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Indoor Positioning for Smart Ambient Assisted Living Services

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Abstract

The advance of information technologies and the increase of awareness of healthy living cause the development of a new field, which promise to respond human needs and build an intelligent user-friendly home environment. Ambient Assisted Living (AAL) services aim to improve the quality of live by providing remote support for safety and comfortable independent life to elderly people. An important element of AAL area is the potential to locate and track elderly patients. Knowing the position and actions are required for medical observation or timely accident prevention.

Presently there are a lot of proposed Indoor Positioning Systems (IPS), but still no one of them is widely commercialized. The success of deploying a Real-Time Location System depends on picking the right performance metrics. The IPS must be with simple interface because of its users, which might be with physical or mental limitations, but not at the expense of reliability and accuracy. On the other hand such a system should be at a reasonable price and with low energy consumption, appropriate for a long-term usage.

In our project, we observe some of the present methods and techniques for indoor localization in the case of AAL. We propose a novel positioning and fall detection algorithms, which are based on the Bluetooth Low Energy technology. Our algorithms are dedicated to elderly and disabled people, so we created them user-friendly and unostentatious. We also test them in real environment and proved their high accuracy and reliability. Due to the current widespread use of the BLE technology, the algorithms can be easily and fast commercialized. And last but not least thanks to the BLE our algorithms can ensure long life of usage, low initial and maintenance cost.

Abbreviations

AA - Access Address

AAL – Ambient Assisted Living

AmI – Ambient Intelligence

AoA – Angle of Arrival

AP – Access Point

BAN – Body Area Network

BLE – Bluetooth Low Energy

BS – Base Station

CRC - Cyclic Redundancy Check

DSSS - Direct Spread Spectrum

ECG – Electrocardiogram

EEG – Electroencephalography

EIRP - Effective Isotropic Radiated Power

EMG – Electromyography

FHSS - Frequency Hopping Spread Spectrum

FM – Frequency Modulation

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

IPS – Indoor Positioning System

ICT - Information and Communications Technology

IMU – Inertial Measurement Unit

INS – Inertial Navigation System

IR – Infrared

LBS – Location Based System

LFSR - Linear Feedback Shift Register

LoS – Line of Sight

LTK – Long-Term Key

MA filter – Moving Average filter

MAC layer - Media Access Control Layer

MIMO - Multiple-Input-Multiple-Output

MM – Map Matching

MS – Mobile Station

NFER - Near-Field Electromagnetic Ranging

NLoS – Non-Line of Sight

OFDM - Orthogonal Frequency Division Multiplexing

PAN - Personal Area Network

PDU - Protocol Data Unit

PHY layer - Physical layer

RBS – Receptive Base Station

RFID – Radio Frequency Identification

RLS – Radio Location Station

RSSI – Received Signal Strength Indicator

RTTT – Round Trip Travel Time

TBS – Transmissive Base Station

TDoA – Time Difference of Arrival

ToA – Time of Arrival

ToF – Time of Flight

UWB – Ultra-Wideband

WMSNs - Wireless Mesh Sensor Networks

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1. Introduction

1.1. Motivation and Problem Formulation

For centuries people were striving to find accurate and reliable technique to navigate in unknown lands or seas. Barely few decades ago we start using aerial photography, satellite imagery and computer innovations to create precise maps of the world. Thanks to the great success of the outdoor location-based services, a new trend is seen in the last years - create a conventional indoor location service. There are a lot of researches and suggestions based on different technologies that have been commercialized, but still no one has proven itself as notable widespread technique such as GPS outside. As opposed to open space services, when it comes to indoor areas often we do not possess present and accurate map information about the buildings. In some cases this kind of knowledge can be provided in cooperation with the building owner, but more often we have only floor plans or drawings used during the construction, which are full of mistakes and symbolism difficult to understand from a computer. Another difficulty of the indoor location-based services is the complexity of guidance and navigation within the buildings. Most outdoor applications use graph of nodes connected by edges to represent the network of streets, which is inapplicable in the case of the free and unpredictable human movement in its home.

The indoor location services promise to present an enormous amount of possible applications: information, navigation, safety-of-life, social networking and joint activities, gaming, retail and commerce and etc. For our project we decided to survey the use of location based systems in the context of healthcare services for elderly people. We worked to develop reliable, inexpensive and user-friendly positioning system, based on the Bluetooth Low Energy technology. It is able to passively track the movements of elderly people inside their homes and watch for significant deviations from their daily routine and accidental falls. The information collected from our algorithm can be used to improve their independent lifestyle and at the same time inform their family members or doctors in case of need.

1.2. Challenges

Some of the key aspects in deploying an indoor location-based systems (LBS) are related to choosing the right positioning technology. There are many existing opportunities to pick, but no one of them is perfect and multipurpose - it is all depending on the delicate balance between accuracy, range, refresh frequency, and cost. Other question is selecting receptive base station (RBS) strategy (when the MS emits signals) or transmissive base station (TBS) strategy (when the BS is transmitting the signal). Both cases are same efficient and the choose is based on concrete user needs or physical environment. Each construction is diferent and has its own characteristics. To install a location system in a real ambience we should take into account all propagation peculiarities of the building.

These and other factors lead to the creation of isolated applications, which are impossible to global deployment of an indoor LBS using one standardized data source. Because of that all applications do similar things in quite different ways, each time providing the best relation between modeling effort and achievable service quality depending on the specific indoor environment.

Thus the particular challenges the indoor LBS face, in the case of healthcare services there are few more additional difficulties. The current systems still cannot fully express the power of human being. To install a location system in an intelligent home environment it is important to make it easy to use from all kind of people. Its price should be reasonable and affordable for the wider community. The positioning system has to be as unobtrusive as possible and do not limit the user's daily activities, because its purpose must be only to improve their comfort and safety. The biggest aim in implementing indoor location system in the Ambient Assisted Living services is to track and monitor the patients reliably without disturb and change their lifestyle.

1.3. Thesis Contribution

Global Positioning System is well known and approved as an outdoor localization technique. When it comes for indoor environment finding the right approach is still open field for researches. In our thesis we present an overview of different solutions and methods that can be applied for the purpose of accurate IPS. Bluetooth Low Energy as part of these solutions is a new technology originally designed for transmission of small amount of data with the advantage of low power consumption. However, presently more and more developers are trying to reach high accuracy level for location estimation based on BLE. There are different variations of devices, but most of them give just an approximate and unreliable results based on the Proximity algorithm. Such an example is the Beacon of Estimote. Except the Proximity estimation the company have own application for indoor location based on Trilateration method with the usage of 4 Beacons.

In our project we propose two novel algorithms with the Estimote Beacons as a core technology. The first one is 2D Trilateration with the usage of only 3 Beacons. The algorithm is using as a smoothing instrument of the RSSI values Kalman filter. For small area scenario that gives an accuracy of the system 1-1.5m in most of the situations. The second is based on the Fingerprint method. With different parameters, but again with Kalman filter, that approach can give good results for position estimation in big room scenarios. Finally, we introduce an innovative application for the purposes of healthcare. The only one input that algorithm needs is the Received Signal Strength Indicator values and as output it can detect the falls of elderly users.

Based on the obtained results, we are currently preparing a research paper to be submitted to the Wireless VITAE conference to be held in September 18-21, 2016 in Dubrovnik, Croatia.

1.4. Organization of the Thesis

The thesis is further organized as follows:

- Chapter is 2 dedicated to present the development of the Healthcare services. In it we describe the fields of Ambient Intelligence, Smart Home Environment and Ambient Assisted Living to introduce the need of continuous tracking and monitoring of elderly or disabled people in their lodgings.
- Chapter 3 gives theoretical overview of the most common location techniques and methods and the differences between them.
- Chapter 4 we surveyed a variety of location technologies, their differences and applications.
- Chapter 5 presents the Bluetooth Low Energy technology and compares it to the Classical Bluetooth. In it we also introduced some of the commercialized solutions, based on BLE.
- Chapter 6 gives an evaluation of the signal behavior in real environment via a sequence of different experiments. We studied the influence of the distance between

the BLE beacons and mobile device and impact of the antennas' orientations. In addition we evaluated several algorithms for signal filtration.

- Chapter 7 proposes the indoor location algorithms. We describe their methodology of work and compare their performance based on several experiments in diverse environments.
- Chapter 8proposes the fall detection algorithm. We present our observations over the RSSI behavior achieved during the positioning algorithm' creation and explain our idea for the fall recognition method.
- Chapter 9 summarizes the achieved results and suggests scopes for future work.
- The developed from us MatLab codes are included in an Appendix

2. Healthcare services

Our second chapter is dedicated to the expansion of the healthcare services. In it we surveyed the developments in the field of the Ambient Intelligence technology and its algorithms of work. We presented several of the benefits of the creation of smart homes and the most widespread applications of environmental and body sensors. We introduced the potential of implementing reliable and adaptive indoor tracking systems in the healthcare services. Last but not least we outspread the concept of Ambient Assisted Living services and their key limitations.

2.1. Ambient Intelligence (AmI)

A new trend is observed in the advanced healthcare technologies development. Ambient Intelligence (AmI) is direction of evolving of the modern scientific knowledge and inventions with a view to comprehend people's needs and abilities by means of digital environment. AmI technology aims to respond all real life scenarios by being sensitive and adaptive to user's needs and by take into account their personal habits, preferences and demands. To create convenient and friendly environment we cannot rely anymore to the conventional methods for data collecting, instead it is necessary to implement all kinds of independent sensors and processors into everyday objects, that will readjust in a transparent and anticipatory way to the user wishes [1]. The new tendency incorporate range of additional fields, such as “sensor networks” to expedite the data collection, “robotics” to build helpful robots, and “human computer interaction” to form more natural and easy to use interfaces.

Nowadays most of the industrialized countries experience growing difficulties with the number of senescent people. Despite the scientific advances, in the range of healthcare a lot of services are still unjustifiably expensive and inaccessible from those in need. The necessity of high quality and affordable price of wellbeing services lead mass of challenges to the modern scientific and technological society all over the world. AmI and its derivatives fields promise to improve drastically the area of healthcare with technologies used for monitoring of people with chronic diseases or providing care for patients with physical or mental limitations or just to develop and motivate people to lead healthier and fulfilling life. In general it can support and facilitate the treatment by providing innovative communication and supervising services in discreet and inconspicuous way.

