environment. The testing environment for this research is the Bernoulli Borg [20], an academic building of the University of Groningen (RUG). Specifically the ground, first and second floor on the left side of the building are used, as can be seen in Figure 7.

The research is split up in two parts between two researchers as can be seen in Figure 1. The researchers are Dennis Kanon with his part of this research in [16] and the researcher from this paper. In this figure a calibration pinpoint is the signal strength data collection in a predefined position on the map. The Features that are devised by [16] are used to extract useful information out of the raw data from the pinpoints.

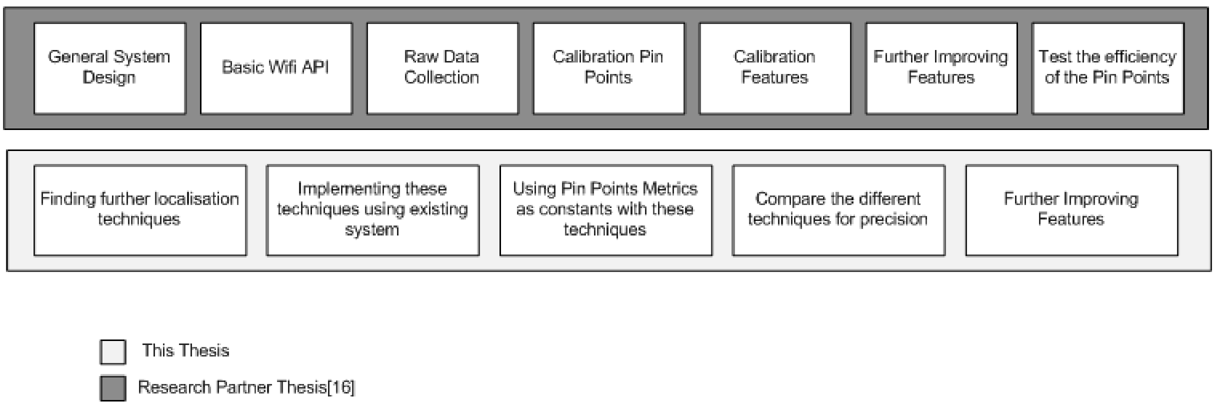

Figure 1: Division of research

The main research questions for the problem statement are:

1) Is it possible by storing measuring values to solve the problem of a buildings layout and interference?
2) To what level is it possible to negate this interference, by using these stored values and the features extracted from them?
3) What other features can one add besides the stored data, to further negate this interference?
4) To what extend can this stored data, features and other features be used to find a device with stored data location (Pin Point) precision?

5) Is it possible to use the stored data in the Calibration Pin Points, Calibration Features and the Mapping of the environment to set up a system capable of device localisation with further precision?
6) What are the steps to set up a system based on pinpoints, and how is it deployed in an existing building?
7) Which tracking method is capable of detecting a position in between the pinpoints?
8) Which features work best for the tracking methods?
9) What is the precision of detecting a position in between the pinpoints?
10) What are the biggest influences on the system?
11) Is it possible to actively track a position in between the pinpoints?

Research questions 5 to 11 are covered by this paper and are all based on and around using the mapping of the environment to locate the exact position inside the building.

With the help of features this paper implements tracking by means of methods that analyse the current measured signal strengths of a wireless networking capable device to determine its position between the pinpoints. These methods could use all the different features as described in [16].

The tracking methods explained in this thesis are based on different locating techniques. These techniques vary from converting signal strength to distance, or using signal strength as a ratio difference between distances, to using signal strength to get the average distance variation in an area.

It might also be interesting to combine the different tracking methods. With the idea of making the new combined method less prone to false results generated by one of the methods. This combined method might also lead to a better overall performance but at the cost of processing power.

These tracking methods are all tested while using single value features and are compared to each other on various aspects. The main tests that are performed are the precision test and the predefined signal strength positioning test.

In section 2 the related work linked to this research is given. The related work presents multiple indoor techniques that have already been researched. In section 3 the approach of this research is given, with the problems of an indoor environment and the start of the tracking method. Section 4 is the implementation and presents the equations that are the essence of the tracking methods together with some pseudo code examples to demonstrate the mechanism of the tracking methods. In section 5 the experimentation is given. This consists of the set-up of the experiment including the equipment needed and the test that are preformed. In section 6 the results of the tests are given. Section 7 discusses the results from section 6 and elaborate on the conditions of the influences on the results. In section 8 the conclusion of this thesis is given. Section 9 takes a look in the future for the further researches that can be done and improvements that will benefit the system build by both research partners.

2 Related Work

In the field of research there have been many efforts that have resulted in different ways of locating devices and people in an indoor environment. The techniques and equipment used for this are very diverse and each have there own advantages and drawbacks. The techniques that are useful to this research are all examined and explained below. Some of them even had a great influence on forming a base for this research.

2.1 RFID Technology

It is possible with the use of Radio Frequency Identification (RFID) tags and receivers to build a locating system in an indoor environment. This is possible because the tags send a signal to the receivers and these can use the signal strength to get an indication of the distance. How this is used is discussed below for the various papers that use this technology.

Lighting control

The first paper [4] that uses the RFID technology is interestingly using it for control of the lighting in a building. The writers tested it in an area that is divided into rooms. Through out the area enough readers are placed to cover all the rooms sufficiently. The readers are placed strategically to receive the signal strength without to much interference from the main influences like multicast, line of sight, etc. They use an algorithm based on a Support Vector Machine (SVM) to create results for all the rooms, for the received signal strength from a RFID tag. With the results per room each room is compared to each other with a round robin system, resulting in a win 3 points a tie 1 point or a lose of 0 points between each room. With these point scores for each room a rank is calculated.

They also analysed the layout of the test area to predict which room a person would move to next. This is done to increase the efficiency of the system and increased precision of the results, but it also resulted in a drawback because if a person moves too fast the system could not keep up and would get stuck in one room. In this case the system would compare the rooms again and if the resulting room is different then the room the system is stuck in, it is changed to the new resulting room.

LANDMARC

LANDMARC (Location Identification based on Dynamic Active RFID Calibration) is the technique that is used in [5] that also uses the RFID technology. It uses a raster of RFID reference tags to fill a room together with RFID readers on each side of the room. This can be seen in Figure 2, an illustration from [5].

If a person wearing an personal RFID tag enters the room the signal strength form this tag and the rasterized reference tags is used in a equation to determine the closeness of the personal tag compared to the other tags. The reference tags with the lowest values are used to calculate the position of the personal tag. This technique leads to a very precise location of the person in a room, but unfortunately interference can have a significant negative affect on the LANDMARC system.

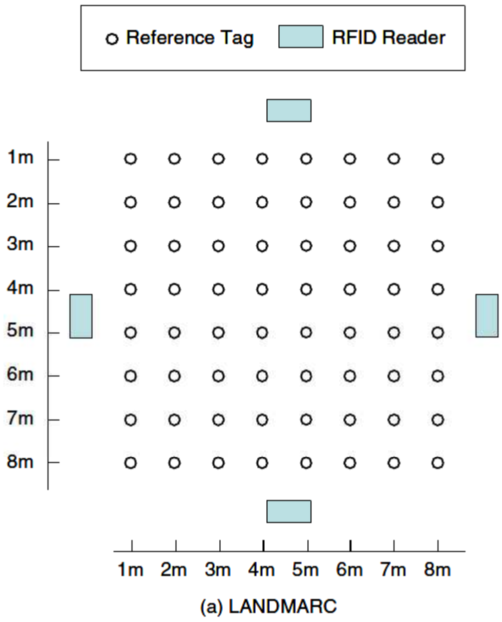

Figure 2: LANDMARC raster layout [5]

FLEXOR
The technique use in [6] is FLEXOR (Flexible Localization EXplOits Rfid) and is an extended version of the LANDMARC system. Instead of creating a raster they create cells. At the centre of these cells a tag is called cell tag and at the border the tags are called boundary tags, the RFID readers are still placed at the same locations. This can be seen in Figure 3, an illustration from [6].

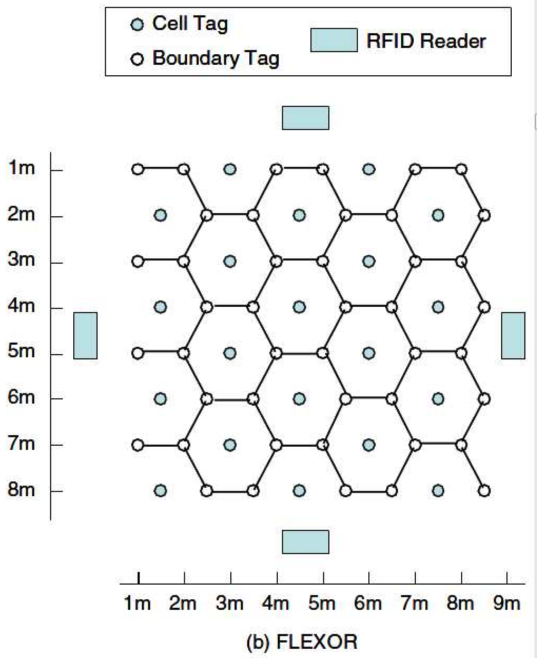

Figure 3: FLEXOR cell layout [6]

FLEXOR can detect in two modes, region mode detection and coordinate mode detection. The region detection is useful if the precise location is not needed the FLEXOR system then uses the cell tags in the same way as the LANDMARC system uses its reference tags and detects which cell tag is closest to the personal tag. The system than knows the area the personal tag is located in.

The coordinate mode is an extension of this and will also check the personal tag with the boundary tags of the indicated resulting cell tag. With this information the system can determine the boundary tag with the lowest value to the personal tag and the following lowest adjacent boundary tag. These and the cell tag can be used to calculate the position of the personal tag with a three nearest neighbour algorithm.

2.2 Received Signal Strength

The Received Signal Strength (RSS) from a transmitter is a nice way to determine the distance from that transmitter because a signal its strength gets weaker the further away the receiver is from the transmitter. If there are object in between the transmitter and receiver, they will also affect the signal. Unfortunately this will cause problems in most cases but it can be useful to detect objects in the area. It is clear that RSS is not only used by the RFID technology, but also in other techniques. A selection of these is presented below.

RSS is being contested and it is said that Link Quality Indicator (LQI) is better, while some show that this not necessarily has to be the case. Like [2], who indicates that signal strength is more useful than some thought and that it can be used very well. LQI indicates the quality of the received signal in percentages instead of the current signal strength.

The method used in [1] is to surround an area with sensors at its border and than measure the signal strength in that area. If an object in their case a person enters the area the signal strength at the different sensors would change. They have tested this in an outside environment and used six sensors to measure the test area, and they divided the area into a raster. With this it is possible to test what the affect of a person is if he is located in each of the raster its sections

A follow up research of this subject was done [10]. Some of these researchers are the same as in [1] but they now focussed on an indoor environment. In this research they did a deep analysis into what the signal is affect by and how it is affected. The objects used ranged from office furniture to people. This indoor system required more training then the outdoor system, mainly because an indoor environment has interference from multicast (reflection of the signal) and such problems.

The way [8] uses RSS is by placing and using multiple transmitters to find a single receiver. All the transmitters send out their signals, which as we know degrades over distance and thus the position of the receiver can be estimated. This sounds good but this system does not work perfectly and requires a lot of calibration and in an indoor environment. This is caused by the line of sight and multi pathing problems.

The writer of [14] called their technique “Radar”, which is not the same as Radar (Radio Detection And Ranging) technology. The “Radar” technique tries to estimate where receivers are in a building by using the signal strengths of the receivers. The main draw back is that the system needs to be recalibrated if the environment changes drastically.

Ad hoc wireless sensor technology is used by [15] in their SpotON system. This system is unique because its can handle fully 3D localisation while the sensors used can be placed randomly and do not need a central controller.

The above mentioned researchers have shown that with the right algorithms and enough calibration RSS can be used for location awareness. If the resulting system is regulated right the resulting location measurement can be very precise.

2.3 Time of Arrival

Time of arrival is used by techniques that measure the distance from a radio transmitter in a different way [7]. These techniques measure the time difference of a message send from the transmitter to the receiver where the time determines the distance because the speed of the signal is known. The radio signal travels with the speed of light and because of this specific hardware is required. For the techniques to work the signal also needs to work with lower frequencies and measuring the time difference with software is also not possible with out the help of dedicated hardware that is precise enough.

The main problem with the techniques that want to use time of arrival based technology is the way it needs to be implemented. Another problem is the synchronisation of the transmitter and the receiver and the bandwidth between them. This because the message that is send from the transmitter to the receiver requires a timestamp which is data that has to be received correctly and needs to be tested. This can be seen in [8].

2.4 Angle of Arrival

Another way to determine the position of a transmitter is with angle of arrival. The angle the transmitter has towards the several emplaced antennas has to be measured to find the position of the transmitter. When two antennas are placed an imaginary line is formed through them. If the transmitter is located on this imaginary line it has angle of 0 degrees, this is called (bore-side). With the transmitter broad side the angle will be 180 degrees.

A third antenna is needed to determine the exact location of the transmitter. This third antenna will add two more angles if it is placed correctly. With all the angles acquired the position of the transmitter can be located. Because with these lines can be formed corresponding to the right angles to the antennas and the intersection of these lines is where the transmitter is located at. A drawback for this technique is that it requires directionally sensitive antennas, which are quite large compared to conventional wireless network antennas.

This technique is used to locate a cell phone in between the cell towers [9] and is also already implemented to find missing persons who still have their cell phone activated.

2.5 Other technologies

There are also other location techniques that do not depend on radio signals. These techniques range from using infrared to cameras for determining the location and will be discussed below.

Active badge location system
In 1992 a system was designed to locate badges carried by the occupants of a building with infrared signals. This system is called active badge location system [12] and it will send out its infrared signal in bursts every time interval. During these bursts a badge needs to reflect the infrared signal, which needs to be received again to indicate that a person is in the room.

The problem with infrared is that it cannot pass through any non-transparent material. This means that any object blocking the infrared signal from reaching the badge or the receiver will be interference. The infrared signal does also not pass through the walls so every room needs to be fitted with infrared transmitters and receivers. The badge needs to always be worn visibly so the infrared signal can reflect from it because even an arm or a piece of clothing could obstruct the signal.

Cricket
Another technique that uses infrared is cricket [13] but this system also uses ultrasound. This technique uses Time Difference of Arrival (TDOA) to determine the distance between multiple transmitters and one receiver to locate the position of the receiver.

But just like the previous technique this one also suffers from the fact that infrared and also ultrasound do not pass through certain objects. Thus every room needs to be fitted with the infrared and ultrasound devices.

NIST smart space system
The NIST smart space system [17] is not only focusing on localisation but has constructed an elaborate network of 280 microphones to extract all the useful information from their receiver data. The main aim of the system is to create a smart room for meetings and the system collects a whopping 200gigibyte of data per hour. This data is used to locate where the people are and keep track of what they said to each other and can be used to extract anything the raw data can portray. There have been multiple localisation systems that use the techniques implemented by the smart space system; one of these is the SLAM system described below.

SLAM
Simultaneous Localisation and Mapping (SLAM) builds a map and will try to locate a camera-based device at the same time. Localisation is based on the data from the camera which needs to be processed this is closely related image recognition in the field of computer vision. This is also often used in the field of robotics who try to implement these techniques if they use a camera as their main sensor as can be seen in [21]. But SLAM is also used to locate people and objects in an indoor environment [22], even though it has a hard time identifying people in the environment and it requires a lot of data processing from all the camera data collected in every room.

Indoor camera phone localisation
Another system that uses cameras is the system that uses camera phones and their GPRS connection seen in [18]. This is also linked to the fields of computer vision and robotics because they use the cameras of the phones as eyes to identify their location. This comes with the problem that the phone needs to be carried with the camera exposed and pointed forwards. Other problems like the duration of the cameras battery and the amount of data that is send via GPRS connection are also considered disadvantages to the system.

2.6 Discussion

The above mentioned papers gave an inside into the accomplishments and techniques in and around the focus of indoor localisation. The techniques and equipment used are very diverse and each have there own advantages and drawbacks. Each of the techniques examined and explained are useful to the research done in this paper even if it just created a mindset.

The RFID based systems was especially useful, because it had a great influence on forming a base for this research. But instead of using RFID tags, virtual software calibrated pinpoints are used as reverences for the environment. The readers they used are represented by the transmitters in this system and the personal tag corresponds to the receiver. But the essence is the same with the difference that this research implements it over an must larger area with multiple rooms, and only uses three transmitter across the entire environment and that the collected values in the pinpoints do not change once created. The positioning of the location in between the tags is not considered, because of the differences between the systems, and thus this system uses different based calculations that better fit its circumstances.

3 Approach

Multiple effects need to be considered for indoor location with signal strengths form WiFi transmitters. These effects and other information that can be useful are described below. Finally the idea of the tracking methods is explained. Mainly what it needs and what kind of positioning techniques are used.

3.1 Signal Strength Over Distance

Signal strength degrades the further it has to travel. But how it behaves exactly is dependent on multiple factors. To give an indication of signal strength degradation a signal strength test has been preformed. This test has been preformed in the actual work environment, in the hallway on the second floor of the Bernoulli Borg. The signal strength is measured between two laptops, one as stationary transmitter and the other slowly moving away as the receiver and nothing in the line of sight between the two.

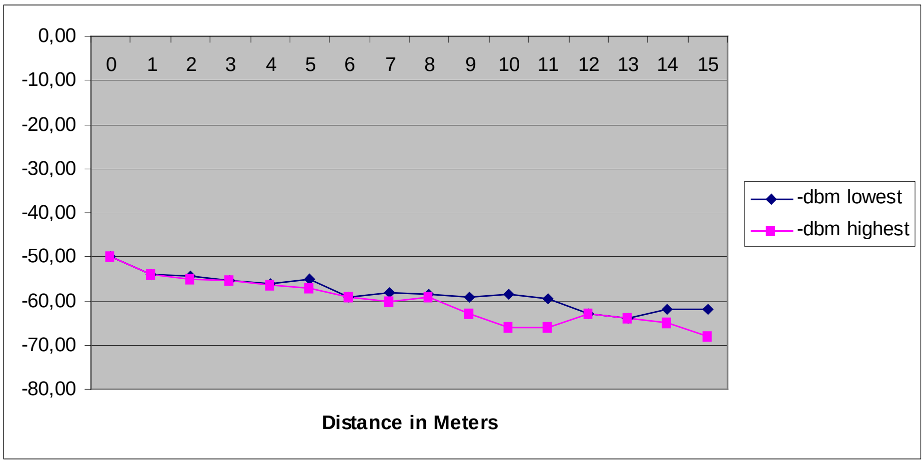

Figure 4: Degradation of signal strength over distance, the blue line presents the lowest loss of the signal and the pink line the highest

Figure 4 shows the results from the signal strength test. The results indicate linear average signal strength degradation over the distance. Although one has to keep in mind that “dbm” has a logarithmic scale. An exception is that in the higher distances the signal strength would sometimes not be picked up for a very short duration. This signal loss indicates almost reaching the maximum distance of the transmitter. The signal fluctuation difference can have many different causes, for instance the walls of the hallway or metallic beams of the building its structure. It is also possible that the transmitter and/or receiver have some irregularities, which may cause some erratic behaviour.

Even though the results of the test show some irregularities, the signal strength degradation per meter is good enough to be used in the experiments of this research. The signal strength variation might even be useful as is considered in the next section that discusses the likely problems to be encountered in a building.

3.2 Problems in a building

The most important problems in respect to this research are the problems created by the building itself. As shown in the section above signal strength degrades fairly linear over distance and will also always do this in a perfect environment. But a building is not a perfect environment because of different kind of line of sight blockers and materials that influence the signal and of course a multi-story building has floors as special line of sight blocker and the with the height difference. These things in a building each have an influence on the strength of the signal in their own way. The problems with the most impact on this research are multicast and line of sight. These two problems are described below in the following two subsections.

3.2.1 Multicast

Multicasting is a very common occurrence in a building. Multicasting is the reflection of a signal of a surface and this reflected signal aids the original signal in its strength or so it appears for the receiver. This reflecting may even have multiple times or on multiple surfaces at the same time. The end result of this is that the receiver has detected the signal with a slight boost. Figure 5 shows the difference between an ideal situation and a real situation. The boost in signal is a real problem for finding the position of the receiver and can lead to incorrect assumptions and will hinder readouts.

