CHALMERS

IMPROVING WIRELESS RADIO HARDWARE/SOFTWARE CAPABILITIES FOR INDOOR POSITIONING SYSTEMS

Master's Thesis in Communication Engineering

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Abstract

Ever since the invention of the global positioning system (GPS), localization around the globe has been an important issue regarding navigation systems and security. Its main disadvantage is that it is limited to outdoors environments with good conditions.

Because of that, there has recently been an increasing interest in location techniques for indoor scenarios, where hardware will play an important role. Its main disadvantage is that it may impose some constraints, like not being accurate enough or losing the signal range due to walls and items in the signal's path.

The work presented here reports a study of the ranging accuracy for an indoor positioning system, the nanoLOC Development Kit 3.0 developed by nanotron Technologies, in an office environment with line of sight (LOS). Using previous studies in the area, the purpose of the thesis is to analyze the capabilities of the different devices in the kit and statistically study the collected data, in order to improve the accuracy of the obtained measurements.

The statistical analysis is carried out using cumulative distribution function (CDF) graphs. These kinds of graphs provide the probability to obtain a certain distance from the boards. With that distance in mind and knowing the real length between a specific anchor and the tag, it is possible to reduce the innate error given by the boards, by taking away the difference between the two distances.

The results show that the accuracy of each of the devices is improved considerably in office environments where the conditions for the LOS are good. But it also shows that, randomly, the equipment gives big errors, which makes it not good for environments where precision is aimed.

Keywords: GPS, indoor localization, accuracy, nanoLOC Development Kit, anchor, tag, cumulative distribution function

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And finally, but not least, I would like to thank my family, for being always there and giving me the chance to study abroad.

Adrián Rubio, Gothenburg, Sweden, June 11th 2012

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Notations

CDF	cumulative distribution function
GPS	global positioning system
IPS	indoor positioning system
LOS	line of sight
NLOS	no line of sight
RF	radio frequency

1

Introduction

This chapter will introduce the reader with a background to the thesis, continued by its purpose, limitations and methods used. Finally, an explanation of the structure of the report will be given.

1.1. Introduction

1.1.1. Background

Ever since the invention of the global position system (GPS), localization around the globe has been an important issue regarding navigation systems and security. At the beginning, its use was only military; but soon it was released to public use with some limitations on the accuracy.

The technology has been evolving over the years up to what we know today [1, 2]. We live in a society where GPS can be found everywhere, especially in mobile phones and cars [3]. But, still, there exist some limitations and those cannot be solved that easily. These limitations are usually related to the loss of signal range.

Losses in the signal are usually due to obstacles between the satellite and the device we want to localize. These obstacles could be anything from clouds to buildings. So it is clear that GPS is limited to outdoors with good weather conditions [4].

In the latest times, there has been an increasing interest in location techniques and applications for those environments where GPS would not work. These are indoor scenarios, where hardware will play an important role, even though it may impose some constraints, like not being accurate enough or losing the signal range due to walls and items in the signal's path.

1.1.2. Indoor positioning systems

An indoor positioning system (IPS) is a similar concept to what GPS has to offer. Its main advantage is the possibility to make it work on indoor scenarios by using a network of devices that will wirelessly calculate the relative distance between them and the item to localize.

Using the GPS as the base structure of a location system, it is simple to describe the components of an IPS:

- Satellites are the *anchors* of the system and their position is always known.
- The item to localize is the *tag* and its position is initially unknown.

The lack of a standardization process on IPS has resulted in a design fragmentation, which resulted in the use of different technologies:

- Radio frequency (RF): it is usually cost-effective.
- Ultrawide band: reduced interference with other devices.
- Optical.
- Acoustic: like ultrasound. Waves move slower, which results in a higher accuracy.

This work analyzes a RF equipment from *nanotron Technologies*, the *nanoLOC Development Kit 3.0*.

1.2. Purpose

The aim of this thesis is to analyze the location hardware radios from nanotron, the nanoLOC Development Kit 3.0 [5] and develop a filter that can provide the user with a precise localization in an indoor environment with line of sight (LOS). In order to achieve this, previous studies on this equipment will be used, so as to determine the accuracy and validity of the collected data.

Such filter was designed to be used in a real environment where there exists mobility. So it should be fast enough so as to keep track of the item to localize. For that, no more than five measurements were taken at a time.

1.3. Limitations

The thesis has been delimited to an indoor environment using equipment made for indoor applications. The implementation was limited to analyzing static points chosen at random, as opposed to a moving object, in an area with LOS. Whereas in a real application there could be some moments when, as a result of people moving in or out, there might be no LOS (NLOS).

The environment itself may cause a great impact to the measured data. Anything can cause interferences with the system, like marble floors, windows, metallic doors... Reflective surfaces, in the end, can make the system not work properly due to multipath interferences. A study on the effects of the environment on the signal will provide more accurate results, which will be translated into a more precise localization.

1.4. Methods

To take all the measures in an indoor environment, the EDIT building from the Chalmers Johanneberg Campus was chosen. Ranging tests were performed using four devices, three of which were used as *anchors* or fixed points; and the last one was used as *tag* or moving point. Every device was placed over a tripod with a height of at least one meter.

The data collected during the verification and implementation was analyzed using statistical methods in MATLAB, and the results were then visualized using different types of graphs.