There are two trends in the AmI field. The first one is based on sensors attached to or under the human skin or its clothing [2]. In the Body Area Network (BAN) is observed an approach to minimize the size of the sensors to make them more comfortable and suitable to wear [3]. These technologies allows real-time monitoring of heartbeat, body temperature, physical activity, blood pressure, electrocardiogram (ECG), electroencephalography (EEG), and electromyography (EMG) in order of timely informing to healthcare professionals or kinsfolks. The second direction in AmI points at creating intelligent and proactive environments, capable to respond everyday needs of elderly people or these who suffer from mental or motor diseases. In the area of Wireless Mesh Sensor Networks (WMSNs) detectors are integrated in ordinary objects from our daily routine to build unostentatious, comfortable and safe habitats for the customers [4]. The ambient sensors enable flexible and smart environments by gather diverse type of information to secure the inhabitants by providing them the most appropriate environment [5].

To develop real operating AmI systems, designers lean on different method and algorithms (Table 2.1) [6]:

- Activity Recognition: To cater convenient cares to its users, the Ami systems first need to deal with one of its biggest challenges – the recognition of human's activities and behavior. Lots of existing systems already combine data from variety of sensors and machine learning algorithms to detect motions and activities [7].
- Behavioral Pattern Discovery: Similar to the activity recognition, this method aims to monitor the human's movements, but in difference is based on unsupervised learning algorithm, so that is able to identify and explore new non-predefined activities.
- Anomaly Detection: Because of its ambiguous nature and human unpredictability, the anomaly recognition has not been clearly defined and is still not enough studied. There are only few present AmI applications based on it [8].
- Decision Support: This kind of systems is used to support the work of healthcare professionals. Decision support systems gather different types of data from multiple patients and help doctors to organize their work, to analyze people personal needs or to survey some common phenomenon.
- Anonymization and Privacy Preserving Techniques: The definition of privacy in terms of AmI is still evolving. In the case of some systems as invasion of privacy is assumed

every nosy obstructive way of collecting data, but in others much more attention is given to methods for securing the collected information from malicious internal or external attacks.

Class of Application	Goals	Environmental Sensors[1]	Body Sensors[1]	Methodologies[2]	System Examples
Continuous Health Monitoring	Using sensor networks for monitoring physiological measures (ECG, EEG, etc.)	●	○	Activity Recognition	AMON, SELF
Continuous Behavior Monitoring	Using sensor networks for monitoring human behaviors (Watching TV, Siting, etc.)	●	●	Activity Recognition	CASAS, IMMED
Monitoring for Emergency Detection	Using sensor networks for detecting hazards, falls, etc.	○	●	Activity Recognition	SmartFall
Assisted Living	Creating smart environments for supporting patients and elderly during their daily activities	●	X	Activity Recognition, Decision Support	ALARM-NET, CAALYX, MyHeart, SAPHIRE
Therapy and Rehabilitation	Supporting people who require rehabilitation services with remote and autonomous systems	○	●	Activity Recognition, Decision Support	Hocoma AG Valedo system, ISH, DAT
Persuasive Well-Being	Systems aimed at changing persons attitudes in order to motivate them to lead a healthier life style	●	X	Activity Recognition, Decision Support	Persuasive Mirror, PerCues, PerFrame, Etiobe
Emotional Well-Being	Ubiquitous systems based on neurological and psychological	●	●	Activity Recognition	AffectAura, EmoSoNet, MONARCA,

	insights to analyze emotions and improve well-being				Emo&Pain
Smart Hospitals	Improving communication among hospital stakeholders trough ubiquitous technology	●	X	Decision Support	SALSA, GerAmI

1 – ●: Mandatory; ○: Optional; X: Not required (e.g. they could increase the intrusiveness of the system without additional benefits)

2 – All application classes use Anonymization and Privacy Preserving Techniques for ensuring personal data hiding

Table 2.1: The most common areas for application of AmI and some existing systems in that field

Some of the present systems are very advanced, but the domain of AmI still need future researches in areas related to the growing use of artificial intelligence. The simple proses of collecting data can be evolved to gather information from similar users and develop huge knowledge base or discover and predict patterns in patient's condition or behavior. Other ongoing challenge is to minimize the side effects from all electromagnetic sensors. Most of the wireless devices transmit weakly, but are designed to work for months or years, so the long-term use should be closely surveyed for unasked influence on human's health. The privacy and security of users also is difficulty that the prospective systems should point at. Adulteration or processing too small amount of the data can lead to misdiagnosis or inadequate supervision. On other hand the breach of confidentiality can either directly or indirectly endanger the users in their own homes. Other difficultness is to do not let all these modern and innovative technologies to embezzle human's life. The over-use of assistive devices can escalate the diffidence of the elderly or disabled people. The absence of personal contact can lead to lack of motivation or depression.

2.2. Ambient Assisted Living

AAL is a new approach that aims to respond the elderly people's needs. The biggest challenge for current healthcare services is to fully express the potential of humans and to do not convert them in prisoners in their own homes. As well known, the percentage of elderly people keeps growing in the las decades. Because of this the last researches aim to develop and improve the services dedicated to these elderly people. To improve the quality of their lifestyle the smart systems should ensure safe home environment and timely help in case of need [9]. AAL try to prolong the time older people can live in their homes by increasing their autonomy, but without isolating them from the outdoor world. A lot of efforts are dedicated to the creation of widely applicable devices, and their implementation in an intelligent environment such as Aware Home [10]. These researches on "smart houses" aim to improve the independence of the elderly people, and reduced the required manual work.

The Aware Home project consists in creating a living lab, in which they tested new devices and their acceptance from the users. Similar to Aware Home, I-Living address its efforts in improving the assisted-living supportive software infrastructure, to allow the cooperation between disparate technologies, software components, and wireless devices. Some of the included services in I-Living are activity reminding, health monitoring, location, emergency detection, and others. The main goal of all similar projects is to facilitate the elderly people lives, by keeping them safe by monitoring some of their health status. However, the most of the current systems are developed in an idealized environment and suffer from variety of limitations.

Still, most of the systems restrict the abilities of elderly people and their potential for social activities and connectivity with friends. Without the communications with the outside world, elderly people assisted by those "smart" devices cannot fully express their potential and slowly converts in hermits.

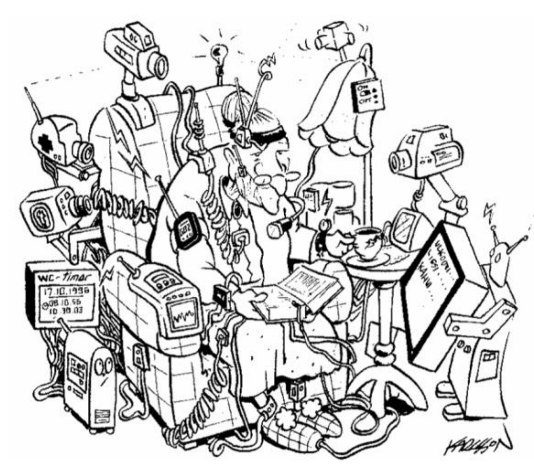


Figure 2.1: Example of excessive use of assistive devices [11]

Figure 2.1 shows the possible side-effect of over-using technology without proper human participation.

A lot of efforts are also dedicated to connect and communication between the assisted human beings. The limitations of this field consist in the fact that the communications are currently focused on exchanging the medical data of the patient, which restricted more generalized application of the data.

The addition of human presses in the monitoring process could help maintain the social awareness in the AAL services. The usage of advanced ICT technology could better connect the elderly people together and organize community activities.

The people's willingness to participate in AAL services development and improvement should be encouraged, to create comfortable and applicable systems. When people are getting old, their fear of losing physical strength makes them lose their self-esteem and become more passive and apathetic to the modern inventions. Most of the AAL systems, dedicated to elderly people usually just assume them as people who are weak and passively assisted by others, instead of providing them an appropriate trainings and involving them to improvement and the commercialization of the new technologies. A homecare system with human participation could help encourage and motivate the elderly people to actively participate in group activities as peer participants, and possibly even to use their experiences to help the younger generations solve, e.g., some of their work and school problems [12].

<u>Short Summary</u>

In this chapter we reviewed the reasons for the observed fast growth in the field of Ambient Intelligence and its high popularity among the society. We characterize several of the trends in healthcare services and turned attention to the distinctive applications of the environmental and body sensors and also reviewed some of the potential benefits of the cooperative usage of positioning system and health monitoring services. We introduced the Ambient Assisted Living Services and their key limitations.

3. Location Methods

In this chapter we present an overview of the most common indoor positioning techniques. We surveyed different methods to show the diversity of options when deploying a new location system. We presented its particular advantages, disadvantages and limitations to show their potential in diversity of scenarios. We proved that the accuracy by itself is not sufficient parameter and that more important is to select the most appropriate methodology based on the balance between precision of the model, its flexibility, cost and the efforts needed to install it.

The Indoor Positioning Systems (IPS) are systems that locate and track people or objects inside the buildings using radio waves, magnetic fields, acoustic signals, or other information collected by sensors [13] A lot of different techniques can be used for indoor location, including distance measurement to nearby nodes with known positions, time to transmitting a signal and other. There are several commercial IPSs on the market, but there is still no standard for an indoor positioning system. Every system is individually created, but all of them lean on the same widespread common methods.

3.1. Time of Flight (ToF)

This is the simplest method to measure distance over a radio signal. It is based on easy calculation of how long way had the signal passed, as knowing the approximate speed and the time to achieve its target pint. Some of it most popular varieties are Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Time Transfer. With all of them, the accuracy of the clocks implemented in the both end devices is extremely important for the correct determination of the ToF. Other factors that cause significant mistakes are the small random errors, caused by signals arriving close to each other through multiple paths and large errors, caused by when the strongest path is not the line of sight path.