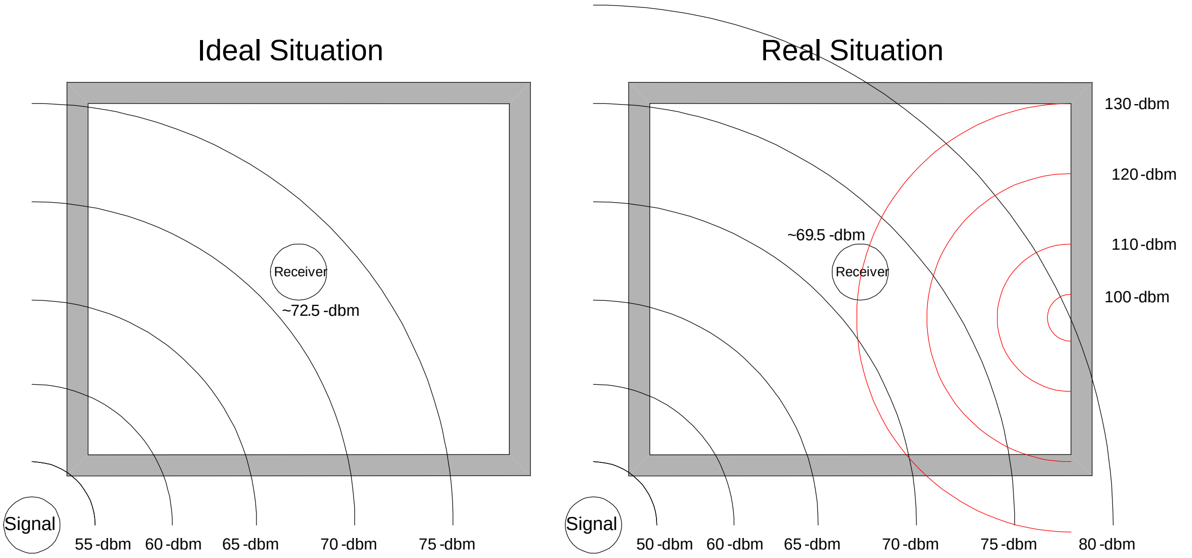

Figure 5: Illustration of the multicast problem. The left image depicts the ideal situation and the right shows a possible realistic scenario.

Actually the problem can be turned into a solution for similar signal strengths at different locations, because even though the signal reflects a surface it will produce a fairly unique measurement at that location. The hypothesis is that if al the signal strengths from the different signal transmitters are measured, that the combined result of these strengths is going to be fairly unique for that position. With this in mind it is believed that the calibration pinpoints will be unique for the positions and will convey into a usable mapping of the environment.

3.2.2 Line of Sight

As mentioned before an indoor environment can have a lot of different “Line of Sight” blockers in between the transmitter and the receiver that will interfere with the signal. Specifically the interference to the signal will be a decrease in signal strength for every object it needs to pass through. This applies to all objects, but the manner of decrease is dependent on the objects material type and the actual distance the signal has to pass trough the object. In an indoor environment the object encountered will be the structure of the building it self like walls, floors, and columns but other things like furniture and even people themselves can also have a negative effect on the signal.

Figure 6 shows the affect walls can have on the signal strength. As can be seen the strength can drop significantly for each wall it passes. This has as effect that it can be difficult to make assumptions and will hinder readouts but can also lead to blind spots where the signal has poor reception or can not be received at all.

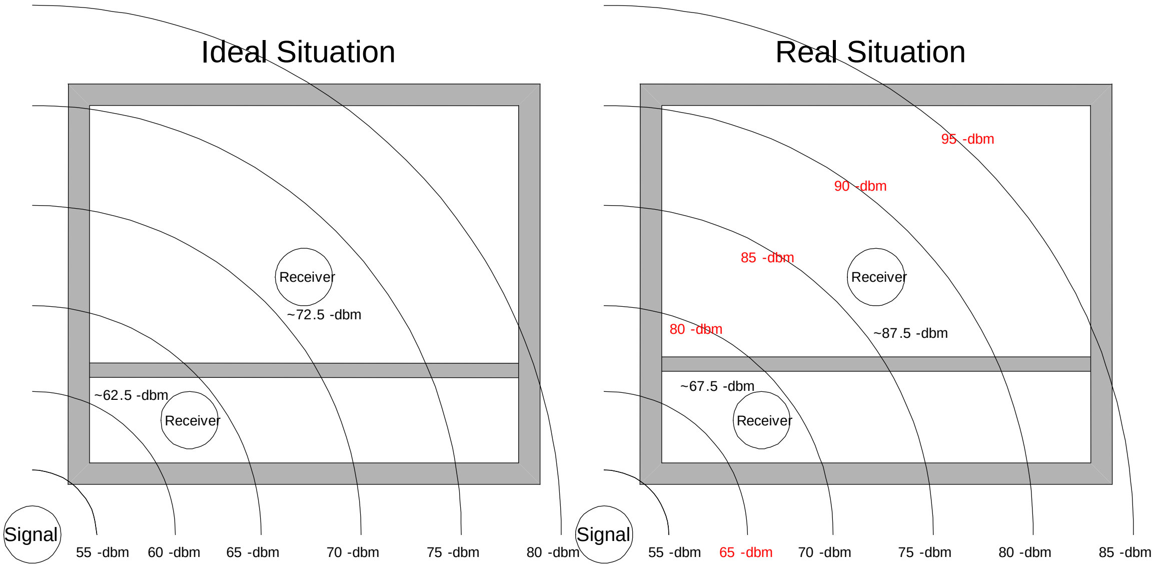

Figure 6: Illustration of the “Line of Sight” problem. The left image depicts the ideal situation and the right shows the affect walls can have on the signal.

This problem really has some negative effects, but just as with the multicast the problem might also be use and thus also has some positive effects. As explained with the multi cast problem the change in signal strength that are caused can be seen more unique values for the calibration pinpoints. The hypothesis is that if al the signal strengths from the different signal transmitters are measured, that the combined result of these strengths is going to be fairly unique for that position. This is because the rooms located in the building will not all be the same and are all in a different angle and position to the transmitters thus will have different combined signal strengths. This will all contribute to the uniqueness of the created pinpoints and will only aid in mapping of the environment. This of course excludes moving objects like people, which only have a negative effect because of the movement factor.

3.3 Calibration Pinpoints

The virtual software defined pinpoints, which are placed in the rooms of the building, and thus create a mapping of the environment, are the cornerstone for the tracking mechanism of this research. These points form calibrated spots, which are used by the features that can extrapolate the data. After this, the received signal from a smart device can be compared with these points or can be tracked in between these points. The main idea behind this is that the environment of the building can be captured by placing the pinpoints throughout the environment. The mapping of the environment is pretty good because every position has a fairly specific signature when 3 or more signal strengths are measured.

The creation of the virtual pinpoints is done by measuring the signal strengths of the transmitters over a certain period of time on the location it needs to capture. The measured values are all stored together with their corresponding time stamps and the graphical location on the map in a file with the name given to that location.

Information that can be used for the positive identification of the earlier mentioned pinpoints would have to be extracted from these points with features. These features can that be used to get an idea of a persons location in between the calibration pinpoints with the use of a tracking method. This technique is researched in this paper and makes use of my research partner (Dennis Kanon) his pinpoint features that are documented in his paper [16].

3.4 Tracking

The main research of this paper is the actual tracking of a Wireless Networking capable device. In this paper tracking methods are devised to be able of producing satisfactory results. These methods will be using calibration pinpoints to get their baring and determine where the current measured signal strength is positioned. To use the raw data from the calibration pinpoints these methods rely on the different pinpoint features researched by [16]. The methods can also be combined to obtain results that are more stable at detecting the location.

3.4.1 The method

The method itself focuses solely on locating the current measurement its position. The information the methods require is the current measured signal strength and the single value signal strength of the pinpoint features and the positions of the signals.

The intensity of the calculation of the method is dependent on the number of pinpoints and the number of signal points. If the number of signal points can just be set to a predetermined collection and just use the number of pinpoints that are beneficial to the process, than the calculation can be tuned to performance as well as precision.

3.4.2 Importance of pinpoints

The pinpoints themselves are most important for the tracking methods because without them only a conversion distance from the current position to the signal transmitters can be calculated. These distances could be accurate if there were no interferences with the signals but in a building this is almost never the case as shown in the previous sections.

The pinpoints kind of represent the layout of the building in signal strengths. This is also why it is important that the pinpoints are placed at strategic locations. Furthermore enough pinpoints need to be placed to ensure a good coverage for the tracking methods to work with.

3.4.3 Use of features

The sort of feature used, can have a significant impact on the tracking method particularly in the way the feature combines the raw data of a pinpoint. The features themselves are thoroughly tested in [16] on closest detection, but how this affects the tracking itself does not have to cohere with the detection. That is why all compatible features need to be considered for the tracking methods. The features might also have to be fine tuned to get the best results for tracking.

3.4.4 Methods of tracking

Tracking is all about determining the actual position at a certain time. There can be serious delays in time because of receiving data to late, intervals between measurements and the actual processing taking to long. These problems can al hinder active tracking.

There are different ways of tracking; it mostly depends on how the available information is used and what is considered viable.

The positioning is done by converting the measured signal strength to distance and using the pinpoint its distance and signal strengths as reference. This can be seen as a straightforward approach that relatively does not have to be CPU (central processing unit) intensive.

Another way to calculate the position is by determining which pinpoints their signal strengths the current measured signal strength is in between per signal. This can than be used as a ratio for the distance difference between the selected pinpoints.

In addition to these it is also possible to take the k-nearest signal strength neighbours of the current measurement. These k-nearest pinpoints signal strength ratios can be combined to determine the current position.

3.4.5 Combining methods

It can also be beneficial to combine the results of the methods this could lead to a more stable result or a better precision. The idea of this combined method is to unite the “best” (closest bunched or smallest distance from the closest pinpoint) results of the different methods with different features. In theory this method should produce the bottom line of distance deviation but it is not guaranteed because the real position is not known and may be closer to a stray value outside the bunch.

4 Implementation

As described earlier the eventual goal is to use a wireless networking capable device to measure the signal strength of various transmitters. During the experiments a laptop is used as substitute for the receiver because this is more useful and easier during testing. In this section of the thesis the actual theory behind each design choice and the decisions and theories of each method used are given. Equations are given of how the tracking methods are implemented in the code of the system.

4.1 Location of Signal Points

The location of the transmitters is very important to this research because all the aspects of the research use the signal strengths from these signal points. The signal points need to be placed so they can all cover the entire environment and in such a way that all positions in the environment have a unique combined signal strength from these transmitters. This means they cannot just all be place in the same room.

The signal points can best be place spread out over the building, forming some kind of triangle also taking in consideration the number of floors that need to be covered. In small buildings it might be best place the signal points near the perimeter of the building, most likely the outer walls. In larger buildings more signal points can be place in between others to correctly locate certain areas and to cover the whole environment, this can be taken into consideration by the system. If the signal points are placed correctly a good mapping of the environment can be made by creating the calibration pinpoints. All the time keeping the problems of a building, like multicasting and line of sight, in mind.

4.2 Tracking methods

These are the methods used to locate a position in between the virtual signal strength pinpoints that have been placed strategically throughout the building.

All vector and matrix calculations done in the equations are done point by point and that is partially why the indices are clearly shown in all equations.

4.2.1 Closest Pinpoint

An apparent method to determine the current position is to use the closets pinpoint as a reference point. The values of this reference point can than be used in comparison to the current measurement.

To calculate the position of the current measure point the closest pinpoint needs to be determined first. The Pinpoint that has the smallest Euclidean distance between all its signal strength values and the current measurement its values is considered the closest pinpoint. In equation (1) the smallest Euclidean distance is calculated and is used to indicate which pinpoint is the closest.

$$cpp = \min\left(\left\| ppss_{1..n\,1..m} - css_{1..m} \right\|\right) \qquad (1)$$

Equation (1) can determine the closest pinpoint.

In equation (1) “ppss” (pinpointsignalstrength) are the different signals their strength for the given pinpoint. The “css” (currentsignalstrength) are the different signals their strengths that are currently measured. The result is the “cpp” (closestpinpoint), which, is the pinpoint closest to the current measured signal in Euclidean distance.

The position of the current measure point is triangulated between the signal points. The distances between the current measure point and the signal points are determined by the differences in its signal strengths and the signal strength values of the closest pinpoint. These differences are used as a ratio for the distances of the closest pinpoint to the signal points to calculate the distances of the current measure point to that signal point. This is shown in equation (2)

$$dts_{1..m} = \frac{\left\| sp_{XYZ\,1..m} - cppp_{XYZ} \right\|}{cppss_{1..m} \times css_{1..m}} \qquad (2)$$

it calculates the current measurement its distances to the signal points.

For equation (2) “sp” (signalposition) is the coordinate position of the signal point. The “cppp” (closestpinpointposition) is the coordinate position of the resulting pinpoint from equation (1). “cppss” (closestpinpointsignalstrength) is the different signals their strength for the resulting pinpoint from equation (1). The resulting “dts” (distancetosignal) is the distance of the current measurement to the different signal spots.

These distances need to be transferred into a coordinate position for the current measurement. The new position can be determined by calculating the radical centre of the signal point circles. How this is done can be seen in the 4.2.4 radical centre section below the tracking methods.

4.2.2 Signal strength wedge

A different approach is too consider each signal strength from the access points separately for every pinpoint. The current measured signal strengths can be individually compared with the pinpoints. Than the pinpoints with the minimum positive and minimum negative distance are both selected per signal strength value. These can be used to get the signal strength ratios, which can be used together to determine the distances from the measurement point to the signal points. In equations (3) to (6) the calculations for this procedure are given.

$$dtsu_{1..m} = \left\| sp_{XYZ\,1..m} - pppu_{XYZ} \right\| \qquad (3)$$

Equation (3) calculates the upper pinpoint its distances to the signal points.

$$du_{1..m} = css_{1..m} - ppssu_{1..m} \qquad (4)$$

Equation (4) calculates the difference between the upper pinpoint its signal strength and the current measured signal strength.

The “pppu” (pinpointpositionupper) is the coordinate position of the pinpoint that is closest to the current measurement in positive signal strength for the given signal. The “dtsu” (distancetosignalupper) is the distances of previous mentioned pinpoint to the signal points.

For the lower pinpoint the same equations (3) and (4) can be used as for upper with the exception that they now have lower in their names. The “pppl” (pinpointpositionlower) is the same as “Pinpointpositionupper” but with negative signal strength. The “dtsl” (distancetosignallower) is the distance of this lower pinpoint to the signal spots.

"Pinpointpositionupper" and "-lower" can be determined similar to the way equation (1) gives the closest pinpoint. But then without the Euclidean distance to get closest positive and negative value for each signal separately. The "ppssu" (pinpointsignalstrengthupper) and "ppssl" (-lower) are the different signals their strength for the previous mentioned resulting pinpoints. If both pinpoints for a wedge cannot be found, meaning the current measurement its signal strength is outside the signal strength span of the pinpoints, only the upper or lower pinpoint is found. This pinpoint is then used as the closest pinpoint and is used in equation (2) to get the distances to the signal points.

$$d_{1..m} = \frac{-dl_{1..m}}{du_{1..m} - dl_{1..m}} \qquad (5)$$

Equation (5) calculates the difference ratio between upper and lower difference.

The result from equation (5) is "d" (difference) which is the signal strength difference ratio between resulting "du" (differenceupper) and "dl" (-lower) from equation (4).

$$dts_{1..m} = dtsl_{1..m} + \left(dtsu_{1..m} - dtsl_{1..m}\right) \times d_{1..m} \qquad (6)$$

Equation (6) calculates the distances from current measurement to the signal points.

Finally the result from equation (6) can be used together with equations for the radical centre to get the coordinate position of the current measurement.

4.2.3 Pinpoint area

For this approach the k nearest neighbours from the current measurement point can be taken to get an average of an area. The Euclidean signal strength distances determine the k nearest neighbours that are taken. The ones that are within a certain radius from the current measured signal strength are selected. The radius itself is dependent on the smallest Euclidean distance. This distance is taken as a basis to see how close the current point is to other points. For this research the radius that is taken is the smallest distance multiplied by 2 and than plus 32.

The k nearest neighbour collection can be found with Equation 1 with the adaptation of collecting the k closest pinpoints instead of just taking the minimum. If the k closest pinpoints results in only 1 pinpoint then equation (2) is used to calculate the distances from the current measurement to the signal points.

$$dtskpp_{1..k\,1..m} = \left\| appp_{1..k\,XYZ\,1..m} - sp_{XYZ\,1..m} \right\| \qquad (7)$$

Equation (7) calculates the distances from "k" selected pinpoints to the signal points.

The "appp" (areapinpointposition) is the coordinate positions of the collection of k nearest neighbours. The result of equation (7) "dtskpp" (distancetosignalkpinpoint) is the distance of these pinpoints to the signal points.

$$dd_{1..k-1\,1..m} = \left| dtskpp_{2..k\,1..m} - dtskpp_{1\,1..m} \right| \qquad (8)$$

Equation (8) Calculates the distance differences between the closest pinpoint and the rest of the "k" selected pinpoints.

In equation (8) “dd” (distancedifference) is the closest pinpoint position out of the k nearest neighbour collection and subtracted from the rest in the collection thus the difference in distance between them.

$$ssd_{1..k-1\ 1..m} = \left| kppss_{2..k\ 1..m} - cppss_{1..m} \right| \qquad (9)$$

Equation (9) calculates the signal strength differences between the closest pinpoint and the rest of the “k” selected pinpoints.

In equation (9) “ssd” (signalstrengthdifference) is the difference in strength of the signals compared between the closest pinpoint “closestpinpointsignalstrength” and the rest of the pinpoints in the k nearest neighbour collection “kppss” (kpinpointsignalstrength).

$$ad_{1..k-1\ 1..m} = \frac{dd_{1..k-1\ 1..m}}{ssd_{1..k-1\ 1..m}} * (kppss_{2..k\ 1..m} - css_{1..m}) \qquad (10)$$

Equation (10) calculates the difference ratio of distances and signal strengths of the area the “k” pinpoints are located in.

The results from equations (8) and (9) are used as a ratio to calculate the “ad” (areadifference) in equation (10). The “areadifference” is a means that is needed to calculate the “distancetosignal” in equation (11). The “k” is the number of k nearest neighbours that are collected.

$$dts_{1..m} = \frac{\sum_{1}^{k-1} \left(ad_{1..k-1\ 1..m} + dtskpp_{2..k\ 1..m} \right)}{k-1} \qquad (11)$$

Equation (11) calculates the distances from the current measurement to the signal points.

Finally the result from equation (11) can be used together with equations for the radical centre to get the coordinate position of the current measurement.

4.2.4 Radical centre

To determine the intersection of three circles this research uses the calculation for the radical centre (also known as the power centre). All the mentioned tracking methods above, result in giving the distances to the signal point. These distances represent the radius of the circles with their centres being the signal point positions. This is al the information required to calculate the radical centre of these circles, for the above mentioned tracking methods. The next equations are used to calculate the radical centre.

$$dbs12 = \left\| sp_{XYZ\,1} - sp_{XYZ\,2} \right\| \qquad (12)$$

Equation (12) calculates the distance from signal point 1 to signal point 2.

In equation (12) the Euclidean distance between signal point “1” and “2” is calculated and abbreviated to “dbs12” (distancebetweensignal12).

$$rld21 = \frac{dbs12 + dts_2 - dts_1}{2 * dbs12} \qquad (13)$$

Equation (13) calculates the distance of the radical line from signal point 2.

In equation (13) “rld21” (radicallinedistance21) is the distance at which the radical line is located from signal point 2 to signal point 1. The “dts” is the “distancetosignal” from the different tracking methods.

$$v21_{XYZ} = sp_{XYZ1} - sp_{XYZ2} \qquad (14)$$

Equation (14) produces a vector from signal point 2 to signal point 1.

$$rlp12_{XYZ} = \frac{v21_{XYZ}}{dbs12} * rld21 + sp_{XYZ2} \qquad (15)$$

Equation (15) calculates the position of the radical line between signal points 1 and 2.

The “v21” (vector21), result for equation (14) is the vector from signal point 2 to 1. With this vector the position “rlp12” (radicallineposition12), at which the radical line intersects the line from signal point 1 to 2, is calculated in equation (15).

$$rl12 = \sum \left((-v21_{XYZ}) \times rlp12_{XYZ} \right) \qquad (16)$$

Equation (16) is the equation of the radical line.

Equation (16) gives the equation for the radical line with “rl12” (radicalline12) being the outside balance of the line equation.

Between two signals the centre position is “radicallineposition12”. When there are three signals the same equations as above are used except values of signal one and three are used instead of between one and two. With the resulting information from the two equation sets the following equations (17) and (18) can determine the “rc” (radicalcentre) in 2D. In these two equations the lower halve of the division is the determinant of the two radical lines. With the three circles there are also three radical lines but only two of them need to be calculated because all three lines converge on the same position. This indicates that the intersection of two radical lines is enough to determine the radical centre.

$$rc_X = \frac{(-v31_Y) * rl12 - (-v21_Y) * rl13}{(-v21_X) * (-v31_Y) - (-v31_X) * (-v21_Y)} \qquad (17)$$

Equation (17) calculates the “x” position of the radical centre.

$$rc_Y = \frac{(-v21_X) * rl13 - (-v31_X) * rl12}{(-v21_X) * (-v31_Y) - (-v31_X) * (-v21_Y)} \qquad (18)$$

Equation (18) calculates the “y” position of the radical centre.