1.5. Structure of the report

Chapter 2 will introduce the equipment and how does it work. It will also analyze how to collect data and the way to store it into a computer so as to process it afterwards.

To do so, Chapter 3 will describe the steps followed to process data and will show the results obtained throughout the experiment. This chapter will get into more specific details as on how the filter was developed to correct all the possible errors and compare the results with and without the use of such filter.

Finally, Chapter 4 will conclude the document by giving a brief summary of the whole study, and it will also show the possible future researches on the same area, but with the use of a different equipment.

2

Data collection

This chapter presents the methods used to collect data by introducing the equipment and all of its components to the user, as well as how to configure such kit. It will also detail the way to store such data in a computer and all the calibration errors that might appear while taking measurements.

2.1. Purpose

The purpose of the collection of data is to investigate the ranging performance of the nanoLOC Development Kit. This performance is evaluated by the accuracy of the collected data, which, in the end, tests how close the measurements are to the real value.

The way to do this, to improve the accuracy of the collected data, will be explained on Chapter 3, where the designed filter will be explained.

2.2. Equipment

Figure 2.1 shows nanoLOC Development Kit, with all of its hardware and software components, required to collect data.

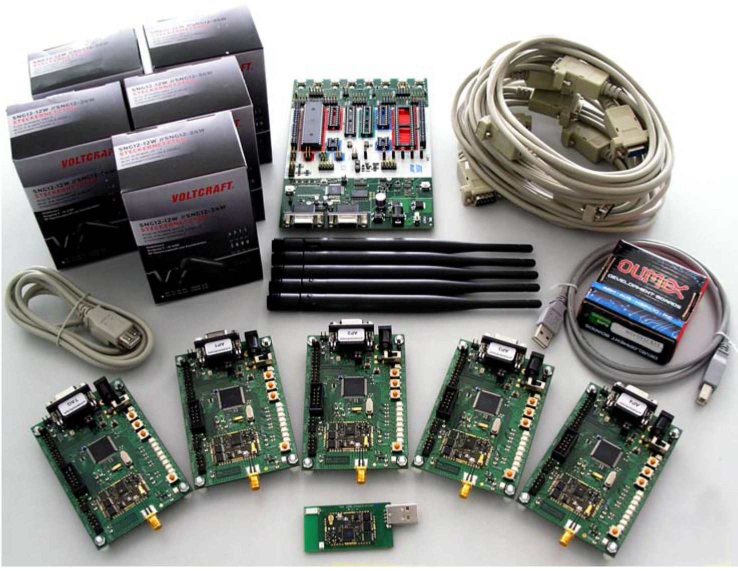


Figure 2.1.: nanoLOC Development Kit [6]

The kit is formed by the hardware components shown in Table 2.1. Table 2.2 lists all the software components. Finally, Table 2.3 includes a reference to the provided documentation.

Table 2.1.: nanoLOC Development Kit hardware components [6]

Hardware	Quantity	Description
nanoLOC DK Board	5	Uses the nanoLOC TRX Transceiver and the ATmega128L microcontroller and is designed for location and ranging applications.
nanoLOC USB Stick	1	Enables the PC to connect to nanoLOC's wireless network via USB port.
USB cable (type A male/female)	1	To be used with the nanoLOC USB Stick.
Atmel AVR® STK 500 Development System	1	Used for flashing and debugging. Uses the JTAG or ISP interface on the nanoLOC DK Board.
2.4 GHz omnidirectional antenna	5	High-quality sleeve dipole omnidirectional antenna.
Power supply units	5	Regulated 3 V power supply that can be used internationally: 100-240 V, 50-60 Hz, 1 A.
JTAG-ICE AVR Adapter	1	Third-party device for flashing and debugging. Uses the JTAG interface on the nanoLOC DK Board and a USB port on the PC.
USB cable (type B male/female)	1	To be used with the JTAG Adapter.
RS-232 cables	5	Required for applications that use the COM port of the PC.

Table 2.2.: nanoLOC Development Kit software components [6]

Software	Description
FTDI Driver	Required for the nanoLOC USB Stick.
Location Server	Required for the nanoLOC Location Demo
Location Client	Alternative access to the nanoLOC Location Server.
nanoLOC Demos	Set of Windows®-based Graphical User Interface (GUI), to test the hardware components.
nanoLOC DRIVER	Source code.
Third Party Software	WINAVR® and AVR STUDIO® 4 are provided for compiling, flashing, and debugging.

Table 2.3.: nanoLOC Development Kit documentation [6]

Documentation	Description
Nanotron Documentation	Documents for application development. Product flyers also included.
Third-Party Documentation	Datasheets and user guides for third-party software included in the kit.

2.3. Configuration

On the first place, the nanoLOC DK Boards (from now on, the boards) need to be configured. For that, the boards are connected to a computer so as to transfer the location software into them. The JTAG Adapter and the AVR STUDIO® 4 are used for that purpose.

Once the hardware is set up, the antennas and the power supply should be connected.

Among all the boards, at least one of them will be called *tag*. The so-called tag is the device we want to localize, and for that, we will need to use at least three more devices denoted as *anchors*, which will be placed in fixed and known positions (see Figure 2.2).