3.2. Time of Arrival

The method is very similar to the above mentioned, but in this case the receiver calculates the duration of the signal’s traveling (ToF) (Figure 3.1). The receiver and the transmitter can work synchronized and the transmitter sends only the time of emitting the signal or they the can be and unsynchronized, but then the devices should exchange additional information [14], [15]. The location of the target point is defined by the following equations for a two-dimensional scenario, which can be solved by the mathematical algorithm of the Least Squares [16], [17]:

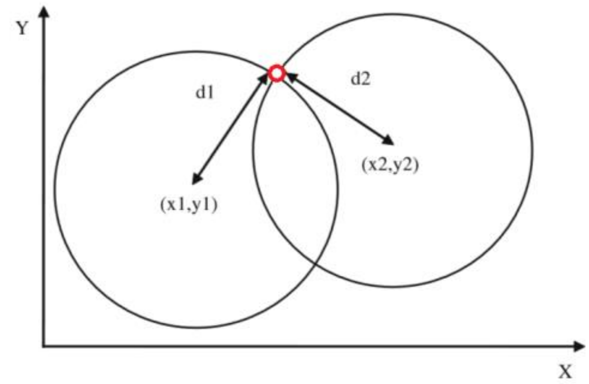


Figure 3.1: Time of Arrival method

$$(x - x_1)^2 + (y - y_1)^2 = {d_1}^2$$

$$(x - x_2)^2 + (y - y_2)^2 = {d_2}^2$$

In the case of indoor environment, where some radio waves need only $0.33ns$to cover 1m distance the delay of the signal is very small and only high accurate and precise clocks are able to define it. The time of travel can be calculated by applying Maximum Likelihood estimation to the following equation [18]:

$$r(t) = \alpha s(t - \tau) + n(t)$$

Where $r(t)$ is the received signal, $s(t)$ is the transmitted signal, τ is the delay and $n(t)$ is additional noise component.

3.3. Time Difference of Arrival

The method differs from ToA in that hire the important parameter is not the ToA by itself, but its difference between signals from group of transmitters and one receiver or in set of receivers, coming from same transmitter. The need of synchronization between the receiver and transmitter is replaced from this to ensure synchronization between all receiving or transmitting nodes. Compared to the previous two methods, this one is less common, because of its higher price and additional hardware for regularly synchronizations for the chosen group of devises.

3.4. Round Trip Travel Time (RTTT)

This algorithm is used when a node needs to determinate its position compared to another node. In this case the firs node (named A) send to the other node (named B) a message at time t_0. After travel time t_{tr} B receives the message (at time t_1) and at moment t_2 sends a response to A, which arrives at time t_3. Synchronization is not necessary for this method because an additional time t_{AB} is added to the equations to illustrate the delay between the watches in A and B. As knowing the values of t_0, t_1, t_2 and t_3 from the nodes' clocks the ToF is simple to calculate:

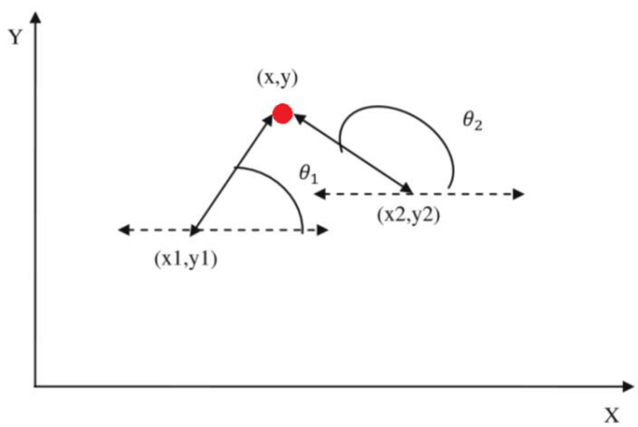
$$t_1 = t_0 + t_{AB} + t_{tr}$$

$$t_3 = t_2 + t_{AB} + t_{tr}$$

$$t_{tr} = \frac{t_3 + t_1 - t_0 - t_2}{2}$$

3.5. Angle of Arrival (AoA)

AoA location method is based on determination of the angle between known points and the target point in respect to a coordinate system (Figure 3.2). For scenario, the coordinates of the target position (x, y) can be calculated by the following equations:



$$\tan\theta_1 = \frac{y-y_1}{x-x_1} \quad , \quad \tan(\theta_1) = \frac{y-y_1}{x-x_1}$$

$$y_i - x_i \tan(\theta_i) = y - x\tan(\theta_i)$$

Figure 3.2: AoA method in two-dimensional space

3.6. Triangulation

As the name of the method shows, it is based on positioning via measuring angles to known points. By simple geometrical calculations the location of the target node is defined like creating a triangle, using the two known positions (Figure 3.3). If we named l the distance between points A and B, and the distance from this line – d, than

$$l = \frac{d}{\tan\alpha} + \frac{d}{\tan\beta}$$

$$l = d\left(\frac{\cos\alpha}{\sin\alpha} + \frac{\cos\beta}{\sin\beta}\right)$$

$$d = l\left(\frac{\sin\alpha\sin\beta}{\sin(\alpha+\beta)}\right)$$

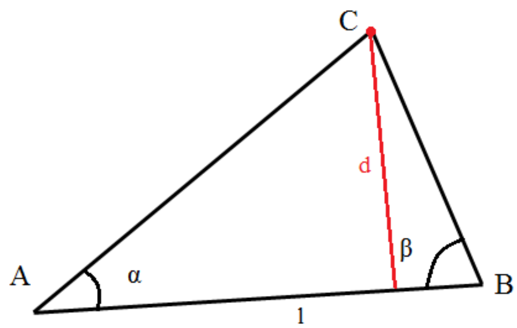


Figure 3.3: Triangulation method

3.7. Trilateration

The method is used to localize the absolute or the relative position of an object by measured or calculated distance to other known places. The distances are taken as radiuses to create circles around the known nodes (Figure 3.4). In difference with the triangulation, hire the calculations are made upon triangles' sides length and cosines lows. The method consists of creating quadrilaterals or polygons by joined or overlapping circles. In two-dimensional case three initial positions are enough to accurately determinate the location of the searched point, but in three-dimensional space the information is not sufficient and additional point is needed. The method is often used because of its simple algorithm, potentially low coast and high accuracy [19].

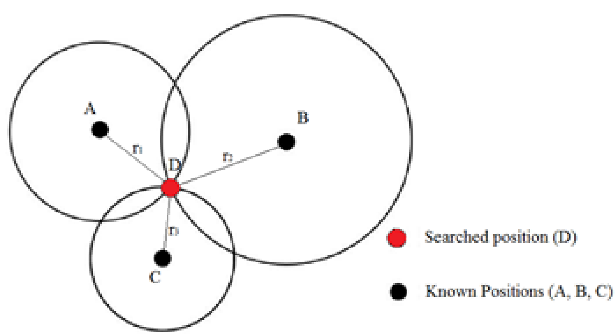


Figure 3.4: Trilateration algorithm

3.8. Fingerprint

The algorithm is based on picking physical low, which characterize and differentiate a set of sections in one bigger area. The point is to create locally unique and distinguishable zones. Every set of measurements at specific location must be similar to all other sets collected at the same place no matter the time or the device they are made, but different of these from other regions. Fingerprint algorithm is used for regression or classification data problems. The method consists of two stages: offline and online. During the offline step (also known as training phase) a data set coordinates, ranges of measurements and labels for all zones are created. The algorithm can consists of Supervised Learning (when every instance of the data set is with predefined location), Unsupervised Learning (when a model prediction is searched over observable variables and decision trees are made to illustrate the relation between the instances) or Semi-supervised Learning (when a prediction model is built from the training data set and unsupervised learning helps to improve the model capabilities) [20]. The online phase is the actual use of the method and during it the fingerprint data set is applied to determinate the appurtenance of the measured value to one of the predefined sectors. One of the first applications of the fingerprint algorithm for indoor positioning is based on Wi-Fi signal strength and weighted k next neighbor approach to determinate the position [21].

Short Summary

In this chapter we introduced the concept of Indoor positioning System. We surveyed the most widespread methods for location and determined some of their resemblances, to show how tough is the correct choices of appropriate positioning technique.

4. Potential Solitons for IPS

This chapter consists of evaluation of the performance of different technologies which have the possibility to be used for indoor localization. Typical applications for each of them are presented with their advantages and disadvantages. Briefly explanation to the methods that systems can use is added. And as a final of the chapter comparison of their characteristics is showed in a table.

4.1. Cameras

Due to the fast progress and the successful miniaturization of lasers and detectors cameras are widely technique used for positioning. They have the ability to achieve different level of accuracy according to the users` requirements. Nowadays the data transmission has reached high exchange rate, which we even did not expected. Image processing is very well developed and still new and novel algorithms in this area are published. These facts additionally contribute to the successful deployment of the cameras.

In an optical localization system of that type usually while the target is moving around, static cameras are tracking its movements in images. The hardest part in that situation is to compute the 3D position of the mobile node. In these systems coordinates measured in the images can give information only about the angles in the frame. With the usage of Angle-of-Arrival method the distance can be estimated.

Another example which can lead to improvements is the usage of movable cameras. This approach is also known as synthetic stereo vision [22]. Here all the images taken by one camera in different orientations are observed in consecutive order. But again only the images are not enough as information for IPS. Additional algorithms to work on the received images are needed to translate the data into distance.

As a technology for localization system in indoor environment cameras shows good results for accuracy – it can achieve position estimation with an error of just a few µm. That makes it big candidate for different type of applications related with real time localization. As disadvantages of the stereo camera system can be said that the results are strictly connected with the stereo baseline (the distance between the lenses) and that does not allow a miniaturization for handheld devices. Speaking for the cost cameras is not that expensive since a lot of manufacturers have proposed their decisions on the market. When we talk about power consumption as indoor positioning technology, cameras` characteristics are not that good as other potential decisions.

4.2. Infrared (IR)

IR signals have wavelength longer than that of the visible light. In normal situation people cannot see it but can feel it as a heat [23]. But anyway in an experimental environment is possible to be seen from the human eye [24]. There is three basic usage of the infrared`s waves: active beacons, natural radiation and artificial light.

4.2.1. Active beacons

Here the receivers are in static positions with known coordinates in the premises. With this approach it is possible to achieve a room-level accuracy location with one beacon in a room. For better results and more precise evaluation of the mobile node position additional configurations of the system are needed and more receivers should be added in every room. Since IR signals are actually light, they do not have the ability to goes through walls or other opaque materials.

4.2.2. Natural Infrared Radiation

In this type of systems the devices work in the long wavelength infrared spectrum (8 – 15 μm: thermography region). The basis of that method is with thermal broadcasting to build a passive picture of the area in the vicinity. Active infrared is not necessary in situation like that. The receivers are used to transform the heat into electricity. Examples for such devices can be thermal cameras, pyro-electric infrared sensors or others. They can measure the persons` temperature remotely without any kind of tag on him. A disadvantage of that type of usage can be add that the passive infrared can be affected by the sun`s radiation.

4.2.3. Artificial Infrared Light

Another approach is the combination of active Infrared light transmitter and Infrared cameras. A real example of that is showed in [25]. A monochrome CMOS sensor and infrared projector making 3D image of the environment. By the Time-of-flight method the infrared light gives the distance to human`s body by reflections from it. In that instance the achieved accuracy is 1cm for distance of 2m.