This 2D equation set is being used in this research because the points are projected on a 2D map and the floor on which the point is projected is determined separately. To calculate the radical centre in 3 dimensions, the three spheres need to be written as trilinear equations as seen in equations (19), (20) and (21). These equations are useful to calculate the 3D radical centre with equation (22). In equation (22) “det” is the determinant of the matrix.

$$(l \times x + m \times y + n \times z) \times (a \times x + b \times y + c \times z) + k \times (a \times y \times z + b \times z \times x + c \times x \times y) = 0 \qquad (19)$$

Equation (19) is the first sphere given as a trilinear equation.

$$(l'\times x + m'\times y + n'\times z)\times(a\times x + b\times y + c\times z) + k'\times(a\times y\times z + b\times z\times x + c\times x\times y) = 0 \quad (20)$$

Equation (20) is the second sphere given as a trilinear equation.

$$(l''\times x + m''\times y + n''\times z)\times(a\times x + b\times y + c\times z) + k''\times(a\times y\times z + b\times z\times x + c\times x\times y) = 0 \quad (21)$$

Equation (21) is the third sphere given as a trilinear equation.

$$rc_{XYZ} = \det\begin{bmatrix} k & k' & k'' \\ m & m' & m'' \\ n & n' & n'' \end{bmatrix} : \det\begin{bmatrix} k & k' & k'' \\ n & n' & n'' \\ l & l' & l'' \end{bmatrix} : \det\begin{bmatrix} k & k' & k'' \\ l & l' & l'' \\ m & m' & m'' \end{bmatrix} \quad (22)$$

Equation (22) is the 3D calculation of the radical centre.

4.2.5 Methods based on the different types of pinpoint features

Of course these tracking methods are all dependent on which pinpoint feature is used. Because each feature has a different influence on the signal strengths as can be seen in [16]. These differences can have a significant effect on the tracking methods, therefore all the different pinpoint features need to be tested to see which works best with a certain tracking method.

4.2.6 Methods combined

It is also possible to combine the tracking methods and their used features. This is done by taking the average of the resulting positions and then selecting the resulting position that is closest to the average position. This can create stable results that for instance can be resistant against erratic behaviour of one of the methods in certain situations. This is mainly because weights can be given to the different methods per new position. These weights can be determined by the distances between the resulting positions of the methods and their used features, as well as the distance from the closest detected pinpoint.

4.3 Software development

The complete software system for the implementing, testing and verifying of the entire research is build and used by both research partners. The development tools used for this system are Visual C# Express 2008 for the actual coding and Microsoft XNA Game Studio 3.1 for the visual part of the system.

These two development tools provided good support in the form of documentation, code examples and online forums and allowed for quick development and test phases. This together proved to be very successful for creating and implementing the system.

The system itself is set up in a multi-threaded design, which divided the measuring, logic, helper functions and Graphical User Interface into separate threads. This ensured that these parts can run side by side, but it is highly recommended to run this on a CPU (central processing unit) that can handle this.

The basic workings and the specific feature procedures of the system are all explained in [16] and have also all been used during the set-up and experimentation of this research. For an inside look into the tracking methods, pseudo code is presented in the next subsection.

4.4 Pseudo code

All that is needed to implement the tracking methods in another project are the equations. These can be used to transfer the techniques into any programming language. This is why the system build and used for the experimentation of this research is not explained further. But to get a better understanding of the tracking methods their procedures, pseudo code is provided.

The pseudo code that is given only consists of the main part of the three tracking methods. This is the part that calculates the distances from the new current position to the signal points, which is the essence of all the tracking methods. Because these distances can be used to calculate the radical centre.

In Pseudo code 1 the distances to the signal points are determined for the closest pinpoint method. The “currentTWI” has all the information of the current measurement. The “featureLogic” contains all the features and their collected values. The rest of the pseudo code 1 speaks for it self and can also be compared to the corresponding equations.

```
Dictionary<String, float> signalDistance = new Dictionary<string, float>();

foreach (TimedWifiInfo t in currentTWI)
{
        String s = t.w.SSID;
        if (featureLogic.Features[closestpinpoint][featureType].Values.ContainsKey(s))
        {
                float sigx = signalPoints[s][0];
                float sigy = signalPoints[s][1];
                float dist = euclideanDist(new float[2] { closex, closey }, new float[2] { sigx,
                sigy });
                float diffRat = (float)(dist / (100 -
                featureLogic.Features[closestpinpoint][featureType].Values[s]));
                signalDistance.Add(s, diffRat * (float)(100 - t.w.SignalStrength));
        }
}
```

Pseudo code 1: Distances to signal points calculation for the closest pinpoint method

Pseudo code 2 is also very straight forward and determines the distances to the signal points for the signal strength wedge method. The “wedge” contains the two pinpoints for each signal strength of where the current measurement is in between. Together with the difference of the signal strengths. This pseudo code example presumes that both pinpoint sides of the wedge exist, which would be the right condition.

```
Dictionary<String, float> signalDistance = new Dictionary<string, float>();

foreach (String s in wedge.Keys)
{
	float sigx = signalPoints[s][0];
	float sigy = signalPoints[s][1];

	string ppName1 = featureLogic.Features[((int)wedge[s][1])][featureType].Name;
	string ppName2 = featureLogic.Features[((int)wedge[s][3])][featureType].Name;
	float curx1 = pinpointpos[ppName1][0];
	float cury1 = pinpointpos[ppName1][1];
	float curx2 = pinpointpos[ppName2][0];
	float cury2 = pinpointpos[ppName2][1];

	float dist1 = euclideanDist(new float[2] { curx1, cury1 }, new float[2] { sigx, sigy });
	float dist2 = euclideanDist(new float[2] { curx2, cury2 }, new float[2] { sigx, sigy });
	float differenceup = wedge[s][0];
	float differencelow = wedge[s][2];
	float difference = (-differencelow) / (differenceup - differencelow);

	signalDistance.Add(s, dist2 + (dist1 - dist2) * difference);
}
```

Pseudo code 2: Distances to signal points calculation for the signal strength wedge method

Pseudo code 3 is a bit lengthier but not more difficult to understand than the other two pseudo code examples. Pseudo code 3 determines the distances to the signal points for the pinpoint area method. It first calculates the distances of all the pinpoints in the selected area to a signal point. These are stored in “pirdist” and used in the next part, which uses the average distance to signal strength ratio to calculated the distance to the signal point.

```
Dictionary<String, float> signalDistance = new Dictionary<string, float>();

foreach (TimedWifiInfo t in currentTWI)
{
	String s = t.w.SSID;
	float sigx = signalPoints[s][0];
	float sigy = signalPoints[s][1];

	//pinpointInRange distance
	pirdist = new Dictionary<int, float>();
	foreach (int i in pinpointInRange)
	{
		string ppName = featureLogic.Features[i][featureType].Name;
		float curx = (float)pinpointpos[ppName][0];
		float cury = (float)pinpointpos[ppName][1];
		pirdist.Add(i,euclideanDist(new float[2] { curx, cury }, new float[2] { sigx, sigy
		}));
	}
	foreach (int i in pinpointInRange)
	{
		if (i != closestpinpoint)
		{
			float disDiff = Math.Abs(pirdist[closestpinpoint] - pirdist[i]);
			float sigDiff =
			Math.Abs(featureLogic.Features[closestpinpoint][featureType].Values[
			s] - featureLogic.Features[i][featureType].Values[s]);
			float sdr = pirdist[i] + ((disDiff / sigDiff) *
			(featureLogic.Features[i][featureType].Values[s] -
			t.w.SignalStrength));
			if (signalDistance.ContainsKey(s))
			{
				signalDistance[s] += sdr;
			}
			else
			{
				signalDistance.Add(s, sdr);
			}
		}
	}
	if (sigdist.ContainsKey(s))
	{
		signalDistance[s] = signalDistance[s] / (pinpointInRange.Count - 1);
	}
}
```
Pseudo code 3: Calculation of distances to signal points for the pinpoint area method

All three pseudo code parts are useful in conjunction with the equations to get a better understanding over the working of the tracking methods. But can also function as a guideline for the implementation of the equations.

5 Experimentation

The set-up used for the performing of the actual tests is explained first. After this the precise position for the signal points and pinpoints that are used are given together with all the equipments needed. Finally the intended performance tests are also introduced.

5.1 Setting up the experiment step by step

The first and most important thing to do is scout the environment; get a real understanding of where the most signal blocking materials and positions are. Start planning where the best positions would be for the transmitters so that they can cover the intended area. Making sure there are no blind spots or as little as possible.

Next up is placing the transmitters. To check if the scouting of the environment has gone right the signal strengths can be measured for each of the placed signal points and check if the strengths are satisfactory and if the combined signal strengths form unique fingerprints for the whole environment. After the right placement the “SSIDs” of these signal points need to be manually registered in the system.

During the scouting and the signal strength checking of the area good positions for the pinpoint will have revealed themselves. These individual positions will than be used during the measurement of each pinpoint. During the measurement the receiver is placed at a desired position (which is than also indicated with the mouse cursor to the system) and collects the signal strength values from each transmitter over a period of time. The pinpoints used in this thesis are measured for a duration of about 15 minutes. The measured information for each pinpoint is stored in a file together with the location on the map and the name of the pinpoint as the filename. These files can instantly be used by the system and are also loaded each time the system is started.

After all the desired pinpoints have been calibrated the system can then use [16]’s features to extract the information out of the pinpoints and convert it into useful values. These values plus the locations of the pinpoints and signal points are together the mapping of the environment and enough for the tracking methods to use for positioning. The mapping of the environment is different for each feature used, because each feature extracts the information in its own way, which results in different values. The tracking methods will each use these values in their own specific way to find the location of the current measured signal strength.

With all these steps taken the set-up is ready to be used for the actual experiment.

5.2 Test environment

The environment used for the experiments is the Bernoulli Borg [20], which is one of the buildings of the University of Groningen (RUG). The experiments have taken place on the ground, first and second floor of the building, the map of these floors can be seen in Figure 7.

All of the experiments have taken place on the left side of the map because of the ranges of the signal points that had to cover the entire area. The maps are provided by the website of the University in PDF format and have been converted into textures to be used by the GUI of the system.

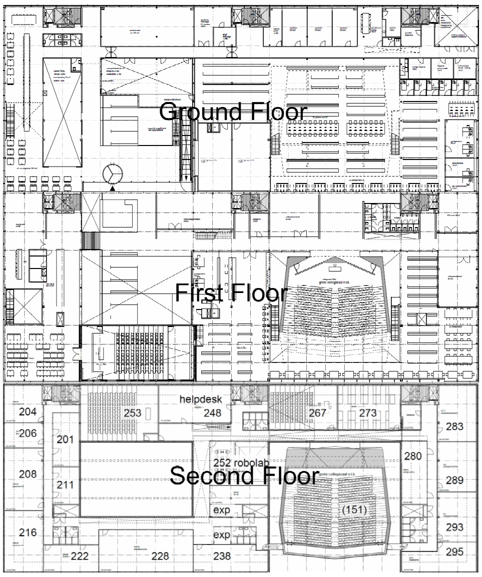

Figure 7: Three floors of the Bernoulli Borg

As can be seen the structuring of the used environment is pretty diverse and is a good choice for performing the experiments in an actual indoor work environment.

5.3 Signal point positions

As explained in the subsection “5.1 Setting up the experiment step by step” above, the signal points have been placed strategically. Even though there were not that many positions available because the signal points had to be secure and inaccessible to not be tamper with.

The first position GeoLoc1, is placed is on the first floor at the top of its map area, this is displayed in Figure 8. This position is chosen for its centred position at the top wall of the building.

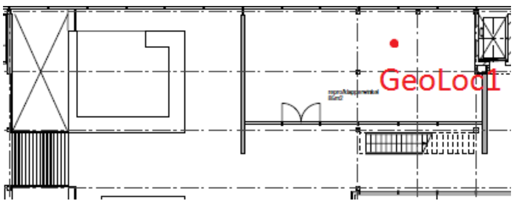

Figure 8: Position of GeoLoc1

The second position for the signal point GeoLoc2 is on the second floor in room “252 robolab” as can be seen in Figure 9. This position is decided on in respect to the other positions to complete the triangle and still be centred and covering the test area. There where first some doubts with this position because there is a lot of wireless equipment used in the robolab. However after checking the signals there did not seem to be a problem.

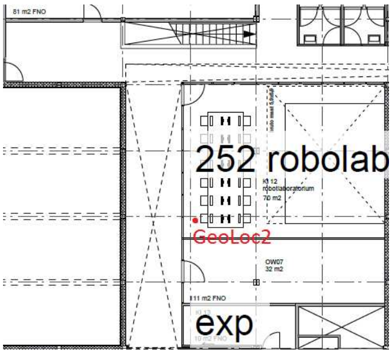

Figure 9: Position of GeoLoc2

The final signal point GeoLoc3 is place on the second floor across from GeoLoc2 in room 207, this position can be seen in Figure 10. The map indicates this room as room 201 but it is in fact room 207 and will be designated and used as such throughout this paper. The choice for this position was made because it is very close to the test area and because it is the room the code for the system is written in.

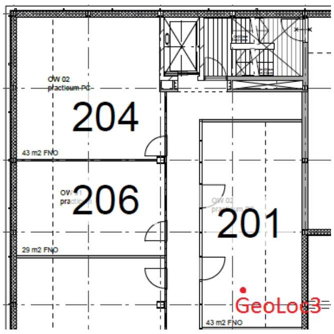

Figure 10: Position of GeoLoc3

The positions as they are placed, formed a good basis form the experiment to work with and had verily unique signal strengths throughout the environment and had very little to no blind spots. There is only one spot that has a significant drop in signal strengths, but the signals are still receivable.

5.4 Calibration pinpoint locations

The pinpoints are place in the area on the left side of the map where the most rooms are in the test environment. Six of the pinpoints are place on the second floor each in a different room, the seventh is placed on the first floor in the cantina as can be seen in Figure 11.

All the pinpoints have been measured over a time period of 15 minutes. It is chosen to not have too many pinpoints to really put the system to the test. With the pinpoints each in a room the tracking methods are given a good opportunity to locate the position in between them, for instants throughout the room or in the hallway. The pinpoints are also shared with [16] which was mainly focusing on pinpoint room detection.

The pinpoints are placed conveniently around the building to convey the test area and thus the features can form a mapping of the environment with them, which is very important to the tracking methods.

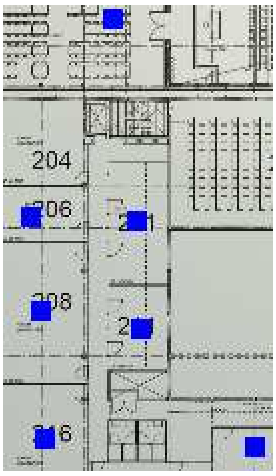

Figure 11: Locations of the pinpoints

5.5 Equipment used

The following equipment was used during programming of the system and performing the experiments. The system is programmed using two laptops, which have also been used during the experiment. Each of them had a different role the “Medion 6200” is used as the signal point GeoLoc3 and the “HP Touchsmart TX2650ed” is used as a mobile receiver.

The Medion 6200 as seen in Figure 12 has the following specifications:

- Intel Pentium 4 2.4ghz
- 512 MB DDR2 Ram
- 80 Gigabyte 2.5 inch HDD
- Geforce 5200 Mobile
- Creatix CTX712 Wifi Adapter
- Running on Windows XP

Figure 12: Medion 6200

The HP Touchsmart TX2650ed shown in Figure 13 has the following specifications:

- AMD Turion X2 ULTRA (ZM82 @ 2.2ghz)
- 4GB DDR2 Ram
- 250GB 2.5 inch HDD
- AMD/ATI Mobility Radeon 3200
- Broadcom 4322AG 802.11a/b/g/draft-n adapter
- Running on Windows 7 32 bits.

Figure 13: HP Touchsmart TX2650ed

The HP is best suited to run the test program because of it multicore processor and overall better specifications. This is because the system in programmed in a multi-threaded architecture and has a 3D accelerated graphical user interface. The Medion could not run the test program at full speed and would thus not deliver the correct measurement results. However, because three signal points are needed it could be used as one of them. It could transmit a steady signal and have its own SSID, which is good enough for the desired experiments, and it saved in only having to acquire two other signal points.

For the signal points geoLoc1 and GeoLoc2 two identical Belkin Wireless G routers are used. These are very cheap routers and are chosen because they would create less then perfect circumstances. This is one of the gaols to test the system in an actual indoor work environment with less the perfect signals.

The Belkin Wireless G router with the type number F5D7230-4 v7000 is shown in Figure 14.

Figure 14: Belkin Wireless G router

5.6 Tracking tests

Indicated here are the tests that this research would like to realize to establish an indication of how the tracking methods perform.

5.6.1 Methods

All the methods will be tested in comparison to each other. The main focus of each test will be to check the deviation of the resulting position from the real position. The methods will be using the features that are compatible with them. These are the single value features because the methods use the pinpoints as single valued indicators to compare the current measured signal strength with.

The single value features are the average, mode and median features as described in [16]. These features provide the pinpoints with a unique fingerprint that is needed for the tracking methods to locate the current measurement.

This conveys that the three tracking methods will each be using the three single value features indicating that there are nine checks to be performed. These nine will be combined into a merged outcome bringing it to a total of ten resulting positions.

5.6.2 Position

This is going to be a time stress test on a single position. This ensures the best result for deviation measurements. The position can be set before the test begins and used during the test to measure the actual distance from the ten resulting positions to this predefined position.

The results from this test not only indicate the precision of the methods but also how much the signal strengths deviate when the receiver is placed on a fixed position. The results from the methods can also be compared to each other to see which performs better in what situation. In addition it is also possible to get a clear view of their behaviour in contrast to each other.

5.6.3 Moving

This test is mainly about the update frequency of the signal strengths. Because for a moving target it is important to get the signal strengths at the position it is currently located at. Depending on the speed of the moving target it can be tested if the rate of update can keep up with the different speeds that are most likely in an indoor location.

A deviation measurement for the moving position does not have to be tested because the exact position during movement is not known. This position can also not be determined before the test starts, because it would be hard to determine at what time exactly the measuring device was located at the position. Hence this would not lead to accurate results and should therefore leave it to be performed by the previous mentioned “Position” test.

5.6.4 Predefined signal strengths

This test can be done to really examine the positioning precision of the methods without the interference of the signal strength deviation. The signal strengths can be set by the user to see the ten resulting positions. These positions can then be analysed to see if they are located where they would be expected. It is also possible to perform signal strength measurements at these positions to see if their results match or concur with the predefined signal strengths.

This test can also be valuable to identify problematic areas of the map that are hard to position or which are not covered by the pinpoints and/or the signal points. As explained earlier the placement of the signal points and pinpoints are very important for a good functioning system and with this test it can be checked if they are positioned satisfactory or that the signal points need to be relocated or maybe only the pinpoints. If the signal points need to be relocated all the pinpoint need to be redone as well, but if the pinpoints are not satisfactory they can either be repositioned or measured again because the measurements may have received incorrect values or one of the signals could have been interrupted.

5.6.5 Two signals

The research from [16] has also tested with two signals and got some unexpected good detection results with it. However this can only be used as a detection mechanism for the pinpoints because if a tracking method wants to detect a position in-between the pinpoints it really needs the three signal triangulation. The tracking methods might still come close with two signals but it is highly dependent on where the positioning is done relative to these signals. This is why this research has chosen only to test with three signals as a base for results for the tracking methods.

6 Results

The resulting values produced by the performed tests are clearly displayed and presented. The discussion of these values will be given in the next section.

6.1 Position test measurement

The results for a precision test are given per tracking method. The position that is tested is located in room 207 left of the position of GeoLoc3 close to the left wall. The position of GeoLoc3 can be seen in Figure 10.

In Figure 7 the map is shown that the system uses. For this map the length of one floor from top to bottom is 18.76m.

The time samples of the results have been divided in half to get a clearer view of the results. The time samples have been divided in 1:4439 and 4439:8879.

The distance error results from the closest pinpoint method test are shown in Figure 15 and 16, displayed are the three single value features (average, median and mode) used by this method.