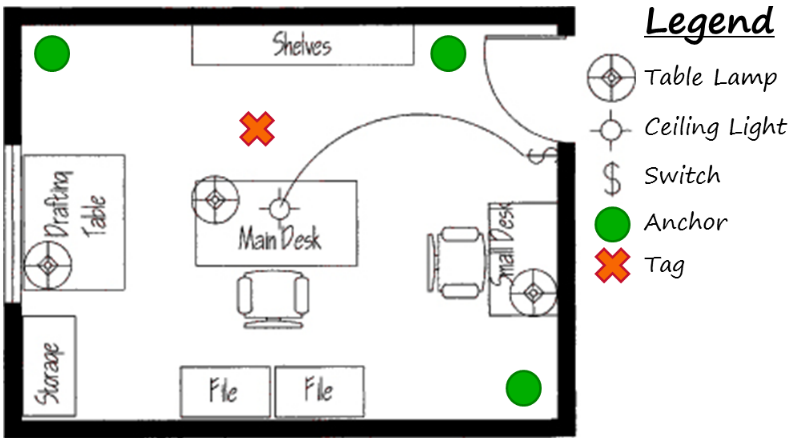


Figure 2.2.: Anchors are placed on known positions, while the tag is on an unknown position.

The anchors will communicate with the tag using wireless signals and will determine the relative position; in other words, the approximate distance between one of the anchors and the tag (see Figure 2.3).

The nanoLOC USB Stick will be used in order to collect the data and store it into a computer.

Knowing the position of the anchors and the relative distances given by

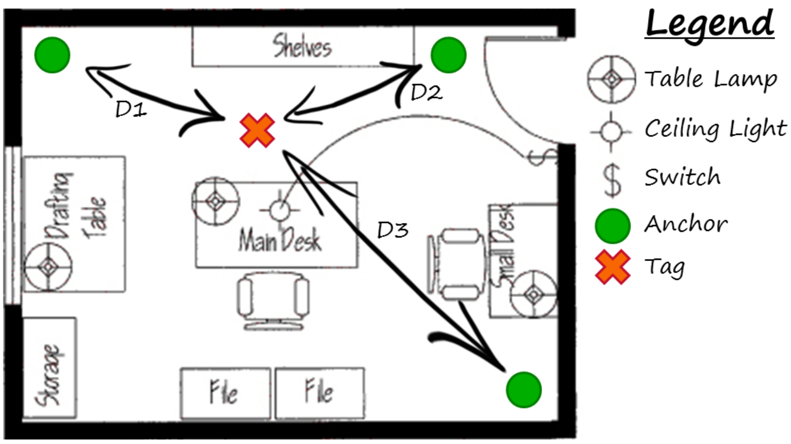


Figure 2.3.: Anchors determine the relative distance to the tag.

each one of them, it is possible to determine the approximate location of the tag (see Figure 2.4).

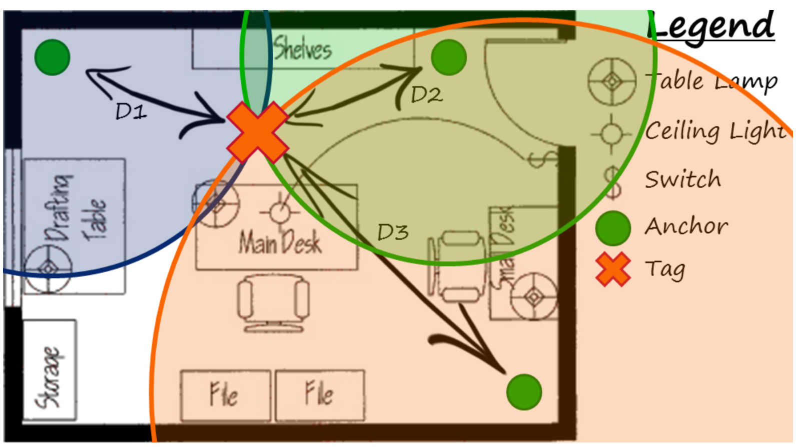


Figure 2.4.: With the given relative distances, it is possible to determine the approximate location of the tag.

2.4. Ranging

The nanoLOC devices have the advantage of being self-configuring, avoiding, this way, manual configuration of the network. *Location Server* is the software responsible to initialize the network. The ranging process is as follows [6]:

1. Location Server searches for all the tags and sends them a list with the MAC addresses of the anchors (see Figure 2.5).

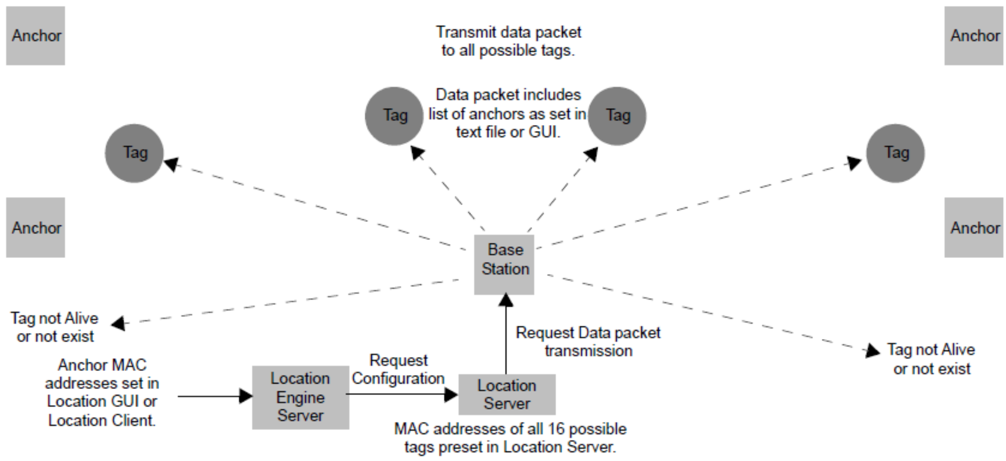


Figure 2.5.: Request configuration

2. Tags that receive the message reply back with an acknowledgement. Location Server adds the MAC addresses of these tags into the *alive list* (see Figure 2.6).
3. A *Start* command is sent to the Location Server who requests ranging to the alive tags (see Figure 2.7).
4. Each tag then performs distance measurements between itself and each anchor in the list of anchors (see Figure 2.8).