As we have seen there are several methods to take an advantage of the infrared waves. The first two of above mentioned would be hard to be used for high-precise indoor positioning system. On the hand the artificial IR light can be used for that purpose, but the cost of system like that would not be that affordable.

4.3. Sound

Sound is a mechanical wave. It is variation in pressure [26]. Sound can travel through anything except vacuum.

4.3.1. Ultrasound

Ultrasound can be used as distance estimating technique between mobile node and receivers through Time-of-Arrival method. This can be done by multilateration algorithm which calculates the distance to at least three static receivers with pre-defined coordinates. This example is also called active device system, due to the active mobile node. The other approach using transmitters with pre-defined placement and when the mobile node receive the signals it calculate its position.

Since the usage of Time-of-Arrival requires very precise atomic clock and synchronization between the devices, another approach is based on Time-Difference-of-Arrival. In this occasion as an addition is added radio frequency signal. The speed of the radio and the sound waves in air are known in advance and when they arrived in the receiver a comparison is done and the distance is estimate due to the difference in the arriving time for both waves.

$V_{US} \simeq 330 \div 355$ m/s is the speed of sound in the air, depending on how dry is the air [27].

$V_{RF} \simeq 3 \cdot 10^8$ m/s is the speed of light.

A possible source of mistake can be that variation of the sound`s speed depending on the air condition and the temperature in the room. To partly fix this problem a thermo sensor can be added which can introduce some corrections into the calculations. For perfect estimation, knowledge about the whole path of the Ultrasound wave should be taken into account to build a precise path loss model. Due to that fact outdoor location is impossible task for a technology like that. The wind and more fluctuations in the temperature values make would lead to big error into estimating. For indoor location the things are much better and Ultrasound has the possibility to be deployed for the purpose of IPS.

Disadvantage here is the high cost of such a system.

4.3.2. Active Systems

In an approach of that type the mobile nodes have the role of the transmitters. They transmit Ultrasounds waves constantly or over some periods. If more than one mobile node is involved in the system these wave should have some sequence. As a drawback of a system like this can be added that if many transmitters are in the same environment the interferences between the different signals become really big.

Example for such type of system is Active Bat [28]. It is a low power IPS which can achieve accuracy up to 3cm. The receivers in that system measures the distance to the mobile node by Time-of-Flight and the exact position is evaluated by trilateration. Anyway for results as that a lot of receivers should be added to the system

4.3.3. Passive Systems

In the passive systems static Ultrasound transmitters are emitting and the mobile node is passive. It just receive on locate itself. For a system like that all the coordinates of the transmitters should be known in advance and every mobile node must have that information. But in this type of systems the amount of users does not affect the signals, since they are do not transmit anything. Typical measurement distance methods again are TDoA or ToF. And based on the received information from that method trilateration can be applied.

4.3.4. Echolocation

Another possible usage of the Ultrasound as a positioning technique is the transmitting of sound waves and after that make a comparison with the received returned echoes. It is a high precise method used also by the bats and it does not need any tags in the located target.

4.3.5. Audible Sound

A possible variant is also to use the sound from the audible spectrum. As a big disadvantage, of course, is that the sound would strongly distract the users, but also because of the low rates delay will occur in the system.

With a sound IPS system it is possible to achieve accuracy of just a few centimeters. Due to the fact compared to the light the sound`s speed is much smaller, the synchronization between devices will be much easier. Disadvantage of that technology is that, it is strongly depending on the temperature. Another one is its high cost.

4.4. Wi-Fi

Wi-Fi is a wireless technology which presents in most of the indoor environments today. The signal can be delivered up to 100m depending on the medium that it is passing through. It is a technology based on IEEE 802.11 standard to provide high-speed wireless connectivity to devices in a Local Area Network (LAN). It is applicable in both the MAC and PHY layers. The 802.11 standard has been modified and extended many times since his first creation in 1997 and now there are a lot of commercial widespread variations. For both personal and commercial WLANs the 802.11b/g/n are the most popular revisions of the standard.

The 802.11b/g is specified to use 11 overlapping channels, only 3 of which are non-overlapped. Each channel is 22 MHz wide. In case of 802.11b the maximum achievable data rate of 11 Mbps with direct spread spectrum (DSSS), but in 802.11g employs orthogonal frequency division multiplexing (OFDM) to achieve data rate of 54 Mbps. The addition to the 2.4 GHz spectrum is 802.11n, which can also be operated at 5 GHz. With this wider channel bandwidth and the adoption of multiple-input-multiple-output (MIMO) antennas, the maximum achievable data rate for 802.11n is 600 Mbps.

The Wi-Fi enabled devices may either be connected to an access point (AP) or, to other Wi-Fi enabled devices using ad-hoc mode. In AP mode, the access point (which is typically a router) is used to connect devices and enable data sharing among them. On the other hand, in ad-hoc mode, two Wi-Fi enabled devices can communicate in a point-to-point topology without requiring an intermediate device as in case of the AP mode. In both the modes, it is necessary to establish a connection before any actual data exchange can commence.

Anyway it gives the chance for localization of mobile node by different methods. The usage of Received Signal Strength Indicator (RSSI) is the most common way for determining positing, but anyway methods like Time-of-Arrival, Time-Difference-of-Arrival and Angle-of-Arrival are still possible. Examples based on the RSSI are Proximity, Trilateration and Fingerprint.

4.4.1. Proximity

This is an approach which does not rely on high accuracy. It just compares the RSSI value from the different transmitters. It accepted that the received signal with the highest value is from the closer access point and the user automatically takes the same coordinates like it.

4.4.2. Fingerprint

Fingerprinting as a positional technique is a process which can be divided into two parts. In the first one radio map has to be built containing pre-collected RSSI values in reference points, which is also called Fingerprints. In the online stage where the mobile node has to be tracked the real-time values are compared with these of the radio map and on that basis decision for the location is taken. With fingerprint a possible accuracy that can be achieved is on meter-level depending on number of access points and Fingerprints. We provided in-depth analysis of that approach in Chapter 3.

4.4.3. Analytical fingerprinting

This analytical overview of the RSSI can include different propagation models of the signal. Received Signal Strength is a parameter that is hardly to be predicted for the case of indoor environment. And that fact makes the mission of finding the most appropriate model, from which the distance from mobile node to transmitter can be obtained, really hard. Of course that analytical method can be used together with the classical fingerprint. With the better model will come and lower fixations in the offline stage of the measurements. There are many propagation models that can be used for the purpose of IPS. However, it always depending on what would be the exact environment, what are the materials of the walls and the furniture. Also other factors such as reflection, scattering and diffraction must be taken into account, which makes the task even trickier.

As a big disadvantage for fingerprinting approach can be mentioned that, when a changes in the environment occur a new radio map has to be built or a new propagation model need to be applied to the system.

4.4.4. Trilateration

By the usage of RSSI another possible solution for localization can be trilateration. It is a method where with three or more locators the position of the mobile node can be estimated. When the distance to each locator is calculated, a spheres or circles with radii equal to that distance (depending on 3D or 2D localization approach is used, respectively) are drawn around the devices. The intersection of these spheres or circles is the place where the tag is located. More widely we have described that method in Chapter 3. The difficulties come with the task of finding the right model for transforming RSSI to distance. For precise estimation, this path loss model should contain factors like fast and slow fading. Fast fading also known as multipath fading has the form of unexpected fast fluctuations in the amplitude of the signal. Slow fading or shadow fading shows slow variations in the amplitude. These slow variations are caused by NLoS condition, where obstacles do not allow direct sight between the devices. With good modeling of the path loss high level accuracy can be achieved. But it will still vary from environment to environment.

4.4.5. Time-of-Arrival and Time-Difference-of-Arrival

As other technologies it is also possible to calculate the distance between Wi-Fi access point and mobile node by ToA. After the distance estimation again trilateration can be used on the information. This method could give more accurate estimations compared to the RSSI translation to distance, but it is not possible without additional hardware to the classical device. Again very accurate clocks should be added to the nodes for adequate localization. This will greatly increase the prize of such a system.

The same is valid for TDoA. The difference of Wi-Fi TDoA is that the mobile node transmits the signal and all of the access points receive it. All of them compare the arriving time and based on that the system make a decision for the user`s position.

4.4.6. Round Trip Travel Time

RTTT is similar method to Time-Difference-of-Arrival and Time-of-Arrival but here firs the mobile node broadcast the signal to the access point and then it waits for answer to compare the time of broadcasting and the receiving time. In the package sent from the access point to the mobile node should be included information for the delay that it contributes to the travel. That value must be added to the whole round trip time, when the user received the message.

4.4.7. Angle-of-Arrival

With another additional hardware, the system will be able to “move” the measured coordinates even closer to the real ones. This can be done by the using of appropriate antennas in the nodes. With that addition every node will have the possibility to calculate the angle of the arrival wave and with that information high 3D localization can be achieved.

As we mentioned Wi-Fi can be used as indoor positing system by the usage of various different methods. Anyway the most common is the fingerprint, even if needs much time to be set up it does not rely on additional hardware to the classical device and a complex model for distance estimation. In its radio map all the values already contain the attenuation in all the reference points and this makes it the most preferred choice. Wi-Fi has an advantage of that it is in almost every indoor environment but it also have a high power consumption compared to other technologies.

4.5. Radio Frequency Identification

In IPS system with RFID the radio waves can be transmitted from the user`s device to receivers or the opposite from transmitters to the mobile node. The message that is sent has the ID of the tag in itself. And with that ID all the users can be distinguished. Typically Proximity is the most common option for such a system but Fingerprint ToA, AoA and Trilateration are also possible. For the Proximity, as general method used by RFID systems, the most important factor related to the accuracy is how dense are placed the readers. There are two possible variants for the RFID systems - Active or Passive Radio Frequency ID.

4.5.1. Active RFID

In that version the locators are searching for the tag which is active transceiver that broadcasting all the time. As a source of energy it uses a battery. This option can give good results but also high power consumption and it is not that cheap.

4.5.2. Passive RFID

Passive RFID uses tags without power source such a battery. Instead of that it uses the electromagnetic energy from the transmitted signal from the locator to power itself [29]. These systems are more appropriate for applications like race timing, smart labels or other. It is much economy system but for localization active RFID is more appropriate since it is providing bigger range.