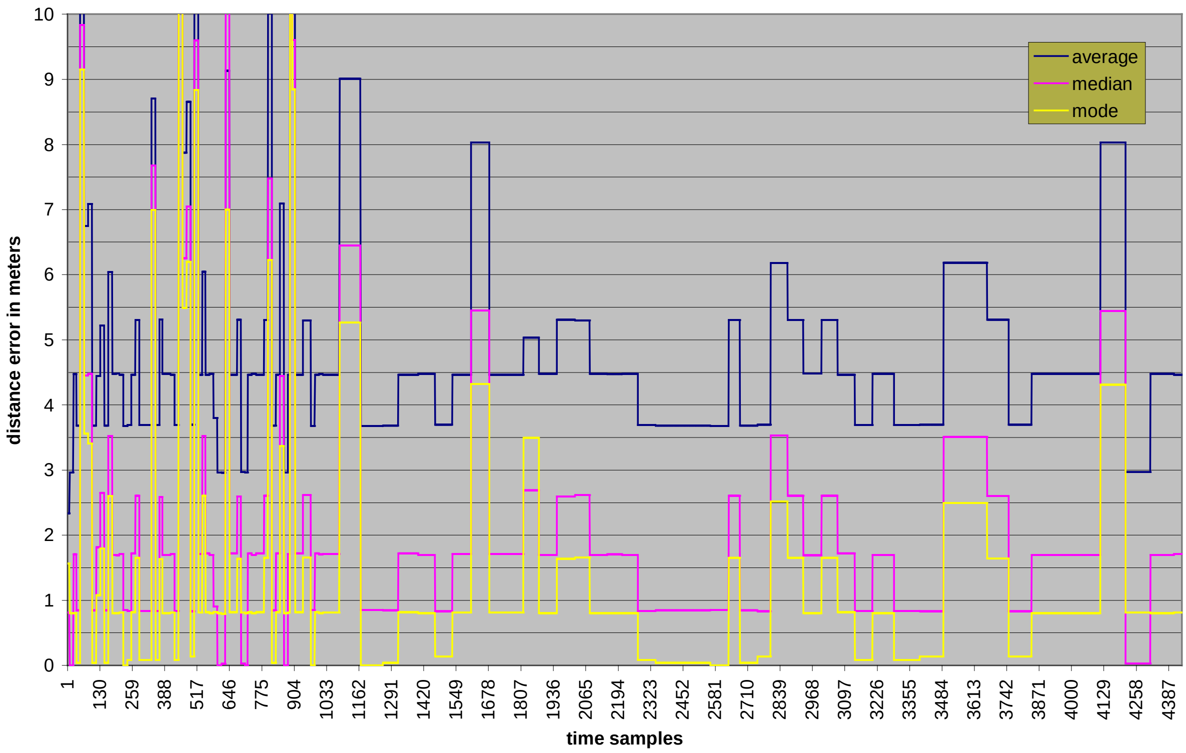

Figure 15: First half of the results for the features used by the closest pinpoint method

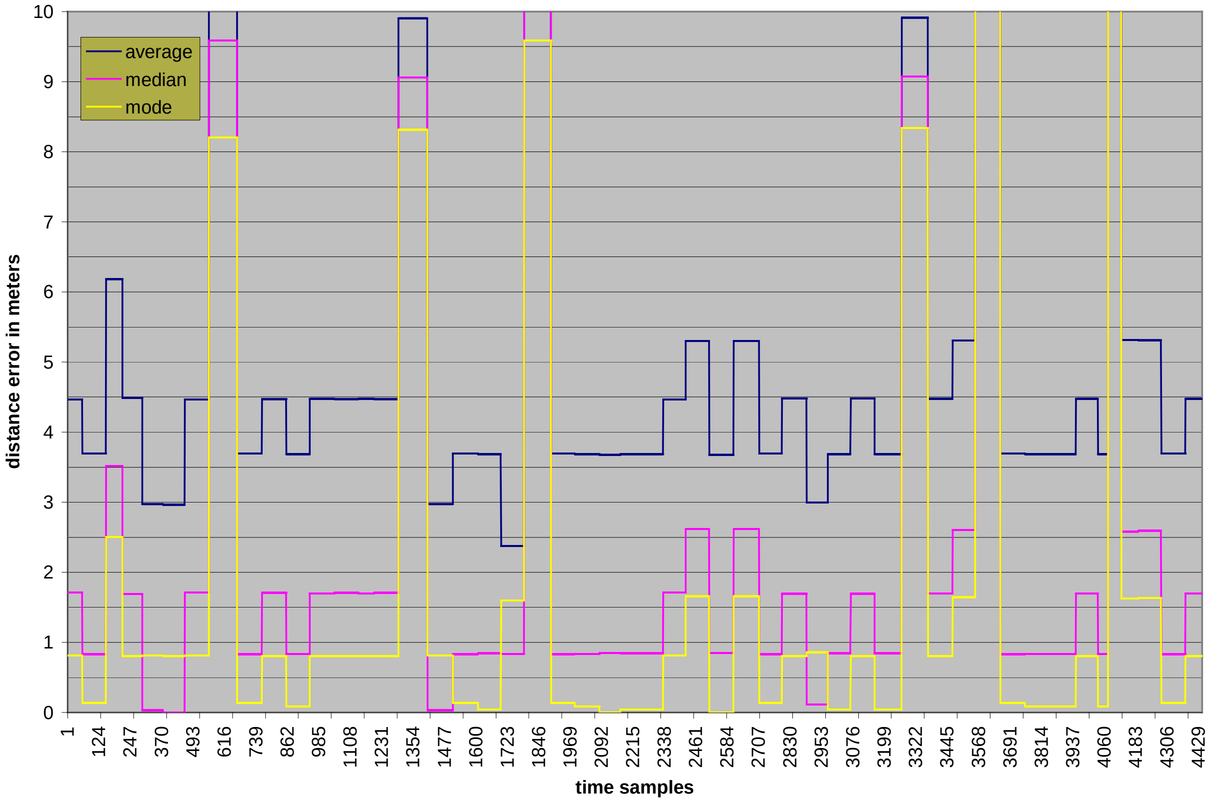

Figure 16: Second half of the results for the features used by the closest pinpoint method

The distance error results from the signal strength wedge method test are shown in Figure 17 and 18, displayed are the three single value features (average, median and mode) used by this method.

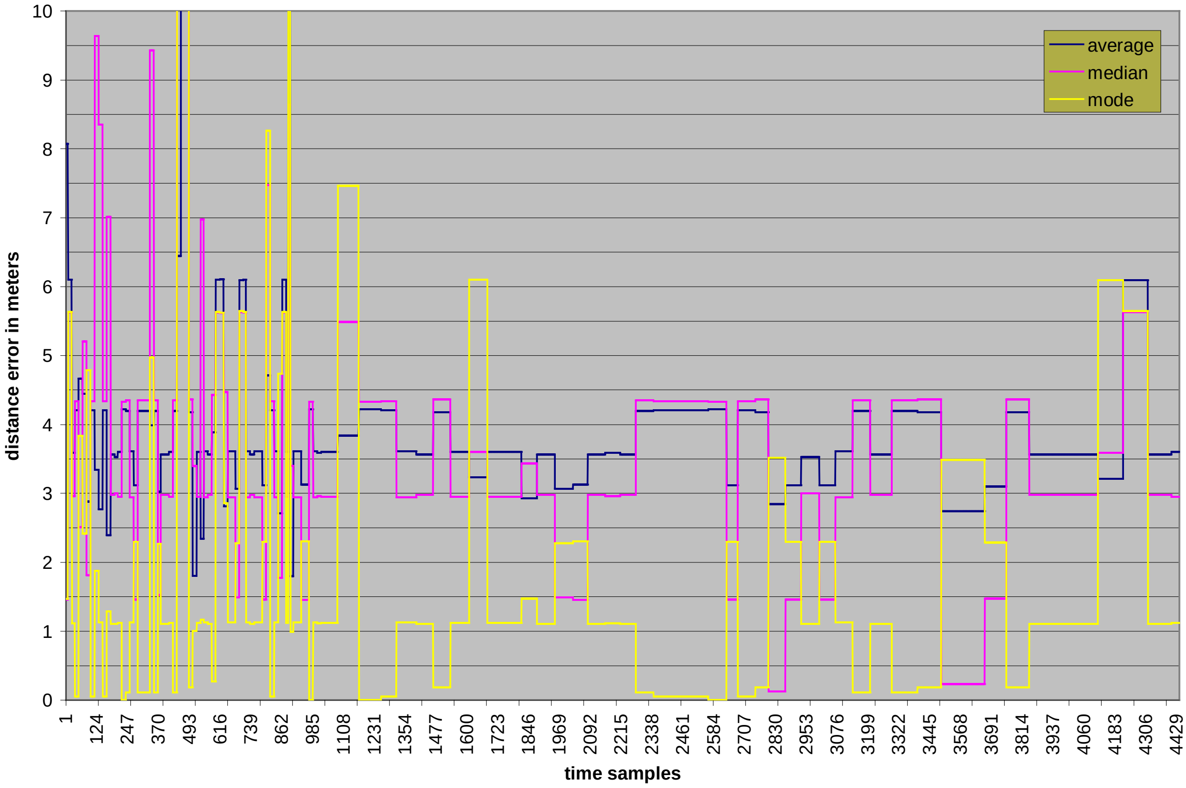

Figure 17: First half of the results for the features used by the signal strength wedge method

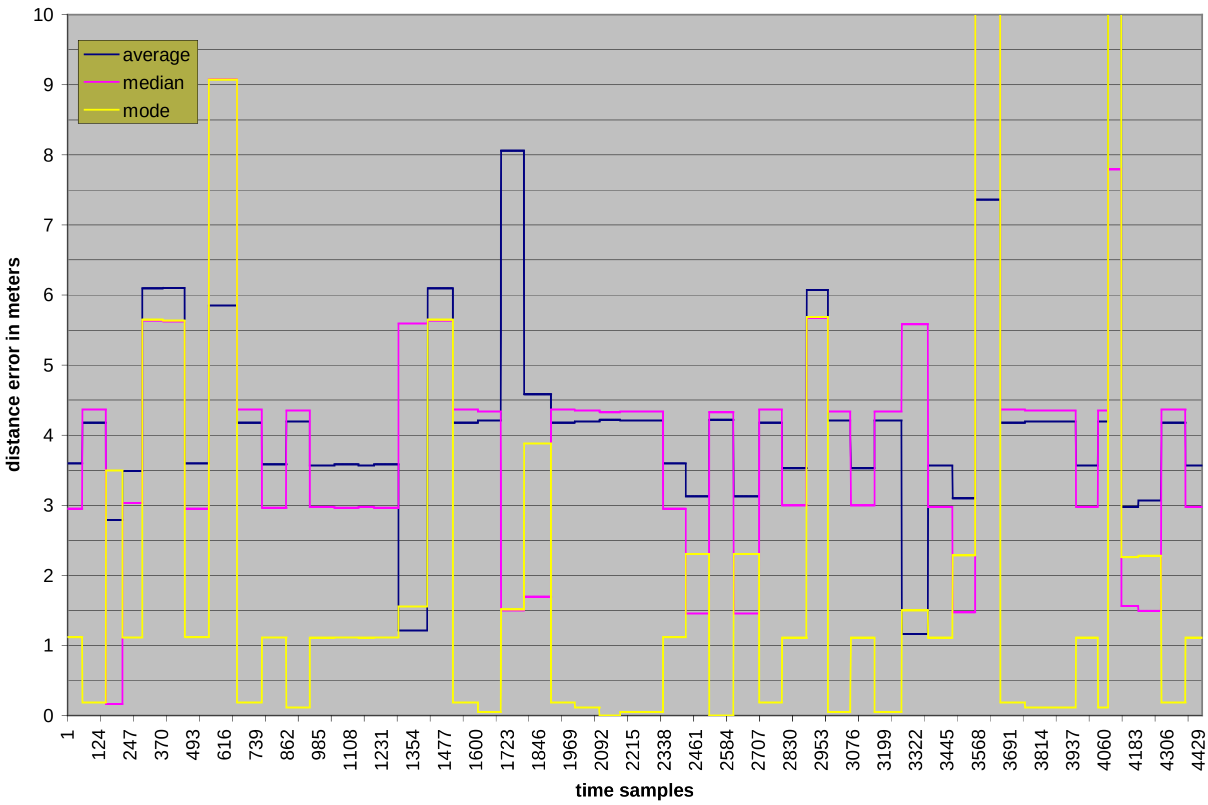

Figure 18: Second half of the results for the features used by the signal strength wedge method

The distance error results from the area pinpoint method test are shown in Figure 19 and 20, displayed are the three single value features (average, median and mode) used by this method.

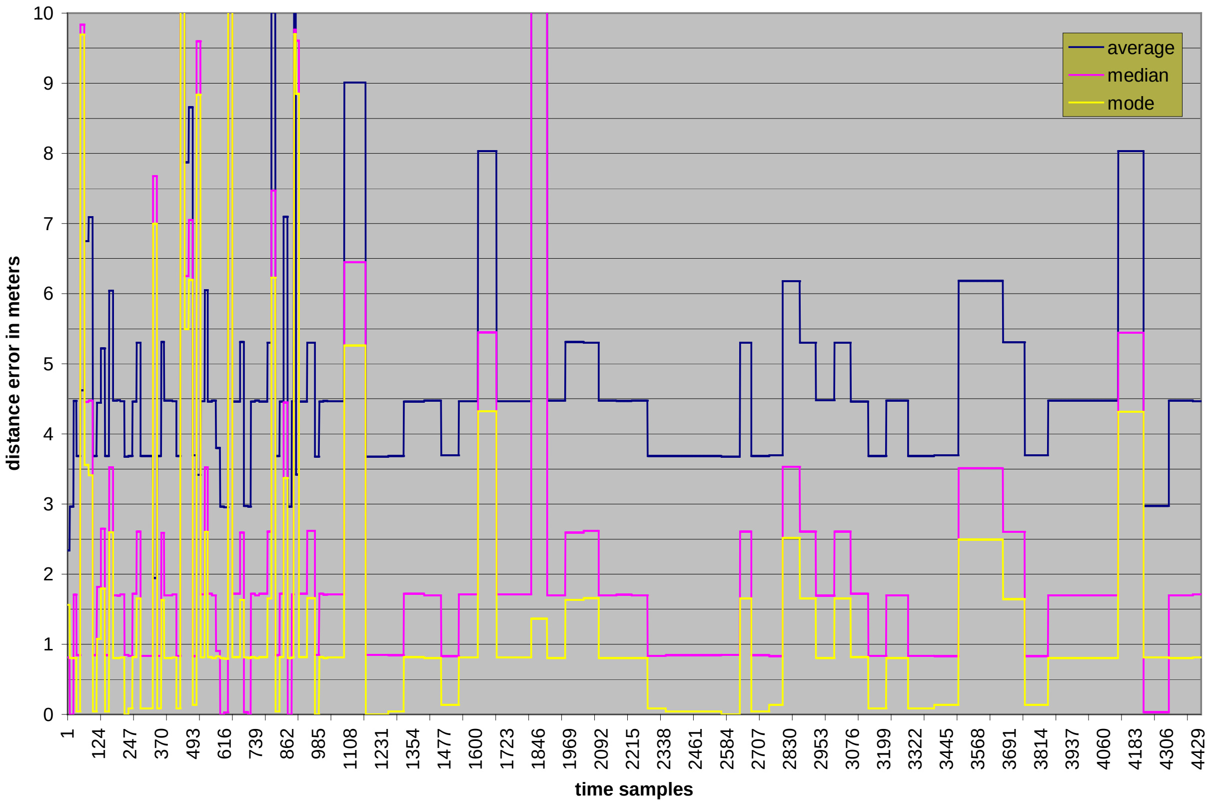

Figure 19: First half of the results for the features used by the area pinpoint method

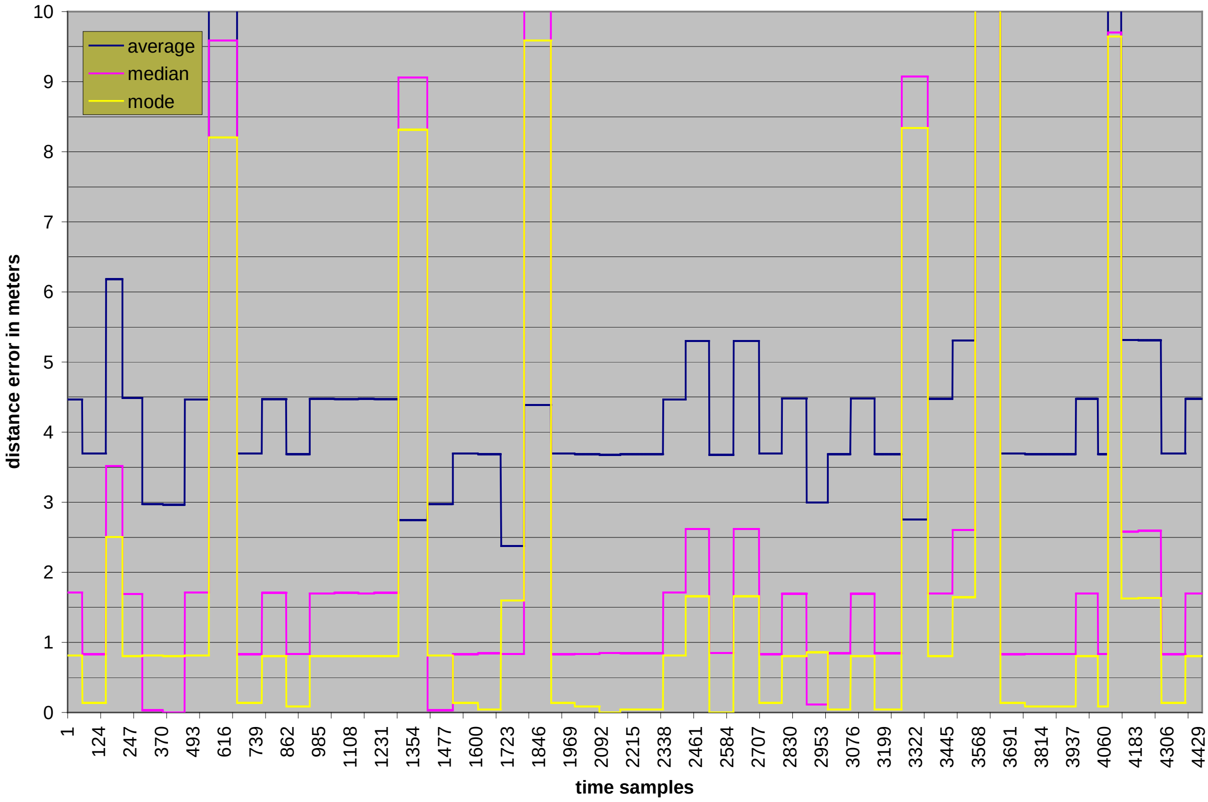

Figure 20: Second half of the results for the features used by the area pinpoint method

The distance error results from the combine methods test are shown in Figure 21 and 22.