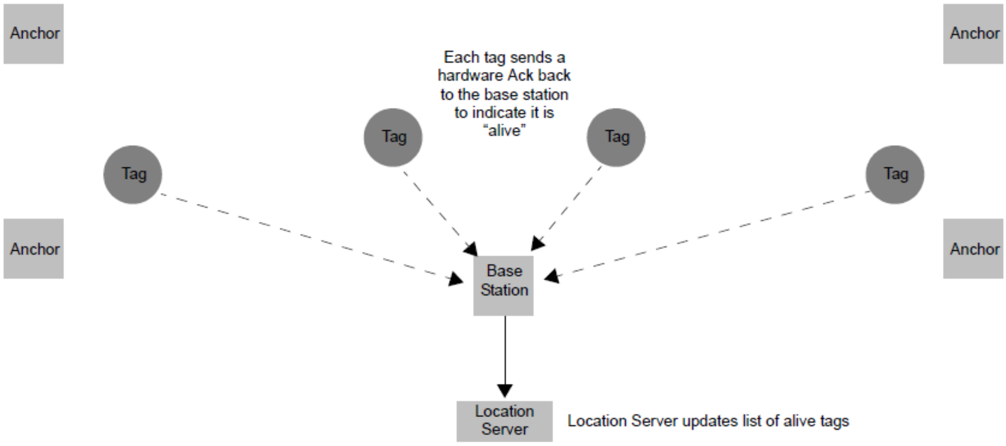


Figure 2.6.: Acknowledgements indicate which tags are alive

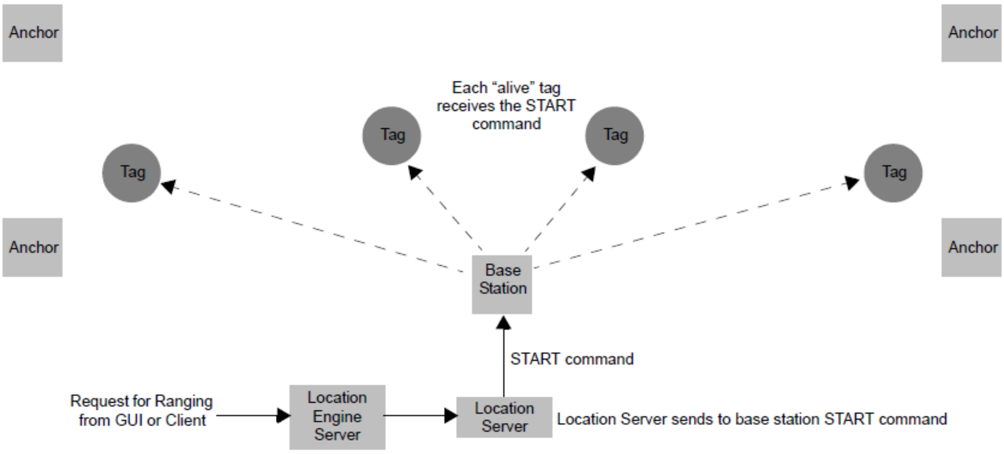


Figure 2.7.: The Start command initiates the ranging

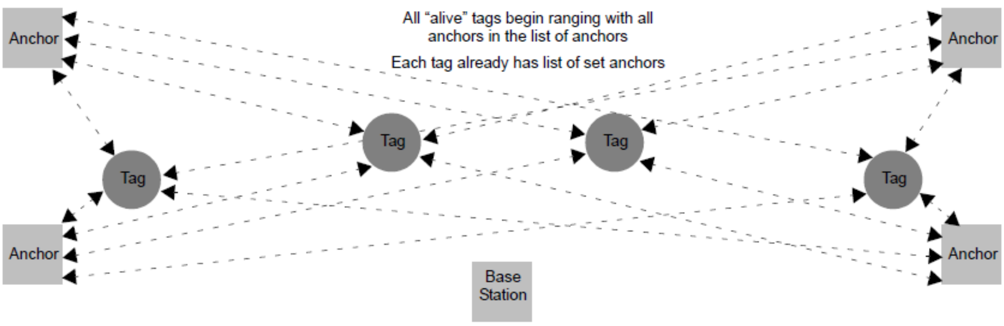


Figure 2.8.: Each alive tag performs a ranging with each of the anchors

2.5. Storing data

From previous studies with the equipment, there exist different MATLAB codes used to store the data into the computer. The code used was initially set to take five measurements using three anchors. Also, at a certain point, it would call the *LocationServer.exe* software file provided by nanotron, which makes the communication between the computer and the devices possible.

This code was modified so as to take a total of 1000 measurements for each of the anchors at a time. These would be stored in groups of five in order to keep the original idea of taking a small quantity of measurements to keep track of the tag.