4.6. Ultra-Wideband

Ultra-Wideband (UWB) is a radio technology that transmitting information over a large bandwidth (>500 MHz). UWB signals can pass easily through walls and others but metallic and liquid materials cause interferences in the signal. According to Federal Communications Commission (FCC) regulation [30] the most energy of the UWB signals follow into the range 3.1 to 10.6 $[GHz]$. And the emitted signal power should not exceed the limit of -41 $[dBm/Hz]$. Below 3.1 [GHz] the signal level is lower than -60 $[dBm/Hz]$. The spectrum below 3.1 $[GHz]$ is left like this to protect the GPS system.

4.6.1. Passive UWB

Passive UWB Localization is based on the reflection of the waves. When the emitted signal reach a target it is reflecting back and based on the differences of the broadcasted and received signal the distance is estimated. The advantage of that type of systems is that there is no need of any kind of device in the user to be located.

Even is just one transmitter is used it is possible to estimate the position of the mobile node. We can assume that when the signal is reflecting from the walls after that it also reaches the target. It can be said that reflections are transmitted from pseudo nodes (with position the place of the wall where signal was reflected first). With this new estimated distances a trilateration approach can be obtain for localization of the user.

4.6.2. Active UWB

Active tag worn by the user is also a possible solution for UWB localization system. Methods on that type can be based on time, angle, distance measurement and fingerprint.

4.6.3. UWB Fingerprinting

As other technologies fingerprinting is one of the common decisions for localization method. The same tasks need to be done first, offline stage with calibrations and building a radio map. Compared to the Wi-Fi fingerprint UWB has the possibility to achieve better accuracy because it has no the problem to with NLoS conditions. But still in comparison with other approaches related with UWB fingerprint is not the most precise method.

Disadvantages of UWB are the higher cost and the developing of the antennas that it uses which are engineering challenges due to the unique demands.

4.7. GNSS

Global Navigation Satellite systems (GNSS) are already system which has proved that they have big possibilities and are capable to give amazing results when the user needs are for outdoor environment. The most widespread system of that type is the American Global Positioning System (GPS). To achieve one-point accuracy it needs the signals from four satellites, with three the system is confused between two points. The system has world-wide coverage but when we talk about indoor scenario the accuracy that can be achieve is on building-level. This is due to the fact the satellite effective isotropic radiated power (EIRP) varies between 25 and $27\ [dBW]$ [31]. The distance from satellite to the Earth is about $21\,000\ [km]$ and the path loss is around $185\ [dBW]$. After that, to reach an indoor target, the signal will be affected also by the building material and factors such as reflection, diffraction and scattering make the task impossible. A solution can be the usage of higher power of the transmitters, which can lead to increasing in signal strength but on the other hand since as a source of energy they use solar panels this remains only as idea. Another approach is to use terrestrial repeaters of the signal. In some unreachable places they are already in use. But to achieve high precise indoor location measurements many repeaters are needed and this cannot be a decision wider use due to the unaffordable prize.

4.8. Radar systems

The radar systems have big usage nowadays. Application examples can be found on every airport, shipping port, police radars and many others. This type of systems can work successfully in the presence of passive interferences. They can be separated in two groups: coherent and non-coherent. The first one uses the known effect in radiolocation of Doppler. This effect can be used for both impulse Radio Location System (RLS) and continues operation mode RLS. And it is based on the formulation for Doppler frequency:

$$F_D = \pm \frac{2V_r}{\lambda_0}$$

Here F_D is the Doppler frequency, V_r is the radial velocity and λ_0 is the wavelength.

The second one is based on comparison between reflected signals on a period of time. On Figure 4.1 is presented the mutual location of the RLS and example for air target. On the figure are shown the most common parameters for finding the right location in system like that.

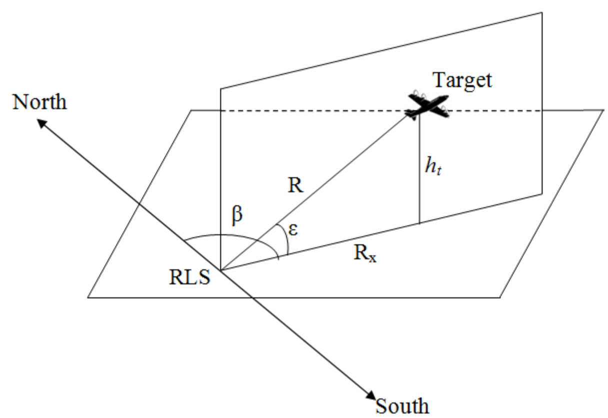


Figure 4.1: Illustration of the measured parameters of a target

The Figures shows in 3D coordinate system the parameters of the target. In the horizontal plane where is the Radio Location System (or Station) are shown the main directions and the azimuth angle to the target β. In the vertical plane in which the target is the direct distance to the target R, angle to the target ε and the height of the target h_t. On the line that shows the intersection of both planes is shown the horizontal distance to the targetR_x. In case of target on the sea level $\varepsilon = 0$ and$R = R_x$.

In the present radiolocation system generally the coherent RLS are found usage for location of moving target. As a process the location of moving include the separation of whole set of reflected signals coming on the input of the receiver from these reflected from the moving target. That is a still current problem in some situations and many specialists work on it.

In coherent RLS is used the principle for comparison the phase of the reflected signal with the reference signal (emitted one). When there is no moving target the signal will not change in the time. By reflection from moving target the phase difference will be a time function. These differences can be found by the usage of phase detector.

Such a system can achieve high accuracy for the purpose of Indoor Positioning but the disadvantages are the radiation that it broadcast, the high complexity and high power consumption.

4.9. Inertial Navigation Systems

This type of system uses Dead Reckoning approach to estimate the location of user. It has Inertial Measurement Units (IMU) and an algorithm to process the received information and to convert it into real coordinates. The main measurement units in this type of system are accelerometer which catch the motions, gyroscope which can give information for the angle, compass that can give us the direction and others. If the starting position of the target is known in advance with the information received from these sensors every next movement and changes in the position can be calculated. Advantage of that system is that it does not need any additional infrastructure and installations. When the user is moving the changes are continuously added to the last measured position and by that method the new position is estimated. A disadvantage of INS without additional hardware is that the estimated positions are very depended on the accuracy of the starting point that is stated, and also if some of the sensors provide noisy and incorrect measurements error in the estimations is increasing with every step.

The accelerometer as a part of that system can be used for counting the steps of the user, to detect steps and to estimate the length of steps. To have these results as output first a setting phase should be done. In that phase a movements such as running, walking, going up and down on the stairs and other different type of movements should be adjusted as models in database and if some of them happen the accelerometer can react appropriate to the actions. Accelerometer is embedded in almost every smartphone and there are also other handheld devices which have the mission of estimating steps. Important factor is how the user is using the device and where exactly it is on the person.

The estimation of the direction can be done by the usage of compass. Most of the time, Inertial Measurement Unit of that type does not have such a good characteristics to be reliable for high precise localization. Nowadays more common decision for that purpose is the gyroscope. It uses the Earth`s gravity to estimate the orientation. It contain rotor (rotating disc) mounted to a spinning axis. When the axis turns the rotor is remaining static to provide stability and to indicate the central gravitational pull.

As we mentioned a localization system based only on dead reckoning leads to error increasing with the time and distance that user is passed. A conclusion from that fact can be that a good idea would be to add another technology to work mutually with the IMU. The work of different systems together can give a better accuracy for the final result. Such an additional system can be Wi-Fi, UWB, ultrasound and etc. The most difficult part of implementing such a hybrid system is to model the right algorithm for data processing and for cooperative work between the devices. Also some good examples for filtration of sensors` data, which can be used for better estimations, such as Kalman filter or Particle filter. Another advantage is that as a compensation of a sensor`s mistake always can be used the measurement from some of the others.

Another variant to use dead reckoning can be, if a pre-defined map is built. With the inertial measurements it is possible to make such a map without any external type of infrastructure. That map hast to be stored in the user`s device. It contains data for comparison in real time and can be used to make corrections in the estimated positions and movements. That approach is also known as Map Matching (MM) [32]

As advantages of the INS we can say: with that system it is possible to estimate a position in an unknown environment without any pre-installed transmitters, beacons and others. These sensors are widespread technology due to the fact in the last few years they are integrated in every mobile phone. Dead reckoning navigation is the process of localization taking as input starting position and then measured directions and movements collected.

The main disadvantage of these technologies is that the error is time increasing factor. This can lead to big uncertainties if a compensation model is not added to the system or another infrastructure which can reduce the effect of that problem.

4.10. Localization through electromagnetic field

The electromagnetic field can be used for localization with the usage of the electric and the magnetic field separately.

4.10.1. Antenna near Field

The Near-Field Electromagnetic Ranging (NFER) uses the characteristics of the radio waves. The distance can be estimated by the phase comparison between the electric and magnetic field components of the electromagnetic field separately. When the target is close to the locator`s antenna the above mentioned have phase difference of 90°. With the increasing in the distance that value is decreasing. This is good information that can be used for location determination. System of that type does not require any type of synchronization. And also it is possible to pass through walls. A drawback is that the antenna that it need to be with large proportions in size.

Another example for that positioning approach is the usage of the magnetic field created by static magnets. This type of system have several magnetic sensor which are used as locators, which measuring the flux density of a mobile magnet on the target. The opposite is also possible if the locators are static magnets and the target has a magnetic field sensor. The magnetic field can be used also with the fingerprint algorithm since at every position in the indoor environment correspond to a different magnetic flux density. As an assumption can be said the magnetic field inside building is almost static and due to that fact an accurate map with magnetic flux values can be created in the offline phase.

Advantage of that approach is that LoS between devices is not a requirement for good results of the system. As a major disadvantage is the complexity of the magnetic field and highly flexible models should be created for a positioning algorithm.

4.11. ZigBee

The ZigBee protocol is created to provide reliable, low-cost and low-power wireless connectivity, in order to create Personal Area Network (PAN). It is particularly designed for applications which demand low-power consumption, but don't require large data throughput. As a localization system the usual usage of ZigBee is by observation over the Received Signal Strength Indicator.

Based on IEEE 802.15.4 specified MAC and PHY layers, the ZigBee transceivers are operated on un-licensed industrial, scientific and medical (ISM) radio spectrums; 2.4 GHz globally, 868 MHz in Europe and 915 MHz in the USA. At 2.4 GHz, a total of 16 channels, each supporting data rate of 250 kbps, are allocated. The typical communication range of ZigBee transceivers is up to 100 meters and the network size of the ZigBee controller can grow up to 65,536 nodes. In order to secure the communication, the 128-AES algorithm is supported. The ZigBee protocol defines three types of devices in order to support multiple network topologies such as mesh, star and cluster tree networks: ZigBee Coordinator (ZC), ZigBee Router (ZR) and ZigBee End Device (ZED). The ZC acts as a central coordinator in both star and cluster tree topologies are the most resourceful device in terms of both its memory and the processing power. The ZR performs application functions and can act as an intermediate router to relay data among connected nodes in both the mesh and cluster tree topologies. In difference of ZC and ZR, ZED is a reduced functional device (RED) as it can only communicate to its parent node (ZC or a ZR).