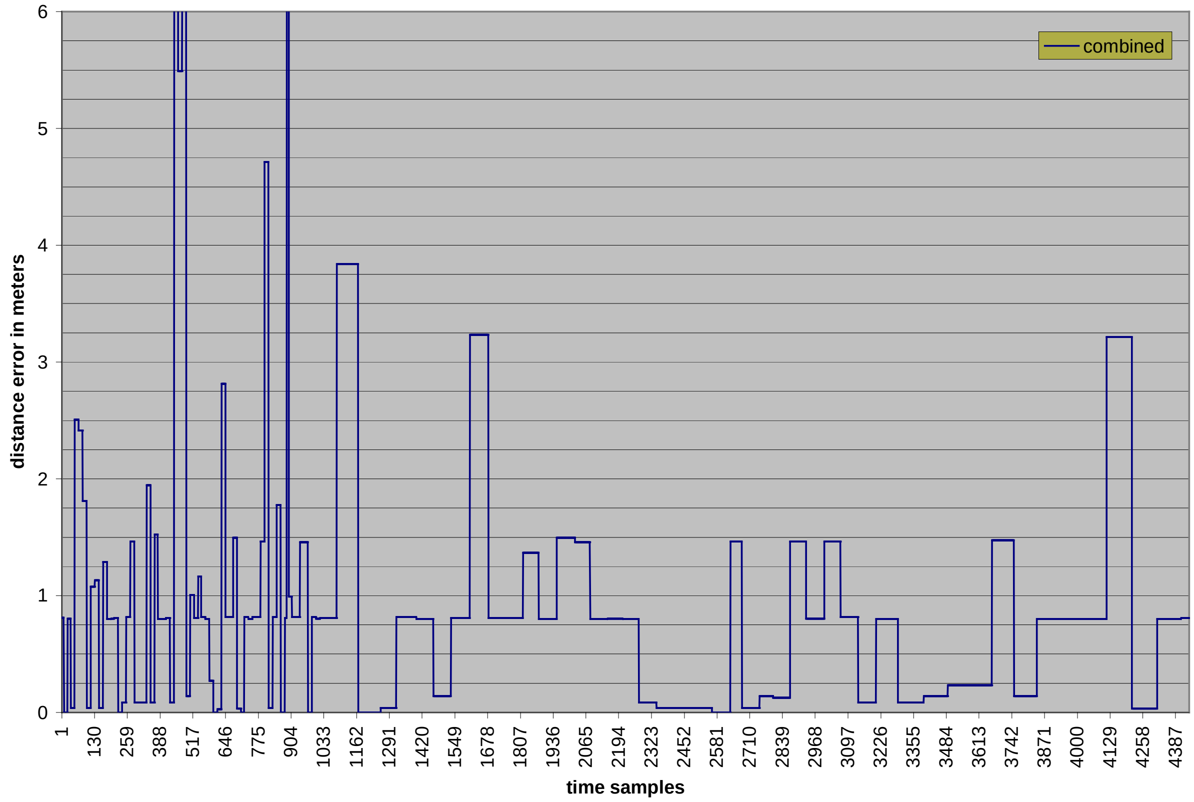

Figure 21: First half of the results for the combined methods

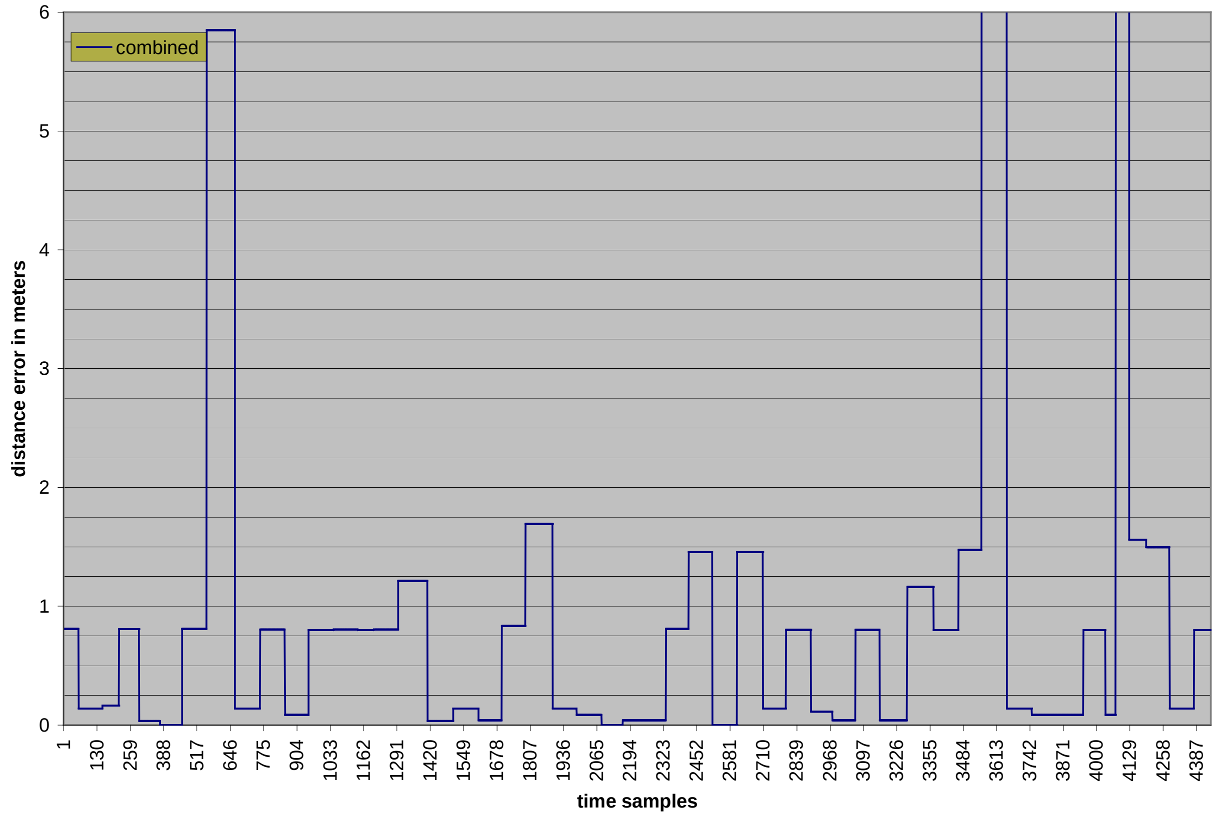

Figure 22: Second half of the results for the combined methods

The results given by this subsection are generated by the system developed for this research and have been saved in a comma separated text file.

6.2 Positioning test

If predetermined signal strength values are set and used in the system then the following positions are given in the current environment set-up.

For the resulting Figures shown in this subsection the colours of the points represent:

- Blue is pinpoints
- Red is closest pinpoint in signal strengths
- Magenta is GeoLoc3
- Yellow is closest pinpoint method
- Green is wedge signal strength method
- Salmon is area pinpoint method

When the tracking methods use the average feature the following positions are given for the indicated signal strength values.

The preset signal strength values in Figure 23 are 48 for GeoLoc1, 33 for GeoLoc2 and 95 for GeoLoc3, which result in the following three positions of the methods shown in the Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

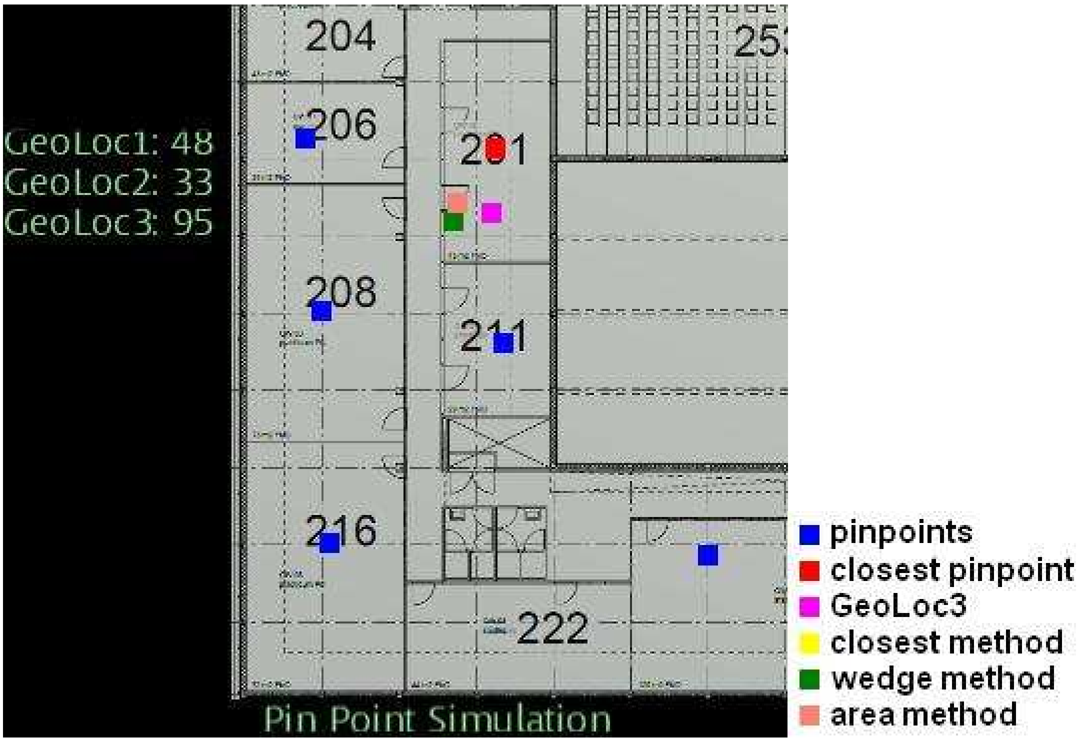

Figure 23: The resulting positions with average feature in front of the door inside 207

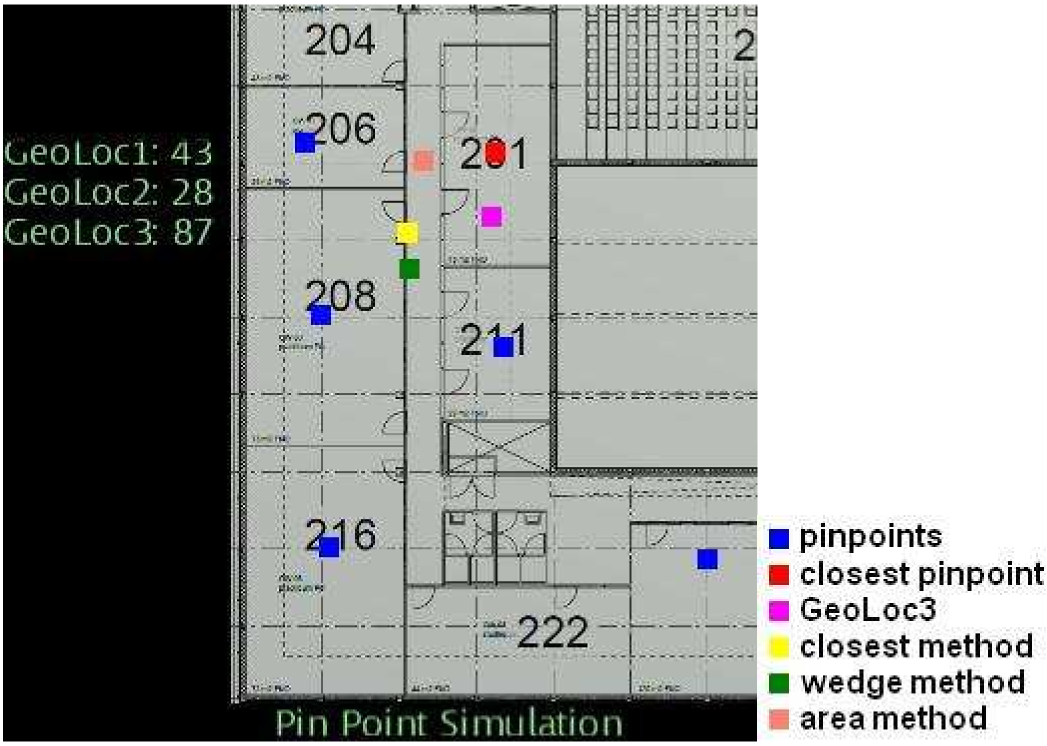

Figure 24: The resulting positions with average feature in front of the door outside 208

The preset signal strength values in Figure 24 are 43 for GeoLoc1, 28 for GeoLoc2 and 87 for GeoLoc3, which result in the three positions of the methods shown in this Figure.

The preset signal strength values in Figure 25 are 24 for GeoLoc1, 26 for GeoLoc2 and 82 for GeoLoc3, which result in the following three positions of the methods shown in the Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

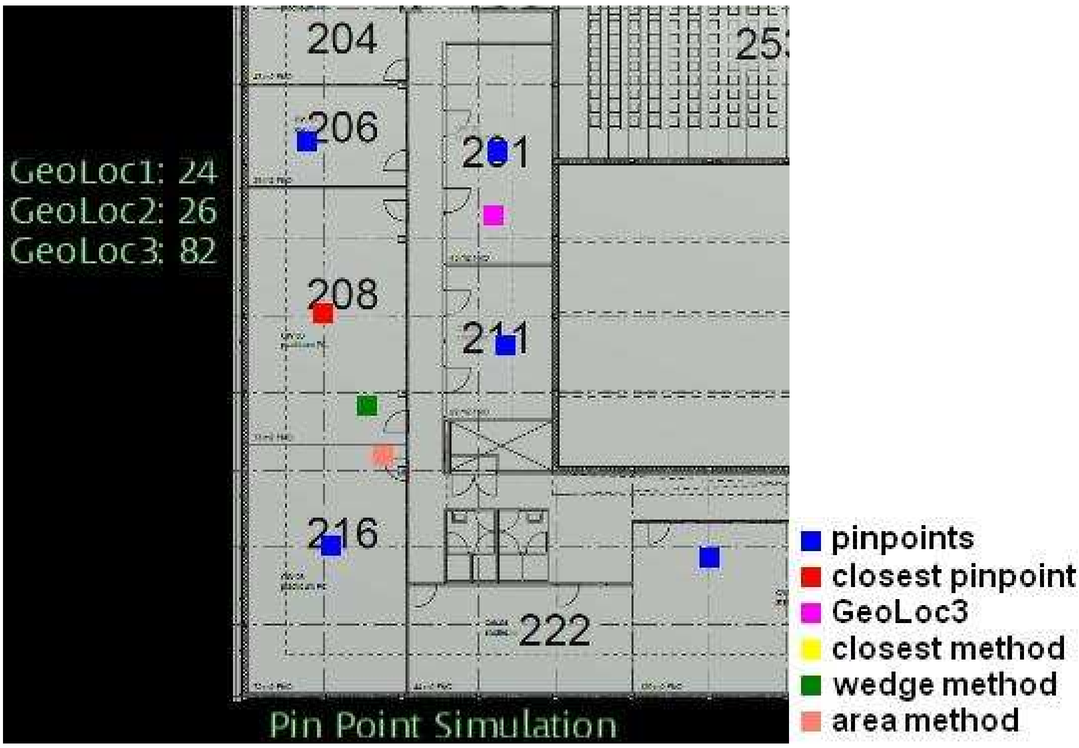

Figure 25: The resulting positions with average feature in front of the door inside 208

When the tracking methods use the median feature the following positions are given for the indicated signal strength values.

The preset signal strength values in Figure 26 are 15 for GeoLoc1, 13 for GeoLoc2 and 81 for GeoLoc3, which result in the following three positions of the methods shown in this Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

The preset signal strength values in Figure 27 are 35 for GeoLoc1, 24 for GeoLoc2 and 34 for GeoLoc3, which result in the following three positions of the methods shown in the Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

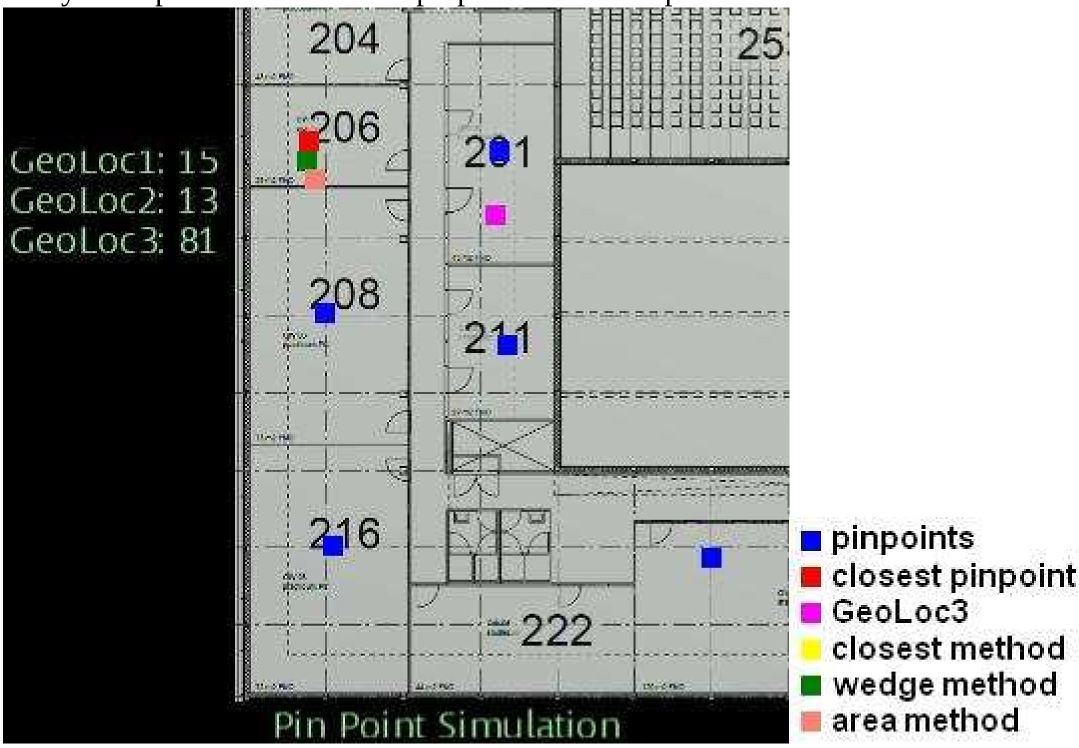

Figure 26: The resulting positions with median feature at the lower wall of room 206

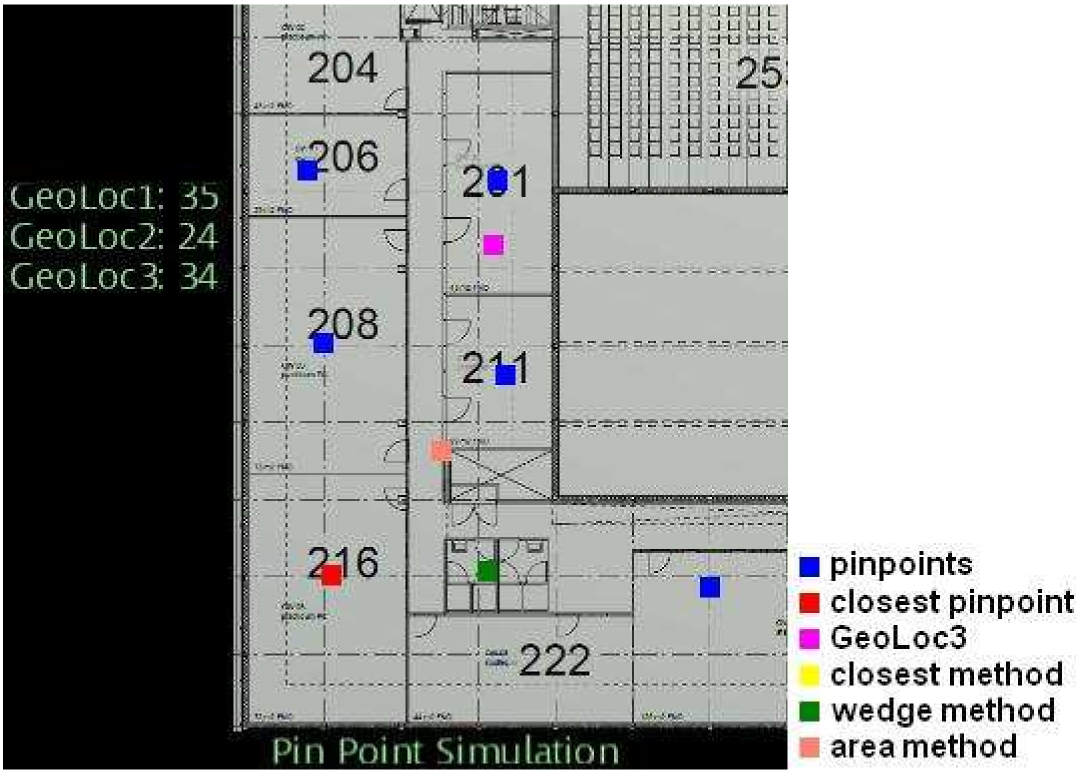

Figure 27: The resulting positions with median feature at the corner near the bathroom

When the tracking methods use the mode feature the following positions are given for the indicated signal strength values.