The final MATLAB file would contain the ranges for the different anchors.

2.6. Environments

The tests were performed in different locations inside the EDIT Building from the Chalmers University of Technology's Campus of Johanneberg, in Gothenburg, Sweden.

These locations are:

- Room where the equipment is stored (see Figure 2.9): small room accessed by code with a thick metal door, five wooden tables, four desktop chairs, metal shelving on the wall to the right, some computers and windows placed on the wall opposite to the entrance.
- Lecture room EE: big room with capacity for 70 students with wooden door, tables placed at different heights plus the professor's table, blackboards and big windows placed on the wall opposite to the entrance.
- Hallway of the Master Thesis' Students (see Figure 2.10): hallway where the offices of Master Thesis' students are located, with some plants placed on one side of the hallway, wooden doors with big crystals and metallic ceiling.

Figure 2.9.: Room where the equipment is stored.

Figure 2.10.: Hallway of the Master Thesis' Students

- Linsen Cafe: big area with wooden tables and wooden chairs for students to eat. It is surrounded by big crystal windows in two of their walls.
- Floor above Linsen Cafe (see Figure 2.11): similar to Linsen Cafe, it is a big area with computer and lecture rooms. It is also surrounded by big crystal windows in two of their walls.

Figure 2.11.: Floor above Linsen Cafe

2.7. Calibration

In order to be able to reduce the errors (see Section 3.4 for further information on errors), a calibration process is required. Such calibration process is done by placing the tag right over each of the anchors that will be used in the measurements.

The distance given by the anchor that has the tag on it will be the innate error of that specific anchor and should be taken into consideration when processing the data (see Section 3.4.2 for further information on how to consider calibration).

If the given distance is zero, that would mean that the measurements given by the devices are perfect and that there is no calibration needed. Of course, this would be the ideal case, which in reality never happens.

3

Data processing

On this chapter, the results of the whole study and how data was processed will be shown by presenting the designed filter, followed by an analysis of the corrected data and the improvements that such filter provides.

3.1. Purpose

Data processing is done in order to investigate the effectiveness of the errors on the measurements and try to reduce them by designing a filter using MATLAB. After applying such filter, results will be compared to the original measurements. The purpose of this section is to provide a good filter design that reduces the error to the minimum.

3.2. Errors

Each of the locations mentioned in Section 2.6, provide different kinds of errors, usually related to loss of signal power due to obstacles in the chosen environment. These obstacles could be anything from reflecting surfaces like windows, marble floor, metal doors and items, people crossing, etc. These kind of errors are always there and they are unavoidable. It will be referred to as *background noise.*

Apart from the errors produced by the environment, there exists the hardware's innate errors, reason why it should be calibrated before taking any measures into consideration (see Section 2.7 for further information).

Other kinds of errors include wrong measurements. These are usually related to a wrong wireless connection, which causes data to be saved as a zero or a negative number. This kind of error is very simple to identify and take away.

3.3. Cumulative distribution function

All the measured data is stored in the computer as the relative distance between each of the anchors and the tag. To process all of it, a CDF graph is plotted using MATLAB. The CDF plot describes the probability that a certain distance value is given by the anchors; in other words, it gives the tendency of the measurements to reach a specific range.

3.4. Error correction

To correct all the errors in the measurements, a filter was designed in MATLAB. The purpose of the mentioned filter is to improve the accuracy of all the equipment, trying to make the nanoLOC Development Kit a reliable system to be used at indoor scenarios.

The filter is composed of the following:

- Odd measurements correction (Section 3.4.1): algorithm to take away negative and very distant from the mean measurements.
- Calibration correction (Section 3.4.2): algorithm to suppress the innate error produced by the anchors.
- Noise correction (Section 3.4.3): algorithm to reduce the background noise from the environment.

3.4.1. Odd measurements correction

Section 3.2 gave an explanation of the different kinds of errors. Odd measurements can happen at any time without any previous notice and they should always be taken away in order to proceed with the processing of data.

In order to correct odd measurements, the implemented algorithm is divided in the following two parts:

- Part one: suppress all negative numbers.
- Part two: take away all measurements which are too distant from the mean. For that, all data that doesn't fulfill the requirement expressed in Equation 3.1 is discarded.

$$\bar{x} - 2\sigma_x \leq x \leq \bar{x} + 2\sigma_x \tag{3.1}$$

  Where $\bar{x}$ represents the *mean value* and σ_x the *standard deviation*, both measured in meters and from the remaining values, in other words, the mean and variance from the measurements which were not deleted in *part one* and not considering zeroes.

3.4.2. Calibration correction

As seen in Section 2.7, the calibration part is the most important one when preparing the devices to work. All the calibration measurements from the different environments described in Section 2.6 are represented on a CDF plot using MATLAB, so as to visualize the existing error in the devices.

For all the different environments, the calibration results are very similar, and a general image for each of the anchors can be seen in Figures 3.1, 3.2 and 3.3.

On the graphs, the vertical dotted lines represent in red the real measurement and in blue the mean value of the collected data. The blue curve represents the CDF plot of the measurements.