In order to allow devices to achieve a long operational lifetime by switching them in to sleep modes whenever possible, the ZigBee protocol supports beacon and non-beacon enabled networks. In beacon mode, a ZR periodically transmits special messages called beacons to inform other devices about its presence, thus enabling a freshly awakened device to relay its data to a router and switch back to sleep mode. On the other hand, in non-beacon mode, an end-device, once activated from sleep mode, senses the carrier and if the carrier is available, it transmits the data to a router by means of a continuously active receiver. In case where the carrier is unavailable, the end-device waits for a random time period and then follows the same procedure until it transmits the desired data. Upon successful communication, the end-device switches back to sleep mode. The signal range of a ZigBee node can reach a target up to 100m but this is true in free space. For indoor environment that value is around 20-30m.

4.12. Classical Bluetooth

Bluetooth® is a wireless technology created in 1994 [33]. It is named after the Danish King from eleven centuries ago Harald Blåtand or translated in English, Harold Bluetooth. The story is that Blåtand helped to unite the Norway, Sweden and Denmark which were in a war at that time. By "similar" way Bluetooth is helping to connect different devices so they can work together. For exchanging data it operates on frequencies between 2400 and 2485MHz. It has low power consumption, inexpensive cost, high security, it is easy for use and it has small size. It gives the possibility to connect different devices to work together. You can connect your phone to everything that has a Bluetooth embedded in – headphones, lights, TV, heater, window and many others and with appropriate command to control all these objects. The only thing that needs to be done first is to build a link between the two devices. This operation is also called pairing. After they are paired one of them should be master and the other slave. Every master is possible to have a connection with 7 slaves at same time.

Bluetooth uses Frequency Hopping Spread Spectrum (FHSS) which helps to prevent interference between the channels. If a message does not reach the recipient it will be send again on another channel.

Originally it has been made for a commutation of a just few meters. Two decades later different classes of Bluetooth technology are fact and it has ability to transfer data up to 100 meters with direct line of sight.

As Wi-Fi and ZigBee, Bluetooth can be used for IPS by different ways. It can use the RSSI values for multilateration approach and Fingerprinting but with some additional hardware it can achieve a TDoA, ToA, AoA and etc. Advantages of Bluetooth for a positioning technology is it is a low power and it is everywhere in almost every mobile phone and other devices.

4.13. Digital Television and FM Radio

Broadcasting of the TV signals can be used also for the purpose of localization. A good decision for that can be the multilateration method. Compared to the Global Positioning System TV signals has an advantage with the signal power so it can reach to indoor environments better and higher accuracy is possible but still not that precise. The stations where the signal is emitting are not that dense to result in good characteristics when we talk about IPS.

Frequency Modulation (FM) using the frequency band between 87.5 MHz and 108 MHz for broadcasting audio signals. These signals anyway can be used for position estimation in indoor environment. Methods base on time are hardly to be applied since there is no any time information in the system. More appropriate would be the usage of method related to the received signal strength such as fingerprinting or multilateration. FM radio has the advantage of that it is widespread technology and as Bluetooth and Wi-Fi a FM module is embedded in every mobile phone. It is also low cost and low power technology.

Summary

In that chapter we showed that there are a lot of possible technology solutions for indoor location system. To sum up a table is presented with a comparison of their general characteristics (Table 4.1) [34], [35].

Technology	**Typical Localization technique**	**Accuracy Level**	**Power Consumption**	**Cost**	**Typical Coverage**	**Typical Application**
Cameras	Angle Measurement from images	cm-m	High	Medium	Up to 10m	Robot navigation
Infrared	Active Beacons, Radiation imaging	m	Low	Medium	Up to 5m	People detection
Sound	ToA	cm-m	Low	Medium	Up to 10m	Tracking
Wi-Fi	RSSI Fingerprint	m	High	Low	Up to 50m	Location Based Services
RFID	Proximity	cm-m	Low	Low	Up to 50m	Pedestrian Navigation

UWB	Reflection, ToA	cm-m	High	High	Up to 50m	Robotics, Automation
GNSS	Multilateration	10m	Very High	High	World-wide	Global Positioning system
Radar	Reflection – Doppler shift measurement	m	High	High	Up to 400km	Tracking airplanes, ships, cars
INS	Dead Reckoning	m	Low	Low	Up to 100m	Pedestrian Navigation
Magnetic systems	Near-field ranging, Fingerprint	mm-cm	High	High	Up to 20m	Locating in mines
ZigBee	RSSI Fingerprint, RSSI Multilateration	m	Low	Low	Up to 50m	Person Tracking
Bluetooth	RSSI Fingerprint, RSSI Multilateration	m	Low	Low	Up to 50m	Person Tracking
Digital TV and FM radio	RSSI Fingerprint and RSSI Multilateration	m	Low	Low	Up to 10km	Person Tracking

Table 4.1: Comparison of different location technologies

5. Bluetooth Low Energy

In the following section we presented an overview of the BLE technology. We surveyed it protocol's nature and secure techniques. We made a comparison between the Classical Bluetooth and BLE. We also determined the BLE potentialities and limitations and through defining its advantages over other technologies we motivated our decided to choose BLE as technology for the development of our IPS. We also presented several BLE beacon solutions for indoor location.

5.1. Technology overview

In order to secure a robust transmission even in harsh industrial environments, Bluetooth Low Energy (BLE), like Classic Bluetooth, practices adaptive frequency hopping. To obtain simpler and cheaper radio chipsets, Bluetooth LE uses only 40 2MHz wide channels while Classic Bluetooth uses 79 1MHz channels (Figure 5.1). Three channels are used for device discovery and connection setup, and they are choose because are located exactly between the Wireless LAN channel.

BLE use the same unlicensed 2.4GHz ISM (Industrial Scientific Medical) band like WLAN, IEEE 802.15.4/ZigBee, WirelessHART and many proprietary radios [36]. Thus this it has robust and reliable communication, thanks to integral adaptive frequency hopping feature and high tolerance for interference. These benefits also allow BLE to co-exist smoothly with other wireless technologies in the same band. This is obtained by avoiding frequencies that are already occupied by other radios in the neighborhood. In addition, via the so-called channel blacklisting, the usage of designated channels can be prohibit.

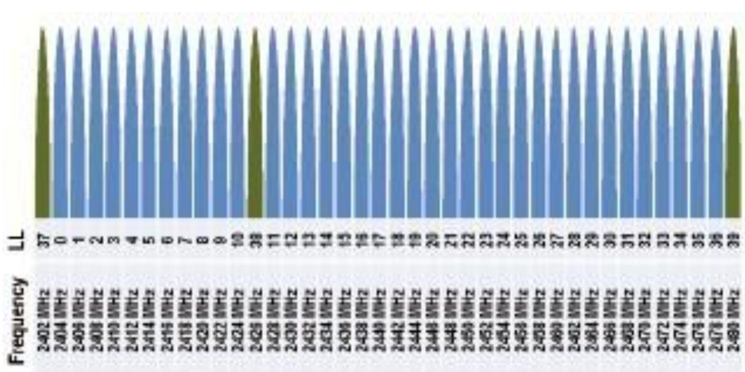


Figure 5.1: BLE frequency channels [37]

In BLE topology a unit is always either a master or a slave, but never both at same the time. The master can communicate with one slave or with multiple slaves. Further, the master controls the timing pattern for the links, and the slaves only pass on requests made by the master.

In BLE units are now allowed to announce themselves by periodically advertisement. An advertisement can also, for example, include a process value or an event that has occurred. A scanner is waiting for an advertisement and is always a master when connecting. When it comes to connection and latency, Bluetooth LE only uses three channels to build connections and to discover other devices; this not only allows for lower power consumption but also for a faster connection. Establishing a link requires just a few milliseconds. The latency periods are dependent on how often the master sends messages to the slaves and how often it receives data from the slaves. The latency period for one slave only is 7.5ms and then increases slowly for each additional slave. Because of its modified modulation, BLE has an approximately 3dB better link budget compared to Classic Bluetooth. A BLE unit can, therefore, offer a range of 200-300m in line-of-sight without needing an additional power amplifier [38]. A comparison of BLE technology with ZegBee and Wi-Fi is shown in Table 5.1

Standard	**BLE**	**ZigBee**	**Wi-Fi**
IEEE Specs	802.15.1	802.15.4	802.11 b/g/n
Frequency spectrum	2.4 GHz	868/915 MHz, 2.4 GHz	2.4 GHz, 5 GHz
Topology	Star, point-to-point	Star, mesh, cluster tree	Start, point-to-point
Network size	N/A	65536	N/A
Data rate (Mbsps)	1	0.02 –0.25	11/54/600
Range (m)	< 50	< 100	< 100
Number of channels	40	1/10/16	11-14 (3 orthogonal)
Security	128-AES	128-AES	SSID
Modulation	GFSK	BPSK (+ASK) O-QPSK	BPSK, QPSK, COFDM, CCK, M-QAM
Average Power Consumption for ten 256-byte messages per day:	50µW	414 µW	>500 µW

Table 5.1: A comparison of different parameters for BLE, ZigBee and Wi-Fi [39]

5.2. BLE challenges

Bluetooth Low Energy is not a perfect decision for all cases of wireless connections and is not clearly different as better than classic Bluetooth, WiFi, NFC, and other technologies. Every one of them has its one particularity and is irreplaceable in some situations. Like all of them BLE also suffer from some key limitations:

- The BLE devices are not able to communicate between themselves. They need a phone, tablet or similar device. Hopefully soon this limitation will disappear - it is not provoked from the Bluetooth protocol and the technology for advertising and scanning for neighbouring devices is already a part of the standard.
- It needs constant connection to a BLE-enabled device to access internet or additional hardware should be added.
- The modulation rate is defined to be 1Mbps, but often is lower because of protocol overhead, CPU and radio limitations, bidirectional traffic, artificial software restrictions or others. In real scenario, the potential maximum data throughout in the neighborhood should be assumed as 5-10 KB per second.
- Often the operating range is dropped to only 3 to 5 meter, because of the constant striving for low level of energy consumption.