The preset signal strength values in Figure 28 are 56 for GeoLoc1, 31 for GeoLoc2 and 97 for GeoLoc3, which result in the following three positions of the methods shown in this Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

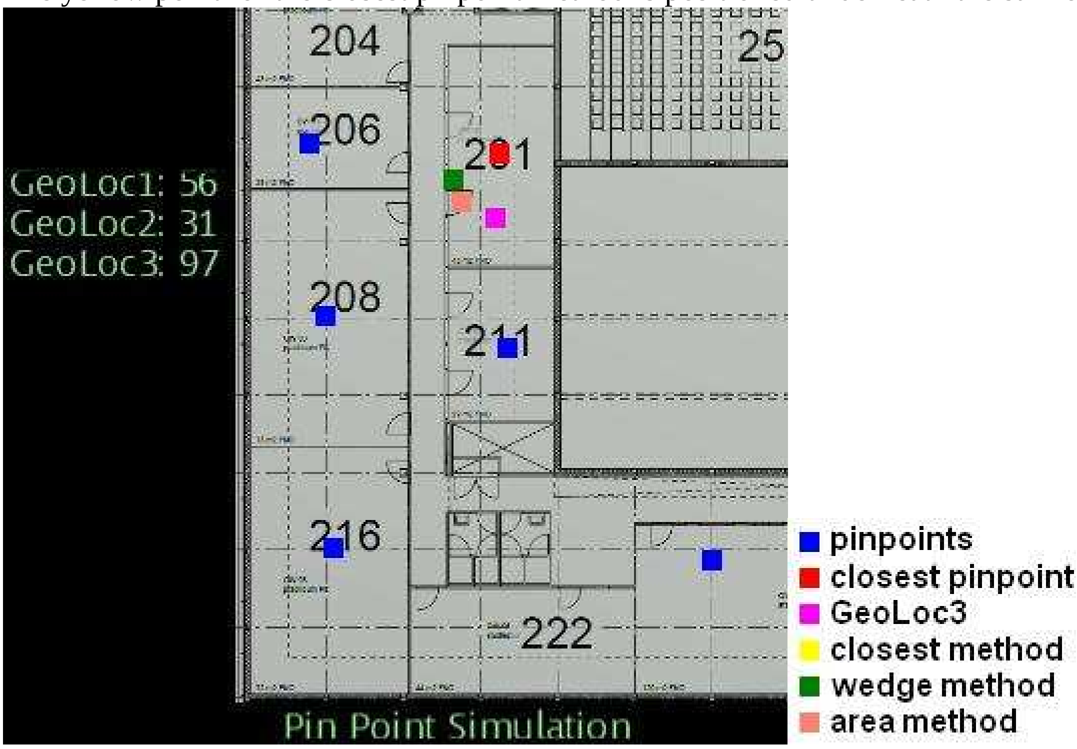

Figure 28: The resulting positions with mode feature in front of the door inside 207

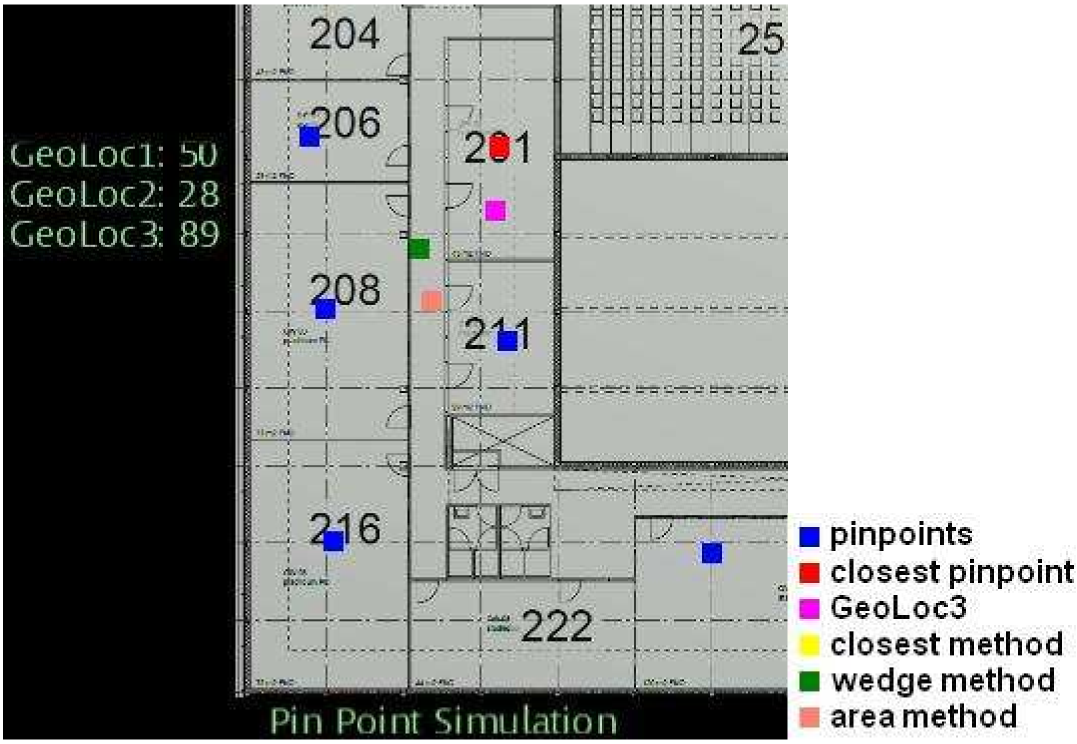

Figure 29: The resulting positions with mode feature in the hallway

The preset signal strength values in Figure 29 are 50 for GeoLoc1, 28 for GeoLoc2 and 89 for GeoLoc3, which result in the three positions of the methods shown in this Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

The preset signal strength values in Figure 30 are 35 for GeoLoc1, 27 for GeoLoc2 and 38 for GeoLoc3, which result in the following three positions of the methods shown in the Figure. The yellow point for the closest pinpoint method is positioned underneath the salmon point.

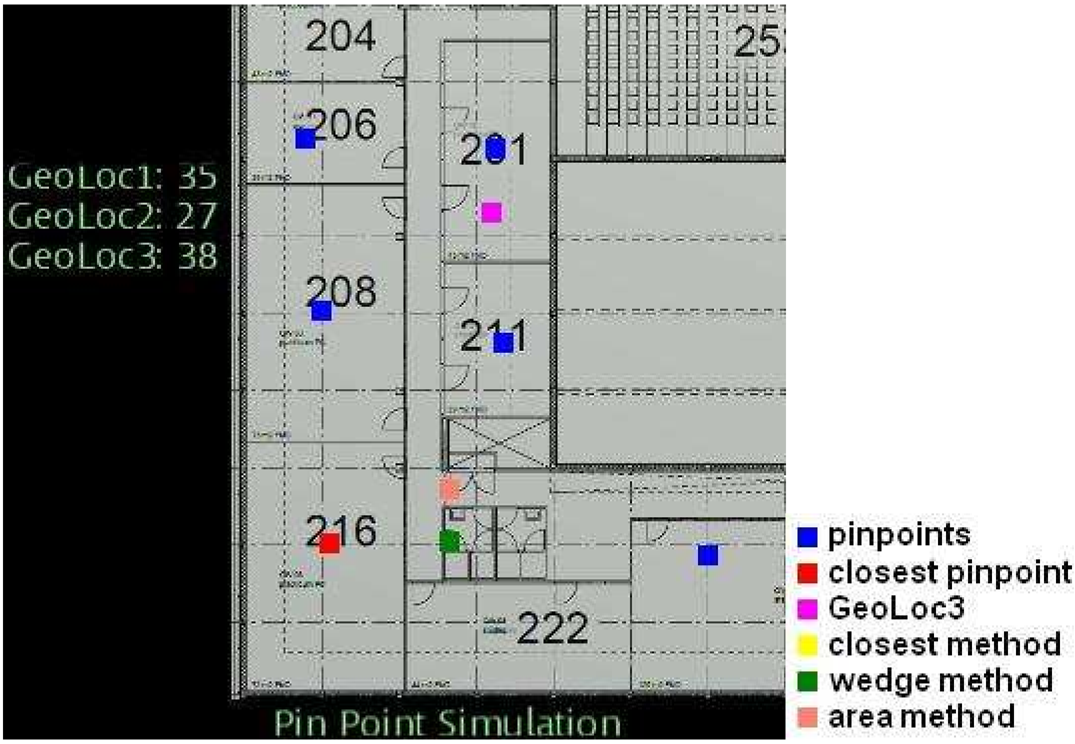

Figure 30: The resulting positions with mode feature at the corner near the bathroom

The results given by this subsection are generated by the system developed for this research and are parts of the screenshots made of the system its graphical user interface (gui).

7 Discussion

The results of all the tests that have been performed are discussed in detail. With these results the methods are compared to each other, even the features used by the methods are evaluated. The results displayed in “7.2 Precision test” subsection are the complete set of results per test to get an entire overview of them. For a closer view the corresponding figures in the “6 results” section can be consulted.

A precision check with the use of the results from the position test is discussed first. This is done for all the tracking methods and the individual features that are used. After this a movement test is done to test the reaction of the system. Then finally a positioning test is done with predefined signal strengths to indicate the approximation of the position in between the pinpoints.

7.1 Expected results

The expectation for this research will first be given as an introduction to the discussion of the results. The predictions of which method will perform better in what kind of circumstances will be given per method. The final part will explain why the combined methods should be performing the best.

7.1.1 Expectation of the overall results

The groundwork for this expectation is already laid, because of this research its theory and of the earlier mentioned points of room uniqueness and the linear degradation of the signal when there is a perfect line of sight, as mentioned in the “3 Approach” section. When the initial degradation scale shown above in the “3 Approach” section was made, it seemed to degrade very linear almost per meter, thus indicating the precision that would be possible with signal strength measurements.

It is of course true that they sometimes slightly overlap, but usually there where plenty of unique features found for each meter. On top of this the system would be using walls to define each room. As each building is build with rooms and hallways it will be even easier to see degradation in the signal its strength per room. This is why this paper presumes that the system will generally work well even in working environments, which are not as perfect as a lab environment.

7.1.2 Closest pinpoint method

The closest pinpoint method is going to be a less intensive procedure than the other methods and this is all due to the first part of the procedure that produces the distances to the signal points. This is because the actual positioning from these distances is shared by all the methods. The overall performance of this method is going to be reasonably good. An inside in this prediction is given below in three subsections.

Precision

The precision for this method is going to be better the closer to a pinpoint it gets then when the method is used further away from pinpoints. That is why it would be best to place enough pinpoints not to far apart and this method will work better the more pinpoints there are spread around.

So the actual precision is dependant on the number of pinpoints but it is also linked the quality of the pinpoints and the placement. The quality is having the right overall signal strength values and the placement being the smart and most covering positions in the building to ensure a good closest pinpoint detection.

Influences
As indicated in "precision" the amount, quality and placement of the pinpoints is very influential for this method. But the structure of the building is also important to this method because it depends completely on one pinpoint. This is of course linked to the placement of the pinpoints but is sometimes hard to avoid. Buildings can have big dips in signal strengths or even blind spots where the signal can hardly penetrate this can last problem can only be solved by replacing the signals.

This method will suffer if the deviation in signal strength is to big because this could lead to closest pinpoint detection switching which could results in an erratic position.

Comparison
This method is probably going to be solid compared to the other two methods if it doesn't suffer too much from its influences. This method is probably the best in detecting small divergences from pinpoints.

7.1.3 Wedged signal strength method

The wedge signal strength method will generate some uncharacteristic results because it splits up the signal strengths to find the closest positive and negative difference pinpoints for each signal. In theory all of these pinpoints could be different and could even be located at the other side off the building, resulting in strange or maybe incorrect distances to the signal point.

Precision
The average precision of this method is probably constant across the building with a possibility of occasional misplacement. How good the precision itself will be is hard to predict but there is a possibility that it will disappoint.

Influences
The basic influences are the same as the closest pinpoint method ones, with the exception that the number of pinpoint should be just right. An equilibrium needs to be found for this amount there should not be to few but to many may not be good either.

This method is probably also very susceptible to signal strength deviation because it is sensitive to all the signals separately. This is also why this method may perform very different depending on the feature that is being used.

Comparison
Because of the unique design if the signal strength wedge method that splits up the signal and uses them separately it is hard to make a comparison between it and the other methods. The wedge method is probably going to be less stable then the other methods. This method may perform better dependent on the feature that is being used, and may get more result with a certain feature than another method would.

7.1.4 Pinpoint area method

The pinpoint area method is an extended version of the closest pinpoint method. While the closest method only uses the closest pinpoint the area method uses pinpoints in an area depending on how close the closest pinpoint is. This should aid the area method to perform better further away from pinpoints where the closest method could be lacking. The overall performance of the pinpoint area method is probably the same as the closest pinpoint method but with improvement in certain areas at the cost of extra CPU time.

Precision
The precision of this method near a pinpoint should be the same as the closest pinpoint method because if the k nearest neighbours in an area is only one than the area method is the same as the closest pinpoint method. But this depends on the density of the pinpoints.

The rest of the precision should be greater than or equal to that of the closest pinpoint method. Although there may also slip in some negative influence from one or even more pinpoint in the area, this could bring the precision down in specific cases or areas.

Influences
This method suffers from the same influences as the closest pinpoint method but to less of an extent. This method does not require as many pinpoint as the closest method but would probably not suffer if there where more. This method should deliver a more stable result although erratic signal strengths still are problematic. The pinpoint area method should of course be able to detect more then one pinpoint in its area or it will not be effective and just deliver the same result as the closest pinpoint method.

Comparison
This method is probably the average method performing good all-round and it is even possible that it is the best of all three methods.

7.1.5 Combined results

The combined result should have the best results of all the methods. This method will be very CPU intensive because it will run all the other methods in order to get its results. A comparison can hardly be made because it should have the best elements of all the methods.

Precision
The average precision should be the best of all the methods, but the precision of the individual results will not improve.

Influences
Completely dependent on the other methods this method could select results that are not the best because most of the other methods delivered inaccurate results. The result will be the most stable of all the methods but it can still not filter out the signal strengths deviation peaks.

7.2 Precision test

The precision test is performed by placing the tracking device in one position and measuring the Euclidean distances from the predefined position to the tracking methods their resulting positions. But this test does not only show the precision on that position but also how much the signal strength will deviated during the test which influences the precision directly. For the testing position a position in room 207 is chosen to be sure that the position was available for multiple test over lengthy periods of time. This test position is located next to GeoLoc3 on the right hand side close to the window.

The precision values of the system are given in meters (m). In Figure 7 the map is shown that the system uses. For this map the length of one floor from top to bottom is 18.76m.

7.2.1 Closest pinpoint method

The closest pinpoint method is counting on the single pinpoint that needs to convey the area around it for a good conversion to the current measurement its position. It is therefore very important for this feature to detect the correct pinpoint that is closest to the current measured value in order to achieve the best precision possible.

The results from the closest pinpoint method test are shown in Figure 31, displayed are the three single value features used by this method.

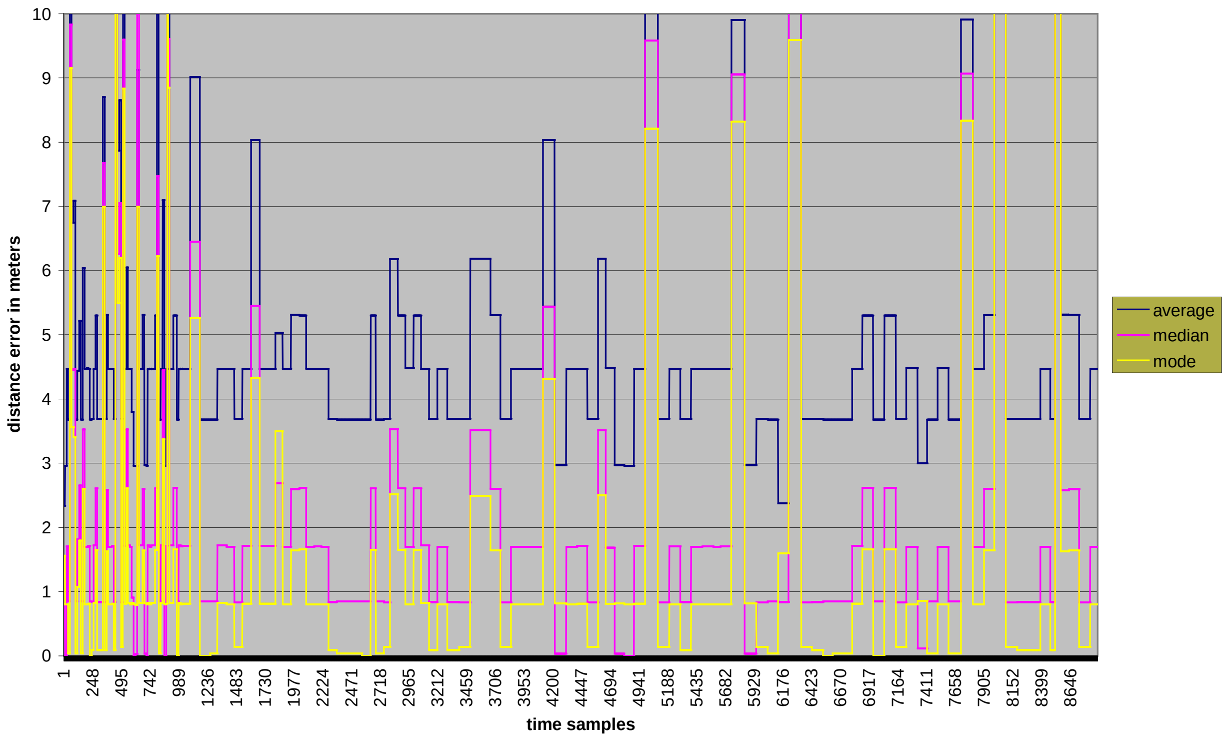

Figure 31: Distance error results for the features used by the closest pinpoint method

From the graph in Figure 31 it can be concluded that the median and mode feature produce better results for the closest method than the average feature this concurs with the results from [16].

During the test it can also be seen that there were moments of signal interference, which resulted in incorrect signal strengths and thus positions. Another thing that can be noticed is that in the first 1000 time samples the signal updated much faster or that in the rests of the time samples the signal was more stable/continues for longer time periods.

Any result under 1 meter can be seen as a perfect score. A person is normally a half by a half meter when standing, and because the direction of standing can not be determined through signal strengths, the person holding the measuring device can turn all the way around which corresponds to the meter of precision needed maximally.

During the time of the test the Average precision of:

- closest average ≈ 5.03m
- closest median ≈ 2.30m
- closest mode ≈ 1.55m

But this is not the complete indication of the actual precision because most of the precision loss is due to the signal strength deviation than can easily be seen between the features as they almost all react to it in a similar way.

Overall the precision of the closest method is satisfactory considering the most results are around or under the 3m mark which is the size of a small room. Also taking into consideration that it is tested in a real work environment with cheap access points, the results would only be able to improve.

7.2.2 Signal strength wedge method

The wedged signal strength method is an intrigued technique. All the different signals are split-up and individually matched to the pinpoints. Resulting in the closest values higher and lower then the current value. With this the distance difference between them can be determined and used to get the current measurement its location.

The results from the signal strength wedge method test are shown in Figure 32, displayed are the three single value features used by this method.

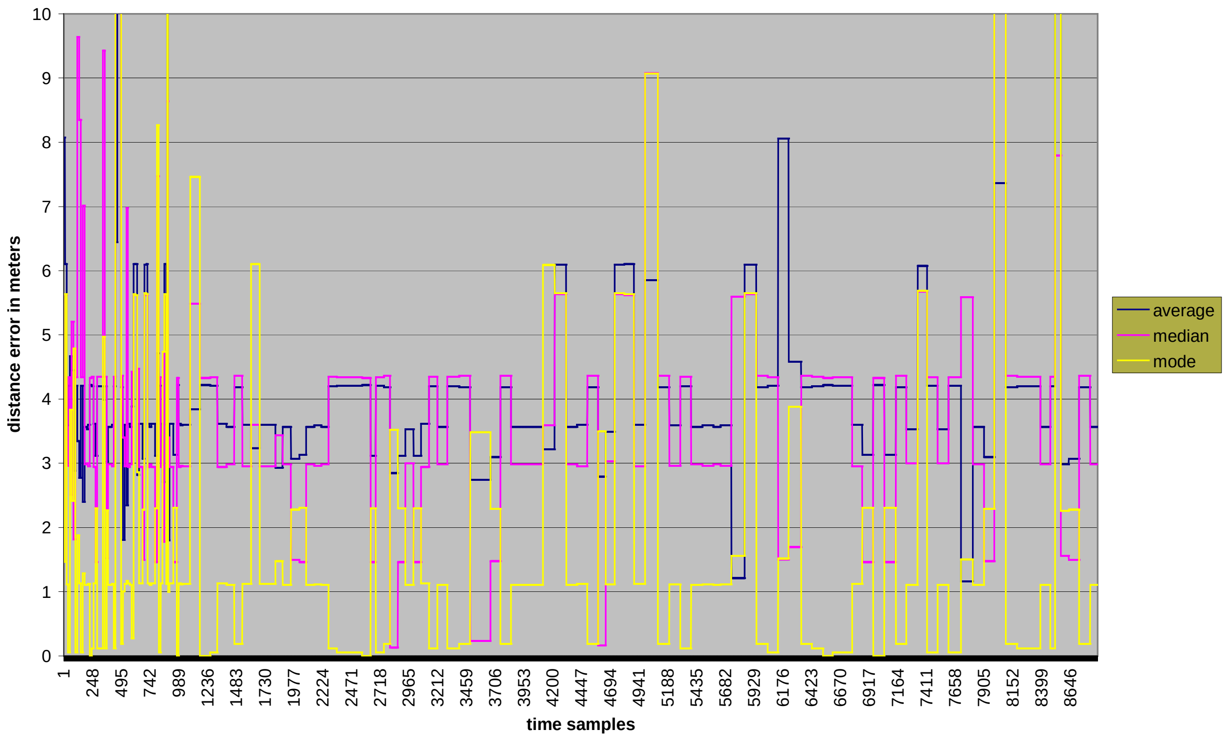

Figure 32: Distance error results for the features used by the signal strength wedge method

Remarkable is that between these features the median and the mode are not close to each other, while their pinpoint values are rather close as can be seen in table 1,2 and 3 and from the results in [16]. Nevertheless the mode is still performing strong and the best for wedged signal strength method.

Looking at these results it seems that they are more erratic than the results from the closest pinpoint method although this method suffers equally from the signal interference. It seems that the wedged signal strength method reacts different to the signal strength deviation then the other methods and that the average feature performs best with the wedge method.

The mode feature for the wedge method is often very close to the perfect score mark of 1m, that it is a shame that if the signal suffers from minor interference it results in high precision loss or an unstable position.

During the time of the test the Average precision of:

- wedge average ≈ 4.01m
- wedge median ≈ 3.73m
- wedge mode ≈ 1.85m

Overall the signal strength wedge methods its precision is still within acceptable performance levels. But because of the special design for this method it cannot be guaranteed that it will even remotely perform the same in a different environment.

7.2.3 Area pinpoint method

This method uses more pinpoints to get an overview of the building section it is in. The further the current measurement is away for the closest pinpoint the bigger the area is of pinpoints that are used.

The results from the area pinpoint method test are shown in Figure 33, displayed are the three single value features used by this method.