Using the CDF graphs and knowing that there should be no distance

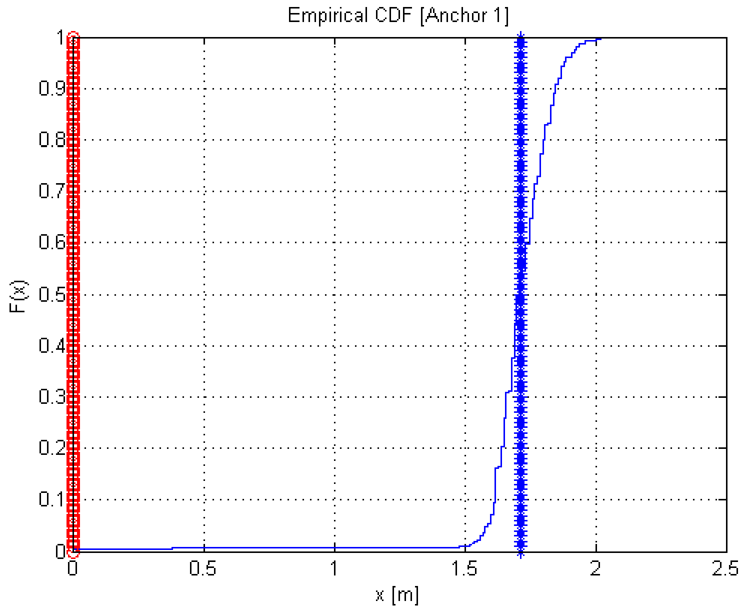


Figure 3.1.: Calibration CDF plot for anchor 1. The vertical dotted lines represent in red the real measurement and in blue the mean value of the collected data. The blue curve represents the CDF plot of the measurements.

between the anchor and the tag, it is possible to determine what the approximate error for a proper calibration is. These errors are shown in Table 3.1. These calibration estimates are the mean values of all the calibration processes done in the different environments described in Section 2.6.

Table 3.1.: Average error given by each of the anchors

Anchor	Error (meters)
1	1.6565
2	1.8939
3	1.6223

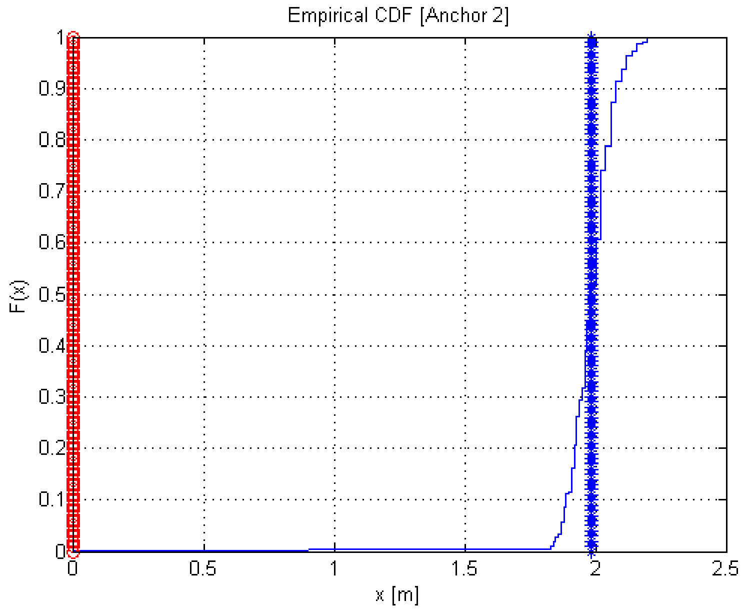


Figure 3.2.: Calibration CDF plot for anchor 2. The vertical dotted lines represent in red the real measurement and in blue the mean value of the collected data. The blue curve represents the CDF plot of the measurements.

3.4.3. Noise correction

Apart from odd measurements and calibration process, Section 3.2 showed that there is a third kind of error that should be taken care of: the background noise. This noise could be originated from anything like an obstacle in the LOS or a reflective surface.

It is always there and cannot be suppressed completely, it can only be minimized in order to make it less striking.

The algorithm takes the different groups of five measurements and applies the mean value to each one of them. In the end, there would be a total of 200 mean values, with every one of them considered as a valid range.

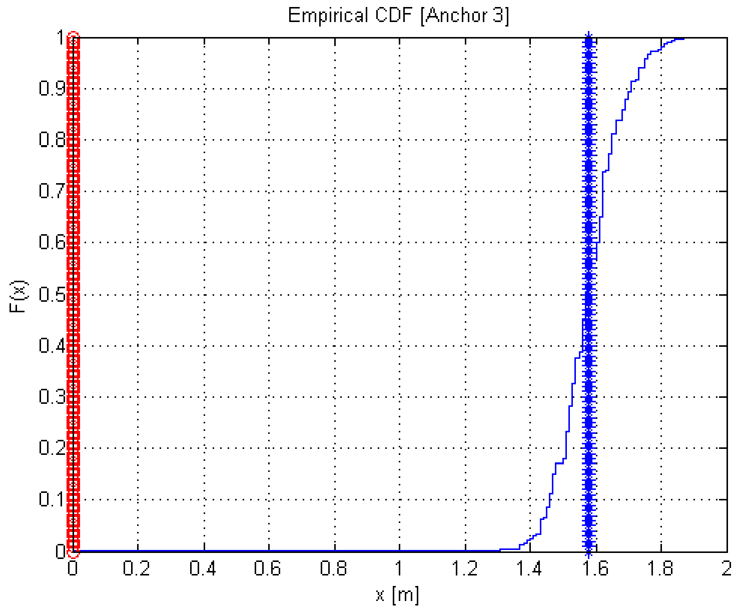


Figure 3.3.: Calibration CDF plot for anchor 3. The vertical dotted lines represent in red the real measurement and in blue the mean value of the collected data. The blue curve represents the CDF plot of the measurements.