5.3. BLE security

BLE operates in the same frequency range as other Bluetooth technologies, its operation at the PHY and link layers is incompatible [40]. To cope with the PHY layer BLE uses 250 kHz offset for Gaussian Frequency Shift Keying (GFSK). BLE splits the 2.4 GHz spectrum into 40 channels spaced 2 MHz apart. During connections 37 of them can be used to transmit data (data channels) and the 3 (advertising channels) are used by unconnected devices to broadcast information and establish connections. Every packet starts with an 8 bit preamble. This is followed by a 32 bit access address (AA) which can be thought of as a unique identifier which defines a particular connection. Following the AA is Protocol Data Unit (PDU) with variable length, which contains the message payload. Lastly all packets finish with a 24 bit Cyclic Redundancy Check (CRC) (Figure 5.2).

Whitened data

Preamble (8 bits)	Access Address (32 bits)	PDU (2 to 39 bits)	CRC (24 bits)

Figure 5.2: BLE packet format

In BLE several major technical hurdles simply prevent the eavesdropping common to 802.11. Firstly, as mentioned before, the technology use frequency hopping and staying on a particular channel only long enough to transmit and receive a single packet. The time spent on certain channel and the channel hop sequence varies from every time. We can only rely on the AA to determine when a packet has been transmitted, a value which also varies. In addition, the Cyclic Redundancy Check (CRC) and the 24 bit value Cyclic Redundancy Check Initial (CRCinit) technique allow filtration of false-positive packets. This is done as calculating the follows parameters:

- Hop interval (also referred to as dwell time) – The hop interval is found by relying that the hop sequence makes a cycle in every 37×1.25× hopInterval.

$$hopInterval = \frac{\Delta t}{37 \times 1.25\, ms}$$

- Hop increment – Is calculated by measuring the interarrival time of packets on two data channels (index 0 and 1).

$$channelsHopped = \frac{\Delta t}{1.25\, ms \times hopInterval}$$

- Access address – To identify the AA search 16 bit header that defines an empty packet. Then we treat the prior 32 bits as a possible AA. We continue filtering the candidate bitstream by 14 bits (without the 2 varying bits of header) to left many false options. We create a table for every candidate AA – a least-frequently used (LFU) table. After we detect some of the candidate AA the needed number of times we assume it as the correct AA and start use it to filter data packets based on it.
- CRCinit – As mentioned before, each packet carries a 24 bit CRC that is calculated over the bits of the packet (including the header). The value is defined using a linear feedback shift register (LFSR) that is pre-seeded with a 24 bit value known as CRCInit. The CRCInit changes in different connections. When we receive a candidate

packet, we seed the reverse LFSR with the CRC from the air. We then run the bits through the LFSR in the reverse order. The value left in the LFSR at the end of this exercise is our candidate CRCInit. As in the case of candidate access addresses, we maintain an LFU table of candidate CRCInit values and treat a value as our true CRCInit after it is observed a fixed number of times.

Another feature of BLE is that uses AESCCM [41], against which there are no known practical attacks. To establish an encrypted session, first a known long-term key (LTK) should be shared between the master and a slave. Usually the LTK is saved and reuse it for future session. Otherwise, the master and slave establish an LTK through a key exchange protocol. Even if the LTK is known, if the initialization of the session is missed, the conversation stays secure, because of the session-specific nonce exchanged only at the beginning of the session. The key exchange protocol starts by choosing a temporary key (TK), a 128 bit AES key whose value depends on pairing mode. The devises use the TK to create a so-called “confirm” value. Both the values used to calculate the confirmation and the confirm value are exchanged in plaintext over the air, but separately. As said before, the TK value depends on pairing mode, which can be:

- Just Works™: 0
- 6-digit pin: a value between 0 and 999 999 padded to 128 bits.
- OOB: a 128 bit value exchanged out-of-band

5.4. Advantages of BLE as indoor positioning technology compared to the Classical Bluetooth

For the purpose of indoor location Bluetooth Low Energy has some important improvements compared to the classical Bluetooth. A simple example for that are the predetermined advertisement channels, which are just three 37, 38 and 39. This can lead to significantly shortened time for searching other devices. With traditional Bluetooth it takes about 5 seconds to find most of the devices around and over 10 seconds for complete scan. With Bluetooth Smart can find devices in the vicinity in less than a second. For localization system this is a great advantage since real-time measurements are needed.

Another evidence in plus of BLE is the new mode of “Advertisement”. With this addition the system can easily cope if there is rise in the users` number. The beacons just need to be programmed to transmit within a specific interval. All mobile nodes which are nearby can receive the emitted signals. Based on the received signal strength, which is part of the received message they can start to locate themselves. In situation like this only the beacons` signals will be contained in the radio spectrum. The mobile nodes are doing just a passive scanning without transmitting. For IPS this is very appropriate addition. In the case of classical Bluetooth all the mobile nodes should do active scanning and in an answer of that the beacons should respond to each request separately. Every mobile node should need different connection with each of the beacons and every beacon with each of the mobile nodes. This will also lead to bigger latency in the system. Since no connections are needed in BLE, it looks like much better candidate for core technology in positioning application.

After these improvements of Bluetooth Low Energy over the classical Bluetooth another fact that can be used as an advantage is that the Bluetooth Smart technology is a widespread in devices all over the world. This is not a plus over the traditional Bluetooth which is even more widespread, but nowadays BLE really fast is been embedded in different kind of devices. Almost every smartphone has Bluetooth Smart integrated in. If a good and accurate position algorithm and application is accomplished that fact can help to a very rapid development.

With the usage of smartphone except the BLE module come also several different sensors which can be used as another source of data for the positioning system. Examples for that type of sensors are gyroscope and accelerometer. In the context of localization they can contribute for a better estimating of the position.

5.5. BLE beacon solutions

Bluetooth smart is area of big researches in the last few years. There are some commercial products based on that technology which can be used for rough indoor location. Some of these products are trying to improve the location accuracy and to give the exact position of the indoor target. Recently more and more famous become the Bluetooth marketing. For these applications the aim of devices is not to calculate the exact position of the person. Systems like this work on the principle of proximity. It just needs to know if the person is close or not. For example, when someone is passing near a shop, an advertisement is popping up on his phone with discounts, promotions or just an invitation with pleasant text to invite the person in. Another instance is if the person goes to a museum, he can receives headphones with Bluetooth Low Energy in and when he is near to exhibit a guide can start talking about what he is seeing. In this section some of these commercial systems and hardware are commented.

5.5.1. iBeacon

iBeacon is the name of an Apple Trademark product which is underlying on the communication technology Bluetooth smart [42]. It can be used for location and proximity detection. Mobile devices can detect beacons nearby. Firstly iBeacon was invented to work with iOS but recently mobile apps which can run on Android also were released and it is possible to detect the beacon on both systems. This product is not primarily designed to measure the exact location. The system provides three different zones, based on the distance. The first is immediate, which is a couple of centimeters away of the beacon, the second is near, it is till to about 10 meters away and the third after the tenth meter is called far. Thus it gives just an approximately estimation of the position.

5.5.2. Indoo.rs

Idoo.rs provides is a hybrid location system based on Bluetooth low energy and other technologies [43]. It is working on the principle of fingerprint. Additionally to BLE Wi-Fi connection can be used for the localization. It is also support iBeacon protocol. Another source of data that can be used here are the sensors of the mobile devices (e.g. compass, gyroscope, accelerometer, barometer). This also helps for accuracy improving. While doing the fingerprints additional information can be added as presence of walls or other things in order to make the system more reliable. The company also adds that indoo.rs algorithm determine the position with accuracy of 2 meters.

5.5.3. SenionBeacon

The SenionLab`s product provides a robust indoor positioning technology [44]. Senion Beacon has the possibility to work with Android or iOS. After pursuing of development kit the user should installs beacons where he wants to be used and with the help of calibration application he can make fingerprint map by collecting the beacons signals and as an additional sources of data are used the mobile node sensors as in the Indoo.rs system. After that all the data and the fingerprint map has to be sent to SenionLab and they provide another calibration service to finalize the process.

5.5.4. Estimote

Estimote is a beacon based on the iBeacon technology and it is also work on the proximity principle [45]. There is user-friendly app which provides distance estimating based on the same zones as in iBeacon. However with the beacons comes an application programming interface (API) and it gives freedom to developers to make their own apps. Also it is possible to build on the proximity estimations and to use it for trilateration. It is also supported by iOS and Android devices. Recently, indoor location app was released for iOS devices, which is working with 4 beacons. The Estimote application give the possibility to change the advertisement interval of the beacons or the transmit power. The beacon is covered with waterproof silicon case. Thus it is also possible to be used in rooms with high humidity.

5.5.5. Quuppa

Quuppa Intelligent Location System™ uses Bluetooth Low Energy in a new innovative way [46]. With the usage of advanced antennas their algorithm is based on Angle-of-Arrival method. In this system the tag is transmitting radio signals and the beacons are these which are receiving it and measure the direction of arriving. With one beacon they warrant accurate 2D localization, with two beacons the system has the possibility to locate into 3D space. The accuracy is linked with the distance and to the number of beacons. The system can achieve 0.5m error or even smaller depending on the needs.

Summary

In this chapter we presented the new Bluetooth Technology – Bluetooth Smart. We described its characterizations and compared it with the Classical Bluetooth. We also collated BLE with ZigBee and Wi-FI to motivate our choice to develop Indoor Positioning System based on BLE technology. At the end of the chapter we presented several of the present commercialized BLE beacon systems.

6. Evaluation of the RSSI behavior

We started the design of our location system with the selection BLE based beacons. Despite the published characteristics and specifications of the devices, we needed to examine by ourselves their capabilities. In this chapter we examined the behavior of the radio signal in an indoor environment. We surveyed the relation the Received Signal Strength Indicator (RSSI) values and the presence of Line of Sight (LoS) between the transmitter and the receiver. We continued testing the beacons' performance in over variations of distances and antennas' orientations. After collecting sufficient amount of information, we studied tree methods for signal filtration, to compare their advantages and select the most suitable one for our system.

6.1. Work environment

For the purpose of our project we have conducted experiments in non-idealized environments – one small (4.1x3.6m) and one larger (8x6m) rooms (Figure 6.1 and 6.2). Both introduce real-life scenario where furniture, objects and noise are expected. The premises are also affected by other active wireless technologies like Wi-Fi and other Bluetooth enabled devices. The above-mentioned have significant negative effect over the system performance and should not be neglected.