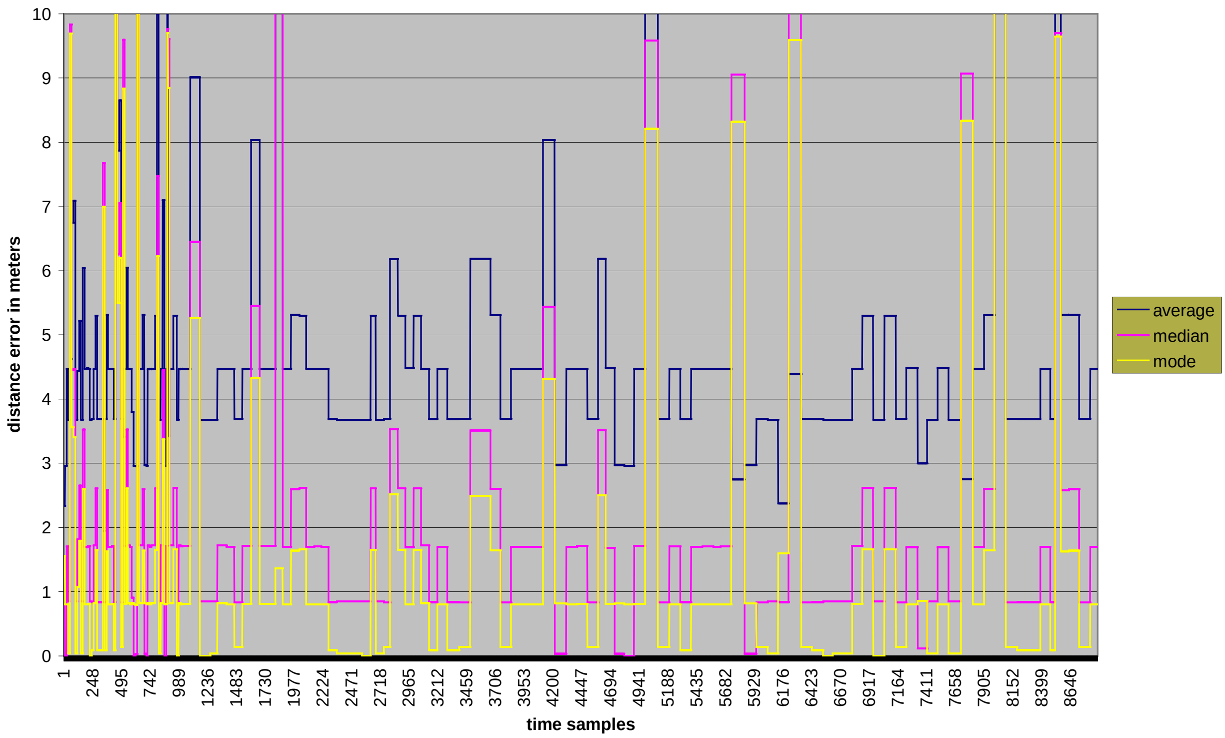

Figure 33: Distance error results for the features used by the area pinpoint method

The results for the area pinpoint method are largely the same as the results for the closest pinpoint method except when the signal deviated away from the closest pinpoint the precision is slightly better. Unfortunately it also has some extra spikes.

During the time of the test the Average precision of:

- area average ≈ 4.75m
- area median ≈ 2.42m
- area mode ≈ 1.62m

With the area average we can see that it can do better then the closest average but the median and the mode prove that the extra precision lose spikes have an overall negative effect on the average precision.

The pinpoint area method its overall precision is reasonable. But the area detection idea behind it is not working satisfactory and should have delivered better results.

7.2.4 Combined methods

As the results from all methods are combined this method tries to select the best results from each of them and merge them to get the best overall result possible.

The results from the combine methods test are shown in Figure 34.

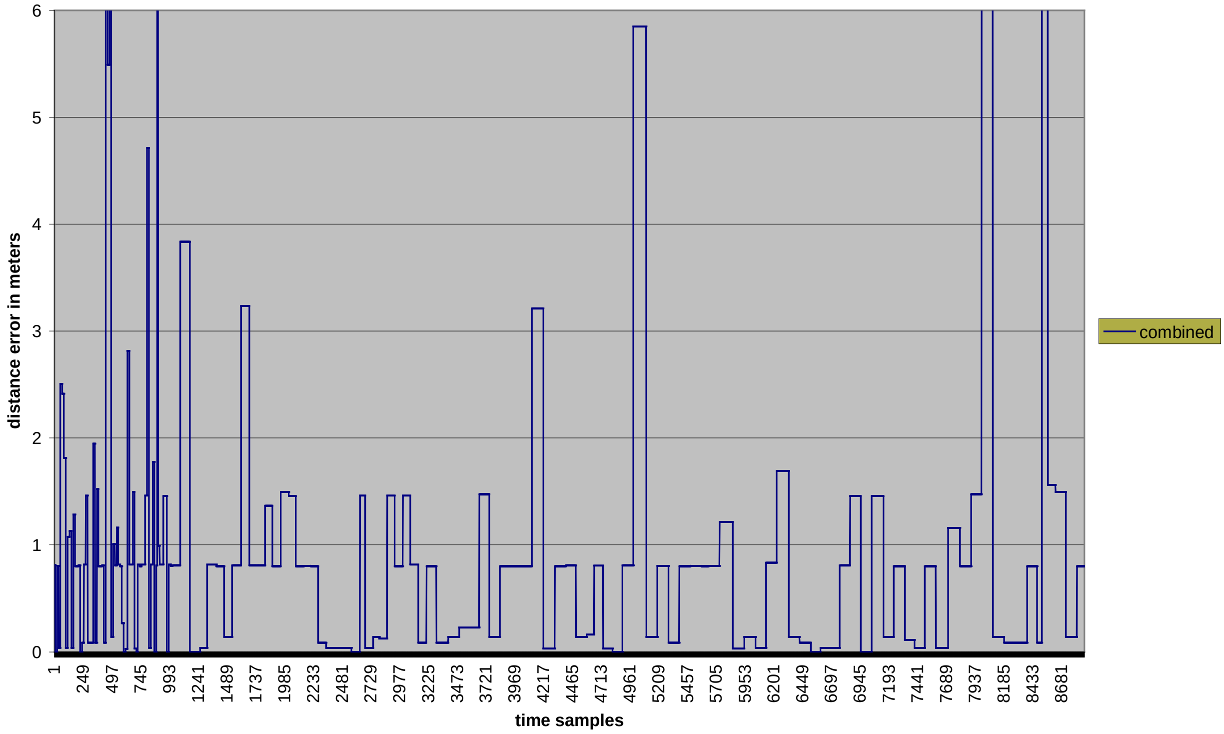

Figure 34: Distance error results for the combined methods

Coincidently this test has resulted in the combination of the best results from the other methods and can show the ideal result of the combined method. It can also be seen that if all other methods fail this method will also fail, but if only a few have a large deviation this method can filter those mistakes out of the results.

Average precision of the combined methods and features is rounded off 0.9m.

The overall precision of the combined methods is very good for the ideal case. In theory there are situations and cases where the combined method will not work so well, that is why there is no guarantee that it will always function so well. But despite of that it will never produce worse results then those produced by the individual methods. Taking these points into consideration, the combined methods will most likely always produce the best overall results compared to the methods. Further it can be concluded that every method is intolerably influenced by the signal strength deviation, which can have a serious impact.

7.3 Movement test

The movement test is done to see if the tracking methods can also be used for active tracking of a moving target. The main requirements to test for are the update rate of the signal strengths and influence of signal strength deviation. This test is not suited for a predetermined path comparison. Because it is very hard to compare the resulting times at the corresponding positions of the test with the predefined path positions. This is hard because of variables like various walking speeds, path deviations and other unforeseen interferences. Therefore it would not give precise results like precision test already did and would thus not be required to perform this part. Also because [16] has already performed a pathing test and can be consulted for his results.

All movement test performed did not result in noteworthy better result then the path test results presented in [16]. With how the test situation is set up together with the environment and used equipment it would hardly contribute to the results in [16]. This is because the signal strength deviation corresponds to half the distance between the pinpoints and is close to the distance a person would normally move when travelling indoors. Plus the fact that moving targets are highly dependent on the signal strength update frequency to get the right values on the exact times needed, which could not be achieved nor guaranteed.

The conclusion of the movement test is that the update rate of the signal strengths could not be regulated and were far from constant. This could already partially be seen in the results over time from the precision test with the added fact that a signal could sometimes not be pickup thus only reading two signal strengths. Some of the time the refreshment rate of the signal strengths was good but this could not be maintained nor guaranteed for even one test period, let alone continuously. The signal strength deviation has a very big negative impact on active tracking and was too big to receive viable results. A possible solution for this would be to get better transmitters and if necessary receivers.

7.4 Predefined signal strength test

With the predefined signal strength test the three signal strengths from geoloc1, geoloc2 and geoloc3 are set manually. This test will show where the methods their resulting positions are displayed when the signal strengths have a certain set of values.

It is important that signal strength values are tested which can really exist. Because not all signal strength combinations are viable. Therefore three tables are given for the pinpoint signal strengths to get a general idea of the signal strengths at certain positions. Also an eye needs to be kept on the structuring which might influence the signal strength.

For the Figures used in the next subsections the colours of the points are:

- Blue is pinpoints
- Red is closest pinpoint in signal strengths
- Magenta is GeoLoc3
- Yellow is closest pinpoint method
- Green is wedge signal strength method
- Salmon is area pinpoint method

Unfortunately the yellow point is very often positioned under the salmon point because it is hard to separate them at the test positions and have feasible signal strengths.

7.4.1 Average feature

In this part of the tests the average feature is used to test its performance and to show the differences in methods that use this feature.

In Table 1 the average feature signal strengths for the pinpoints on the map are presented.

Average	GeoLoc1	GeoLoc2	GeoLoc3
206	17.1843460350154	11.2662721893491	80.8326530612245
207	52.9545715928695	35.8884321785085	92.6394849785408
208	25.6078157711096	20.2143364088006	84.0264239577217
211	62.0308395202741	56.4565345949143	81.685527099464
216	27.3386211104332	18.7876447876448	43.1360741169658
228	57.9132851584213	36.3583098591549	35.2444725205306
cantina	69.6211604095563	42.8171557562077	17.9040307101727

Table 1: The pinpoints signal strengths for the average feature

In this part of the test some positions near doors are estimated. The first is located in front of a door in room 207 as can be seen in Figure 35. The second one as shown in Figure 36 is on the outside of room 208 in front of its door. The last is positioned on the inside of the lower door of room 208, as shown in Figure 22.

If the signal strengths from the test in Figure 35 are compared to the values of the pinpoints in Table 1 the resulting positions are positioned close to where they would be suspected. This is a good test to show that small signal strength differences can result in a small and correct distance difference. The results from the three tracking method are close to each other, with the closest method and the area method located on the same position because of the closeness to a pinpoint.

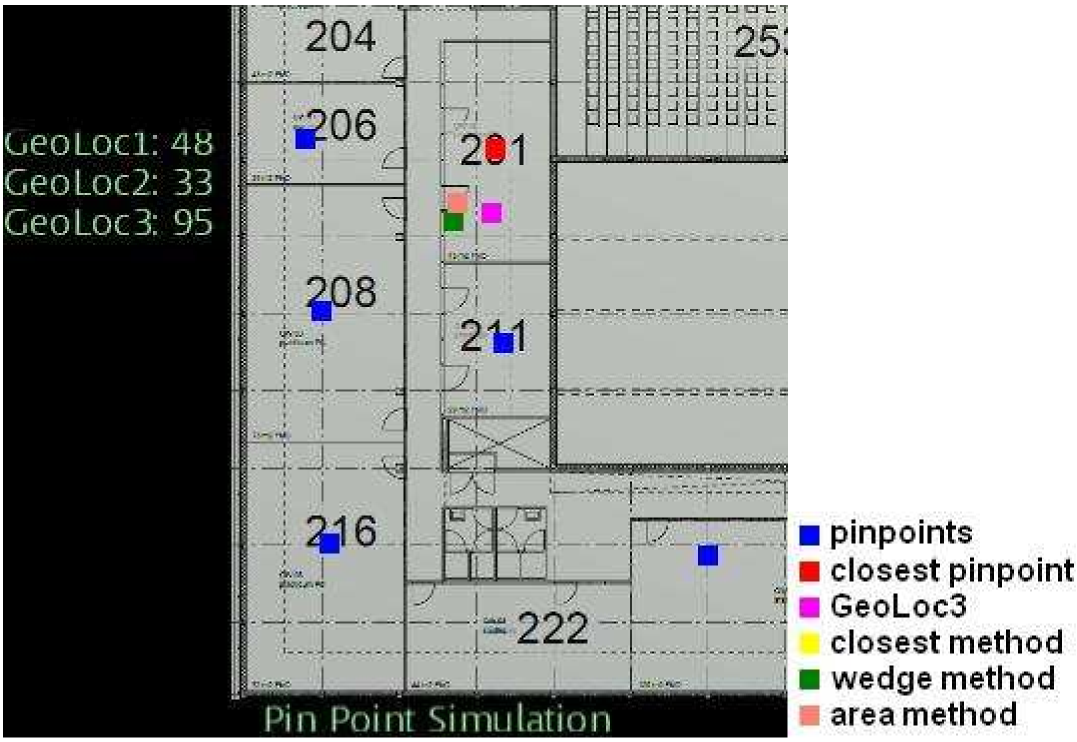

Figure 35: The resulting positions with average feature in front of the door inside 207

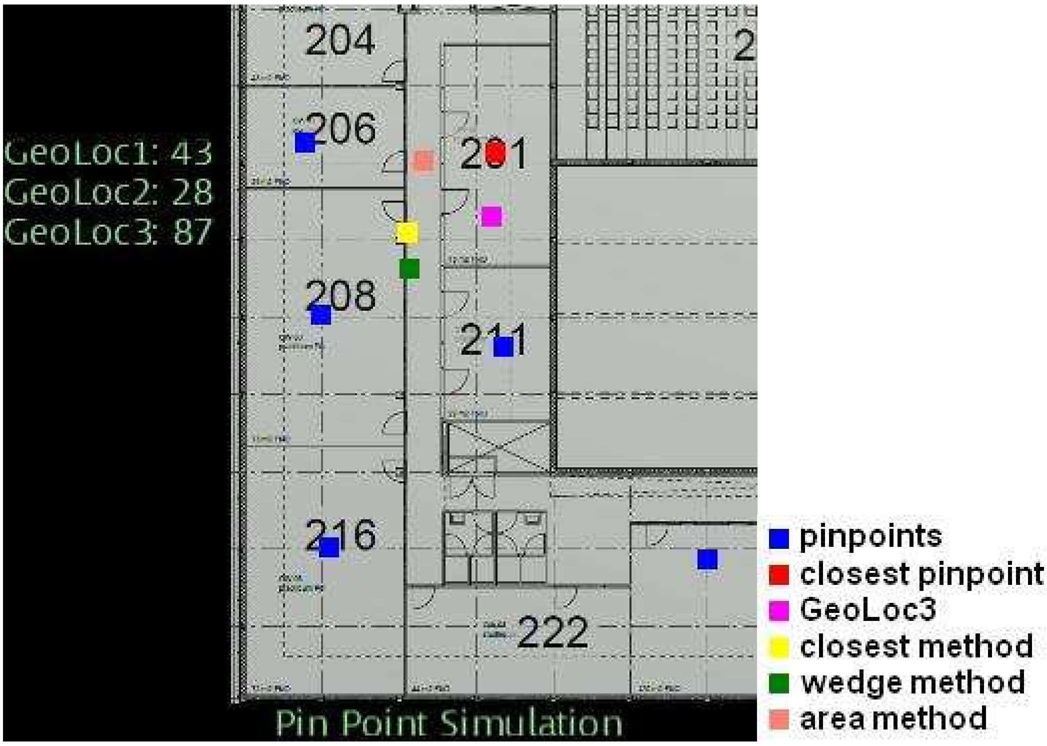

Figure 36: The resulting positions with average feature in front of the door outside 208

In Figure 36 it can be seen that the resulting positions from the methods are fairly different, but it cannot be said that some may be wrong. Because if the signal strength values are compared to Table 1 it is not as easily determined where the actual position would be located. When looking at the positions individually each of them hold some merit. It may be concluded that it is a difficult location to reach a defined result.

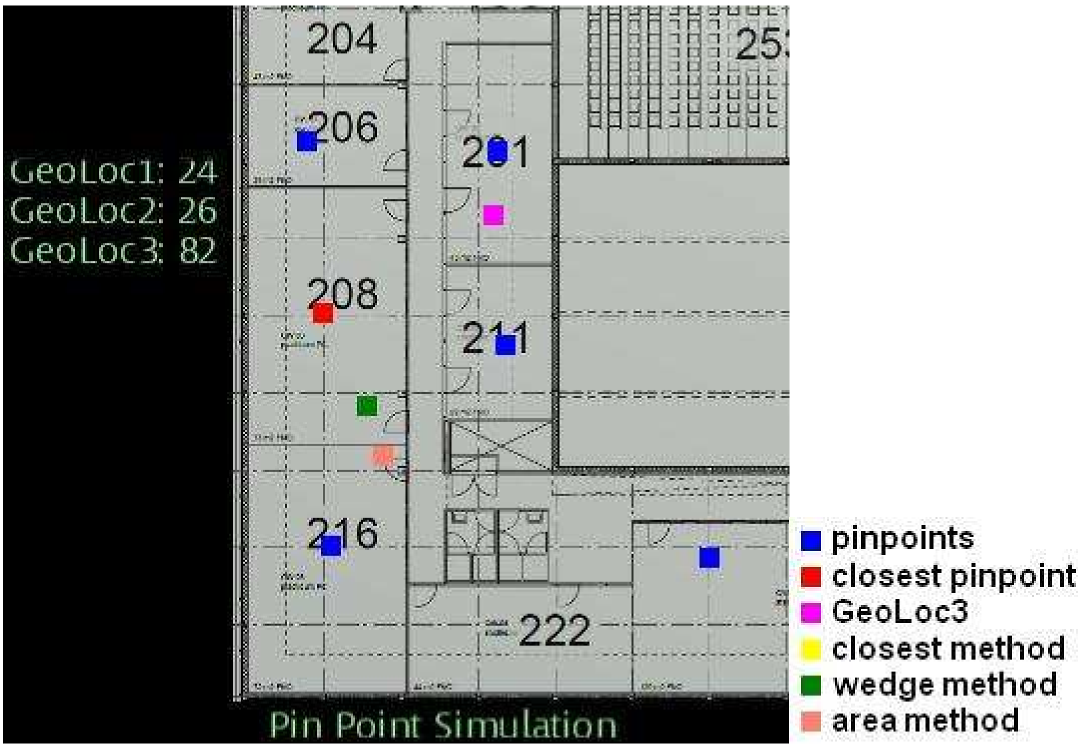

Figure 37: The resulting positions with average feature in front of the door inside 208

When looking at the position in Figure 37, it seems a little strange that the closest pinpoint method and the area pinpoint method points are also located in the same position. Because the location is located close to three pinpoints the area method should thus be influenced by all of them, unlike the closest pinpoint. But when comparing the current signal strengths with the three pinpoints in Table 1 it is clear that those strengths are much closer to 208 then the other pinpoints. Therefore the area method its area is to small to consider the other points or the other points there influence is just to insignificant and the points are coincidentally in the same position.

The position itself may not be entirely in the right position; maybe it should be a bit closer to the pinpoint in room 208. On the other hand looking at the environment the signal drops very rapidly for points behind (when looking from the signal points) the room with the cross in it in the middle of the map above the bathroom. The position would not be influence very much by this and therefore the signal strengths would concur closely with the real situation. This may just be coincidental.

7.4.2 Median feature

The median feature is also used to show the differences between the tracking methods while using this particular feature. The signal strength values for the pinpoints on the map with the median feature are presented in Table 2.

Median	GeoLoc1	GeoLoc2	GeoLoc3
206	16	12	81
207	60	36	94
208	26	20	87
211	64	60	83
216	28	18.5	40
228	62	36	34
cantina	70.5	40	18

Table 2: The pinpoints signal strengths for the median feature

With the median feature some outer positions are tested. A position near the lower wall in room 206 and a position close to the corner near the bathrooms. These can be seen in Figures 38 and 39 respectively.

In Figure 38 a test with lower signal strength values is presented. This is done to indicate that outer position values can still deliver decent results. The three methods are even located closely together (but this is probably do to the closeness of the pinpoint). The position it self is imaginable if the signal strengths are compared to the values of Table 2.