3.5. Corrected data

After applying the filter described in the previous section, it is possible to say that the measurements are corrected. But that does not mean that these are totally precise. Results show that the accuracy improves up to 10 cm on the best cases.

But not everything is perfect. Randomly, huge errors appear after the filter is applied. The source of these errors is unknown, but it could be any kind of interference that avoids the equipment to reach a proper performance. Previous studies with the same equipment show that the system might get interferences from Wi-Fi networks. Also, most of the locations include a marble floor or reflective surface, which makes it easier to obtain higher amounts of noise.

3.6. Improvements provided

Figure 3.4 shows the effects of adding a filter to the processing of the data by comparing the results prior and after such filter.

Improvements are more than noticeable, and Table 3.2 shows how the error in the measurements is reduced after applying the filter. As it was mentioned in Section 3.5, data is now corrected, but is not 100% accurate, as there still exists some error which may vary from 10 to 45cm, as shown in the table.

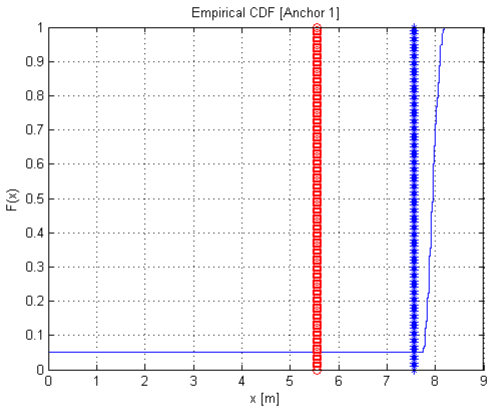
Table 3.2.: Comparison of errors before and after applying the error corrector filter.

	Without filter [m]	With filter [m]
Anchor 1	2.0060	0.4323
Anchor 2	1.7128	-0.0864
Anchor 3	1.7665	0.2091

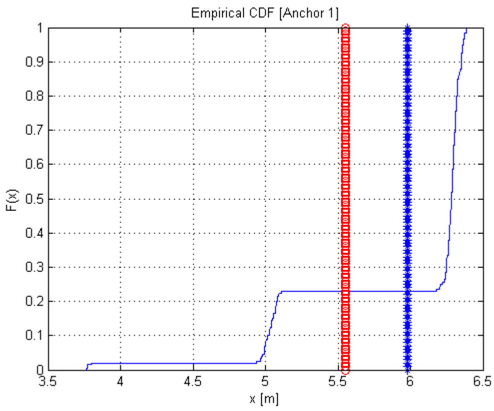
Error is reduced is more than two thirds, which in the end can be interpreted as a more accurate location of the tag.

A negative error implies that the filter was, probably, excessive for this case and it should be softened. It can be seen graphically after analyzing Figure 3.4d, which shows the mean value (vertical dotted line in blue) to the left side of the real measurement (vertical dotted red line). Considering such negative value as positive means that the correction was excellent, as an error of nearly 10 cm can be translated as accurate.

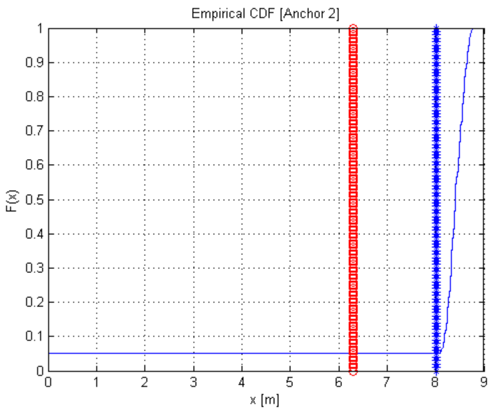
Still, some errors remain in the measurements. To minimize these, a deeper statistical study is needed.



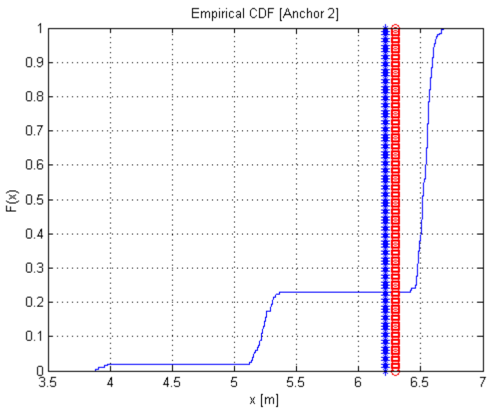
(a) Anchor 1 without filter



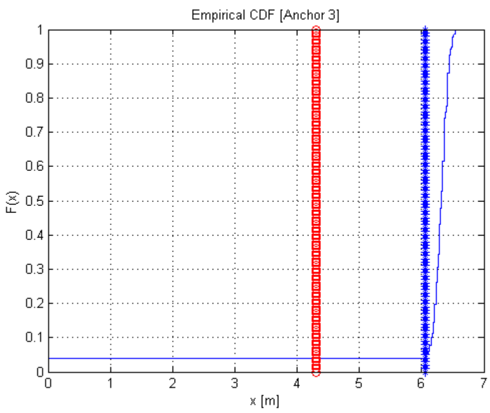
(b) Anchor 1 with filter



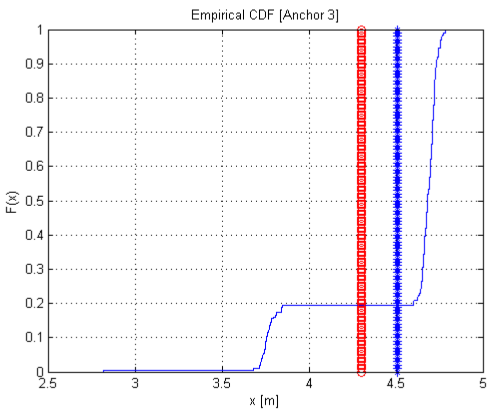
(c) Anchor 2 without filter



(d) Anchor 2 with filter



(e) Anchor 3 without filter



(f) Anchor 3 with filter

Figure 3.4.: Comparison between applying or not the filter.

4

Discussion

4.1. Summary

The idea of a location device for indoor scenarios is to provide a service where GPS has no range. It is a complementary system. This means that one does not substitute the other, as each of them can be used under different conditions. While GPS would provide accurate locations in an open space, its main weakness is on indoor scenarios, where location devices like the studied one will prove to be a better option.

For indoor scenarios, the user is looking for a reliable and accurate system that might help him localize items with the smallest error possible. This means that, for an office environment, an error of 2-5 meters is not acceptable, as that would mean that the tag could be on one room or another.

The nanoLOC Development Kit provides a system which can be used in any kind of indoor environments where it could be useful. But it needs a deep analysis of such environment in order for it to be a reliable equipment.

The study shows that a filter can be developed to improve the obtained measurements to an accuracy of 10 cm on the best case. Still some errors remain and the equipment randomly produces huge errors which cannot be filtered easily.

4.2. Further research

Further research on this same work would imply a deep study of the effect of the environment to the equipment and its communications. In other words, study how different kind of surfaces and obstacles affect the final measurement.

Another key point to improve is the errors introduced by external signals, such as Wi-Fi, which also affect the final measurement.

From the beginning, one of the limitations of the study was that the *tag* was localized while it was on a fixed position. A real life application would demand the location of a moving tag, which, in the end, requires developing the filter further so as to consider mobility.

As for many things in life, the equipment provided by nanotron is not the only existing one. There exist multiple applications for indoor environments which can be more reliable than the studied one by providing more accurate ranges.

The Department of Signals and Systems from Chalmers University of Technology has another and more reliable equipment, which has an innate accuracy of approximately 20 cm without an external filtering process. It also provides better tools to study the received signals and it also includes source codes to be used with MATLAB for further research.

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A

Filter algorithm

A.1. Main algorithm

The following code presents the main algorithm of the filter. This filter calls the odd measurements correction filter, *correctData()*, described in Section A.2.

```
comment: Main algorithm. Inputs: 'dist' and 'outputName'. Outputs: 'a1', 'a2' and 'a3'.
begin
  comment: Initialization
  max_ctr = length(variable);
  samples = 5;                                %Loads all calibration errors
  errors = dataError();
  comment: FIRST PART: DATA PROCESSING
  comment: Load the data from variable 'dist'
  aux1 = dist(: ,1);
  aux2 = dist(: ,2);
  aux3 = dist(: ,3);
  comment: Reshape data
  aux1 = reshape(aux1, max_ctr/samples, samples);
  aux2 = reshape(aux2, max_ctr/samples, samples);
```

```
  aux3 = reshape(aux3, max_ctr/samples, samples);
  comment: Take away the calibration error
  aux1 = aux1 − errors(1);
  aux2 = aux2 − errors(2);
  aux3 = aux3 − errors(3);
  comment: Correct data by deleting negative and odd measures
  a1 = correctData(aux1);
  a2 = correctData(aux2);
  a3 = correctData(aux3);
  comment: SECOND PART: SAVE DATA
  anchor.a1 = a1;
  anchor.a2 = a2;
  anchor.a3 = a3;
  comment: Saves data to .mat file
  save(outputName, 'anchor');
end
```

A.2. Odd measurements correction filter

The following filter corrects odd measurements. See Section 3.4.1 for further information.

```
comment: Odd measurements correction algorithm. Input: 'x'. Output: 'y'.
begin
  comment: Initialization
  [n, m] = size(x);
  aux = zeros(n,m);
  aux2 = zeros(n,m);
  comment: Take away zeroes and negative numbers
  for i = 1 to n do                                              % Rows
      for j = 1 to m do                                          % Columns
          if (x(i,j) > 0)
             aux(i,j) = x(i,j);
          end
      end
```

```
  end
  comment: Take away odd data
  aux_m = mean(aux(aux  = 0)')';
  aux_s = std(aux(aux  = 0)')';
  comment: Maximum and minimum values permited
  maximum = aux_m + 2 * aux_s;
  minimum = aux_m − 2 * aux_s;
  for i = 1 to n do
     for j = 1 to m do
        if m == 1
          if (aux(i,j) <= maximum ∧ aux(i,j) >= minimum)
            aux2(i) = aux(i);
          end
       else (aux(i,j) <= maximum ∧ aux(i,j) >= minimum)
          aux2(i,j) = aux(i,j);
        end
     end
  end
  y = aux2;
end
```