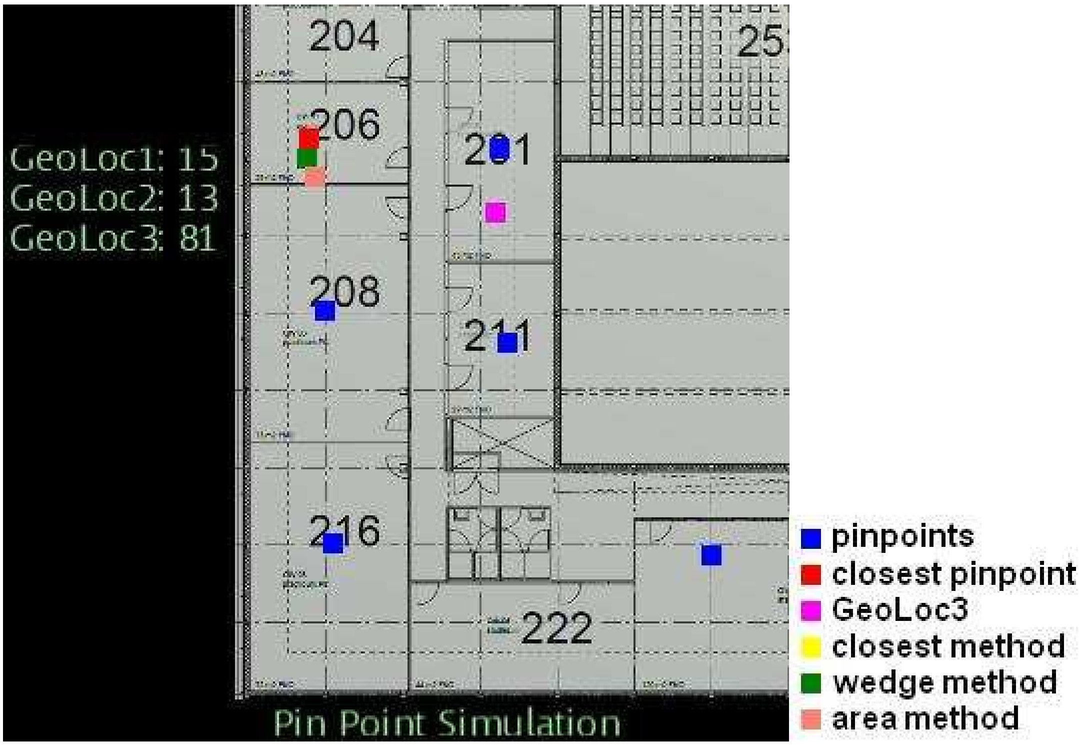

Figure 38: The resulting positions with median feature at the lower wall of room 206

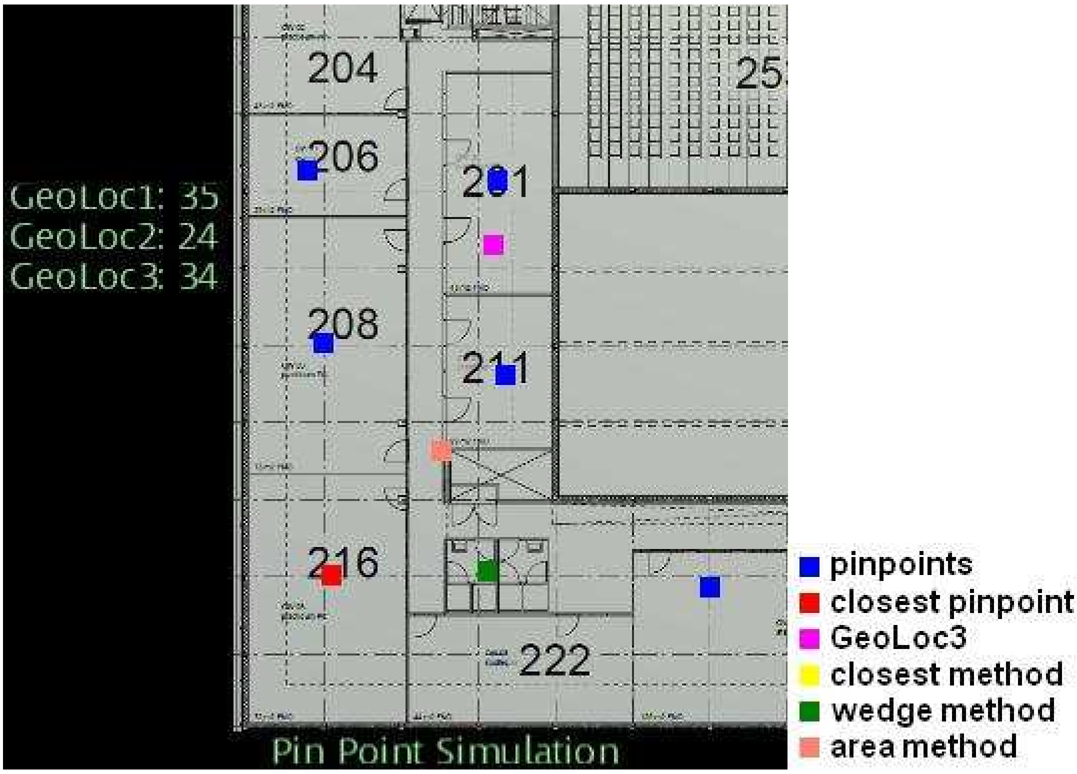

Figure 39: The resulting positions with median feature at the corner near the bathroom

In Figure 39 a very difficult position test is performed. Real signal strength measurements on the corner position in the hallway are very low and often drop away. That is why it would be interesting to see if this position can be approximated with this test.

As can be seen the signal strengths are indeed low but the methods can’t really get a fix on the expected position. It can be concluded that this is really a difficult position, to overcome this a solution would be to replace the signal points.

7.4.3 Mode feature

The mode feature has significant different values then the average feature but closely concurrent values to the median feature. This is why it is most interesting to see how the three methods perform respective to each other with this feature.

The mode feature generated signal strengths values for all the pinpoints on the map are presented in Table 3.

Mode	GeoLoc1	GeoLoc2	GeoLoc3
206	18	14	80
207	60	34	95
208	26	22	87
211	64	60	84
216	28	18	38
228	50	36	34
cantina	70	40	16

Table 3: The pinpoints signal strengths for the mode feature

In this part of the test some diverse positions are tested. The first one as shown in Figure 40 is at a door in room 207. The second is in the hallway between rooms 207, 208 and 211 as shown in Figure 41. The last is shown in Figure 42 and is located close to the corner near the bathrooms.

In figure 40 the position near the door of room 207 is tested again. The results are satisfactory in compliance to the comparison of current signal strengths to the values from Table 3.

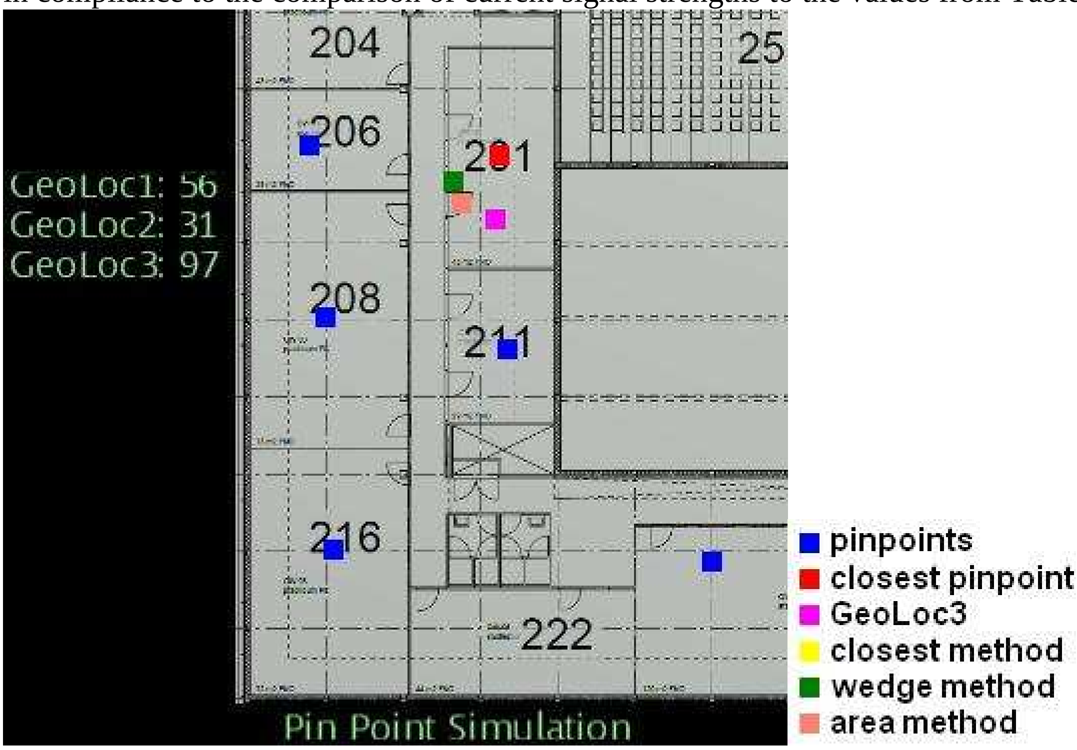

Figure 40: The resulting positions with mode feature in front of the door inside 207

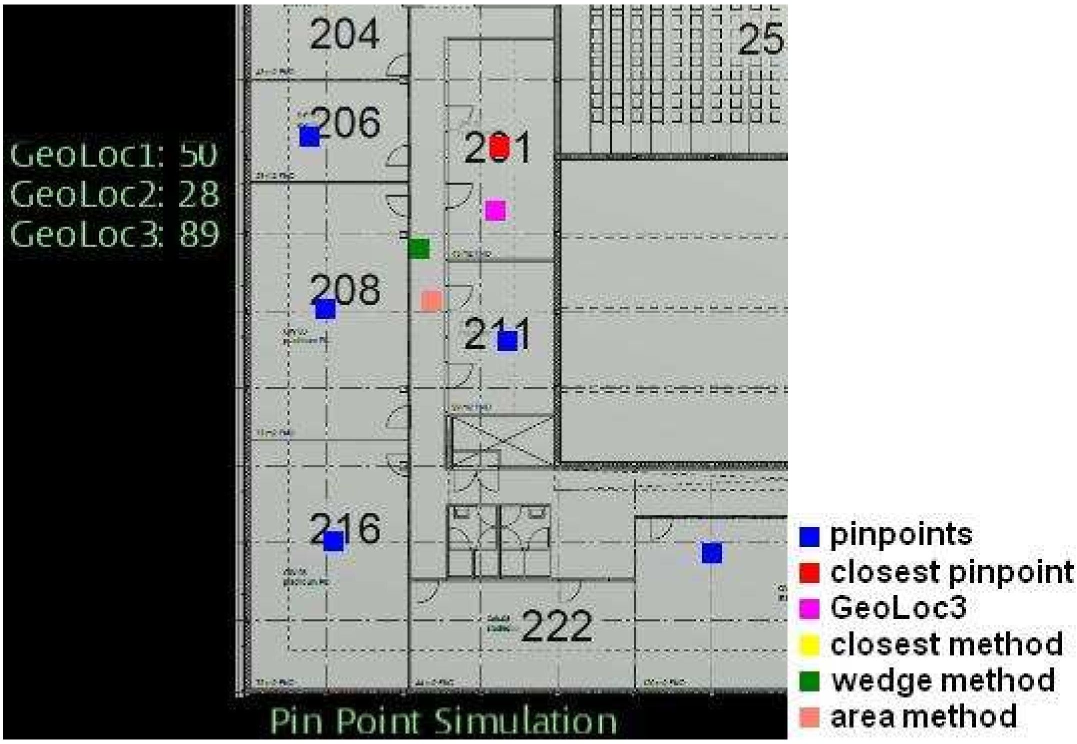

Figure 41: The resulting positions with mode feature in the hallway

The test position in figure 41 is a little bit lower in the hallway right in between rooms 207, 208 and 211. The resulting positions are fairly close the expected position from the comparison of the corresponding signal strengths to the values in table 3. What cannot be explained is that the closest method point and the area method point are not positioned separately; it may just be a coincidence that they are located together.

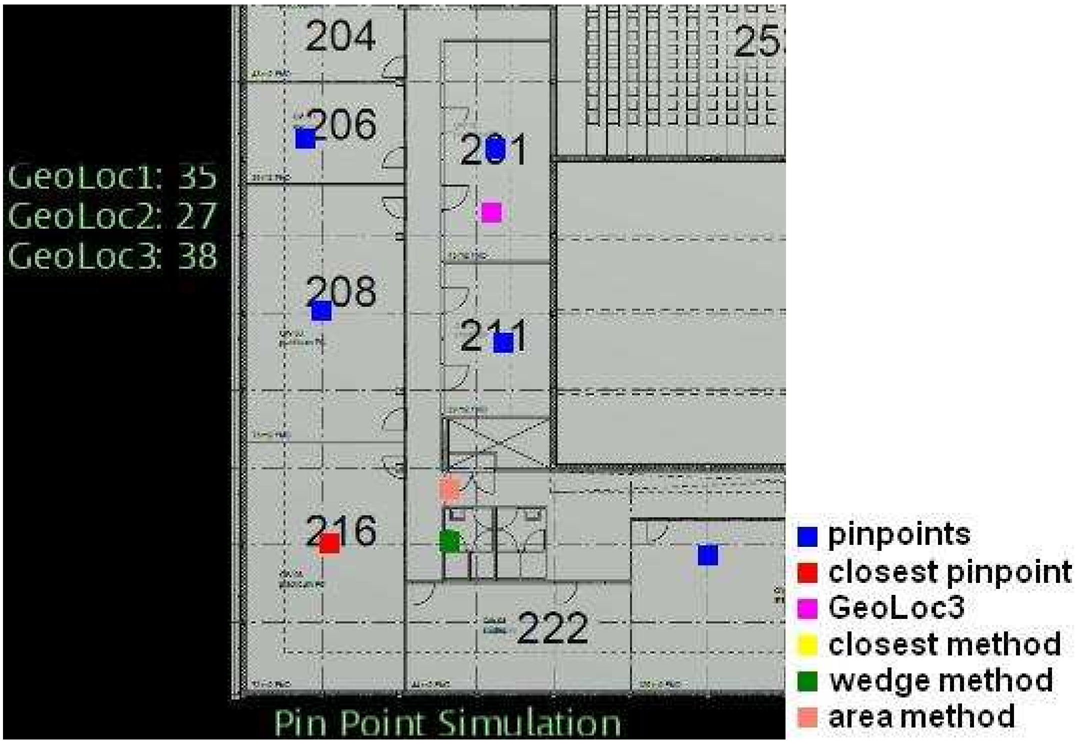

Figure 42: The resulting positions with mode feature at the corner near the bathroom

The final test is testing the position on the corner of the hallway again. The result from this test can be seen in Figure 42. Once more the current values are checked with table 3 to determine the position.

It seems that the resulting positions of the methods using the mode feature are close to the envisioned position. This accentuates the fact further that the mode feature functions the best for all methods.

7.5 Discussion summary

The results from the precision test have shown that the tracking methods can position the receiver fairly accurate for the specified test location. Most methods have an accuracy of about the size of a small room or better. The mode feature preformed the best for all the tracking methods closely followed by the median feature.

In Table 4 the results of the average precision over time have been calculated and rounded off.

method\feature	average	median	mode
closest	5.04m	2.30m	1.55m
wedge	4.01m	3.73m	1.85m
area	4.75m	2.42m	1.62m

Table 4: Average precision over time in meters of the tracking methods using the features

The results of the combined methods are very good for the specified test location. The accuracy of the combined methods is often below one meter of precision. The average precision of the combined methods and features over time is rounded off 0.9m.

Unfortunately the test set up used by this research was not responsive enough for active tracking. The main reason for this is the signal strength deviation of the transmitters and the irregular refresh rate of the signal strength. This is proven by the fact that the tracking methods produce suitable results if the signal strengths are preset manually. The results from the predefined signal strength test are close and in most cases better than the average precision of the precision test. Which demonstrates that the methods would be capable of tracking throughout the environment.

8 Conclusion

The system made to support, test and confirm the tracking methods has overall turned out and performed slightly better then expected. Also when looking at the results and conclusion of the research from [16] (research partner), it is very important that it has achieved such good results because this research depends on it to function well.

Using the pinpoint features to define an environment and use the combined information as a mapping of the area works really good. This can be concluded from the predefined signal strength test in the “7 Discussion” section. This mapping of an environment is really very useful for indoor location techniques and has certainly proven its worth. With this and the predefined signal strength test the theory behind the tracking methods have been confirmed to work well.

Even in an actual work environment with all its interferences the tracking methods performs good enough at indicate the location of the receiver. This has been shown in the “7.2 Precision test” subsection. Even with the cheap routers the average precision on the test position was good enough to detect a small room and in some cases even close to one meter precision.

Unfortunately the system was unable to produce noteworthy results for active tracking of a changing position. This is mainly because the signal strength deviation corresponds to half the distance between the pinpoints and is close to the distance a person would normally move when travelling indoors. Furthermore moving targets are highly dependent on the signal strength update frequency to get the right values on the exact times needed, which could not be achieved nor guaranteed. The causes of this are probably the transmitters chosen but there may also be some interference with the receiver.

Is it possible to use the stored data in the Calibration Pinpoints, Calibration Features and the Mapping of the environment to set up a system capable of device localisation with further precision?
Tracking methods have been devised to do just that. The tracking methods have been designed with different location techniques and they make use of the single value features to extract required information out of the pinpoints. For an in depth view of the tracking methods see section 4.

What are the steps to set up a system based on pinpoints, and how is it deployed in an existing building?
This has been answered in the “5 Experimentation” section where the implemented experiment has been set up and elaborated. “5.1 Setting up the experiment step by step” is a subsection that explains the set up procedure in general. Scouting the environment in a building, placing the signal point, measuring the pinpoints and reading out the pinpoints with the features.

Which tracking method is capable of detecting a position in between the pinpoints?
All the proposed tracking methods show promising results and can detect a position in between the pinpoints. All the tracking methods are a step upwards compared to just detecting the pinpoint locations.

Which features work best for the tracking methods?
The test results have indicated that the mode feature performs the best for all tracking methods. The median feature also performed rather well and is a close second except for the wedge signal track method, where it performed closer to the results of the average feature. The average feature performed the least of all the tested features, but was still acceptable. With the results from these single value features in mind it might be interesting to see how multi value features will perform.

What is the precision of detecting a position in between the pinpoints?
For most methods the average precision is about the size of a small room or better this is highly dependent on the feature used. The average precision of the combined methods is smaller than one meter. These results indicate that the precision of the tracking methods can be really good.

What are the biggest influences on the system?
A correct and sufficient placement of the signal points and pinpoints is very important to the system and really influences the mapping of the environment en the eventual results. It is essential that blind spots are avoided. Moving signal strength blockers are unfortunately unavoidable, but with the moving nature they are will not interfere with the signal for long. Another big influence on the system is the fluctuation of Signal strength and its resulting deviation. The Signal strength update rate can also cause some problems because the system can only detect the position of the current signal strengths, but if they have not been updated yet this position may be incorrect.

Is it possible to actively track a position in between the pinpoints?
Because some influences are to big active tracking is not possible with the currently used test set-up. The main reasons for this are the Signal strength deviation and the update rate of the Signal strength.

The final conclusion is that indoor location based on Signal Quality or Signal Strength can work really well in an actual work environment. The mapping of the environment with the pinpoint feature values really established a good working base for the tracking methods to work with. When looking at the precision of the tracking methods they show great potential to be implemented in for example a smart house.

There is definitely also room for improvement and further research. An enhancement that would be interesting for further research is buffering the current measured signal strength to solve problems with slow signal strength updates or faulty readings. These problems might also be solved by calculating an estimated position and than check if the next position does not diverge too much. Another improvement would be to make the tracking methods compatible with multi-value features. These future enhancements and further research are proposed in the next section.

9 Future Work

Because every research is benefited by improvement this section is dedicated to the specific improvements for this research and any further research that might be linked to it. There were already some ideas for improvement thought of during the process of analysing the results. Other things to add and try out will also be mentioned in this section.

This paper has shown the results of the research in finding the devices location in between the Pin Points. It would be interesting to add more precision to the methods that were investigated. There has already been looked into a few of those together with the research partner from [16]. For example a method that used the pinpoint detection scores from [16] as a distance ratio between the pinpoints was also part of the initial tracking methods. But this method did not deliver correct results and would need serious rethinking to get a new viable method. However it would be interesting to see if further improvements too all the methods are possible. Especially when thinking of actively tracking a device through a building with a precision of about 1 meter.

Both researchers agree that this might be possible if the current techniques are improved together with smart deployment of Pin Points maybe even multiple Pin Points per room, for example one in every corner. A technique which might be interesting to examine, is linked to the mapping of the environment where the system may take into consideration the actual mapping of walls which could be detected beforehand by looking at the average degradation of the signal strength between pinpoints.

All of the further active tracking research would have to have better transmitters that have a steadier and more stable signal and maybe even other receivers, which can achieve a steady refreshment of the signal strengths. Other procedures that can help active tracking or improve the methods are: techniques to indicate incorrect signal strength readings; creating a buffered current signal strength reader; calculating the estimated next position; making the tracking methods compatible with multi-value features. For further precision one can also look into different methods and even having the server itself keep a history of the path a person usually walks and learn to improve it’s precision from that.

It is unfortunate that these points could not be investigated during the current research its given time. These point look like very promising additions to the system and are probably really interesting to research. Additionally this research will probably aspire other new unexplored research topics and of course further refinement and improvement even beyond the few points mention in this section.

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