Figure 6.1: Small room

Figure 6.2: Big room

Bluetooth Low Energy – As choosing as most suitable for our project development we have decided to work with Estimote beacons. The reasons for this were:

- Looks good (colored and covered with waterproof silicone case)
- Certificated
- Large amount of DevKits distributors
- Open development platform (for Android and iOS)
- Easy to try the functionality with their already existing apps (control advertisement interval and transmit power)

Every Estimote beacon consist a small computer. Its 32-bit ARM® Cortex M0 CPU accompanied by accelerometer, temperature sensor and of course – 2.4 GHz radio using Bluetooth 4.0 Smart, also known as BLE or Bluetooth low energy. The device uses CR2477 battery that provides more than 3 years work time on default settings (-12dbm Tx power and 950ms Advertisement interval) [45]. Transmit period varies from 100 to 2000ms and the power from -30 to 4dBm (which allows range up to 70m). To perform the experiments we have took the advantage of 3 BLE devices: CB:BA:B0:9D:61:13, F4:0A:08:E6:C0:36, E7:91:97:D9:E4:A8, which from now on we will call respectively BC, BF and BE

<u>Mobile node</u> – We have taken the advantage of LG G3 for our experiments. It runs android 5.0 and supports Bluetooth smart. We have used it to collect the data from the beacons and process it to define its own location.

<u>PC</u> –The software tool used for evaluation and visualization results is Matlab R2015b.

6.2. Factors affecting the wireless propagation

To implement location system based on Bluetooth low energy good understanding of the RSSI measurements is needed. In system like this the only one input that is measured are exactly the RSSI values. In the real world there are many factors which influence the transmitted signal by the BLE node. In the next few pages we briefly consider some of them.

The three basic mechanisms which impact the propagation in the wireless communication are reflection, diffraction and scattering [47]. When a wave passing through a medium, it loses some of energy, due to the absorption of the atoms passes through. Emitted waves also lose some of their energy when they reach an object or when they pass through a different medium. This is the fading effect, which affect the signal`s strength. To describe the exact effect of these factors complex function is required. This function will be changed from environment to environment. The material type of the walls and all the surface structure affect that function. To build model like this for real practice in indoor environment is almost impossible. This is due to the fact even if all the input parameters are calculated they can be changed very fast. A simple example for that is if a table is moved from one place to another or even if some door is opened or closed. All of that may lead to mistakes into positioning.

6.2.1. Reflection

Reflection occurs when the electromagnetic wave hit an object with very large dimensions compared to the wavelength. Energy of the reflected ray depends on the angle at which it arrives to the object and also on the properties of the material that it is built from. In real life scenario walls are made from several materials, so to predict reflection from a wall it is not that easy. Maybe some type of calibration model should be involved to be done.

6.2.2. Diffraction

Diffraction occurs when the radio wave obstructed by an object with sharp edges. In situation like this, waves can “spread” in a rather unusual way when they reach the edge of the object - this is called diffraction. Actually the waves go around the object and continue straight after that, even when line of sight does not exist. The amount of diffraction depends on the wavelength and the size of the object.

6.2.3. Scattering

Scattering occurs the on the path of the radio wave have an obstacle with dimension smaller compared to the wavelength. It can also be result of surface that is not completely flat.

6.2.4. Slow fading

For indoor scenario the direct line of sight between transmitter and receiver is not always guaranteed. Sometimes an obstacle can stand on the path of the wave. As a result the RSSI value decreased. This extra loss is called slow fading. The slow fading is expressed with changes into the signal that are more predictable and slow in the time.

6.2.5. Fast fading

Fast fading is caused mainly by multipath propagation. It is reason for additional signal's attenuation variation in areas smaller than the wave length (For Bluetooth Low Energy, which works on 2.4GHz wavelength is about 12.5cm). It is expressed with changes into the signal that more unexpected and fast.

For better evaluation of these factors some experiments were done. We started with 1 minute test in which a BLE beacon and mobile node were placed 2.5 away from each other. At the beginning of the test the direct line of sight was obstructed. In the second part of the test the obstacle between the two devices was removed. This is shown on figure 6.3.

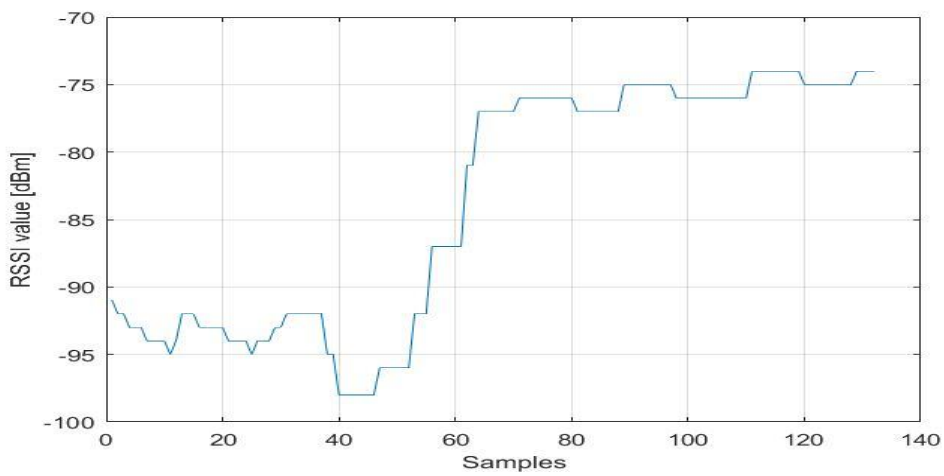


Figure 6.3: RSSI values passing from NLoS to LoS condition

On figure 6.3 it is easily observed that an immediate increase in signal's strength is observed when obstacle's obstruction disappear and RSSI mean value increase in a matter of seconds, according to slow fading rules. In the Non-line of sight part of the test the signal varies from $-90\ [dBm]$ to around $-100\ [dBm]$, when the direct line of sight appear between the transmitter and receiver the signal pretty fast increases and the variation in these samples are between $-78\ [dBm]$ and $-73\ [dBm]$.

The second test that we did was based on 2 phases. In both parts the beacon and mobile node was placed on 3.5 meters away from each other without moving them. In the first phase, which continued for 15 minutes the receiver was collecting the signal in a static environment –

without any movements, human presence or any changes in the conditions. The second phase also continued 15 minutes, but in harsh environment – which includes human movement in the area around the devices. This is shown on the following figure 6.4, figure 6.5 and figure6.6.

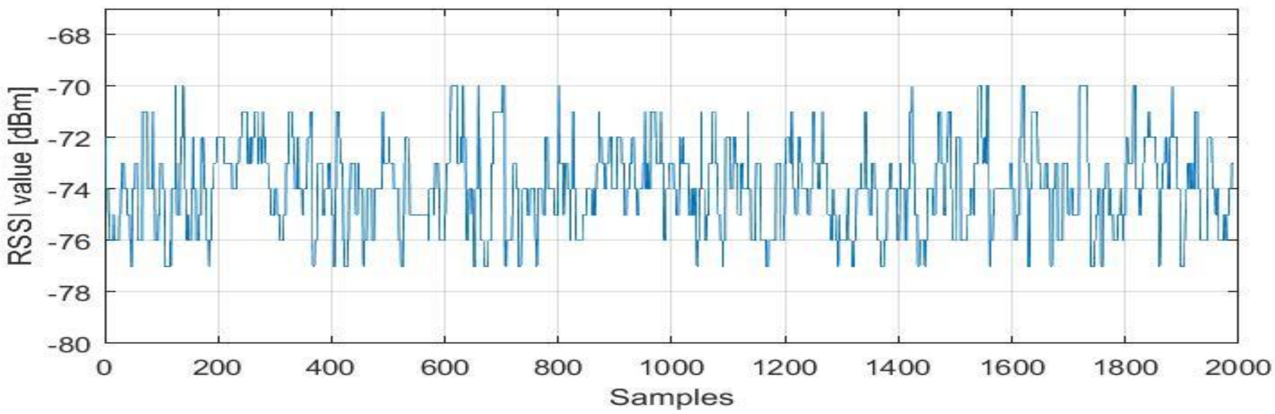


Figure 6.4: RSSI test in static environment at 3,5m

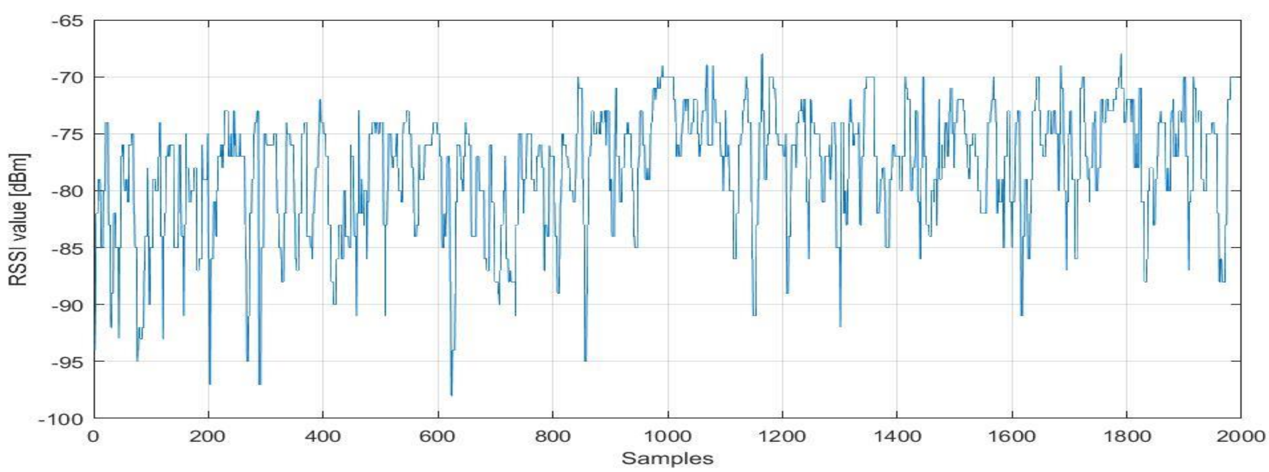


Figure 6.5: RSSI test in harsh environment at 3,5m

On figure 6.6, in static environment the values are more concentrated around a single dominating peak. In contrast in harsh case RSSI varies more in time. For instance, in first case the RSSI varies from $-70\ [dBm]$ to $-77\ [dBm]$ and in harsh from $-67\ [dBm]$ to $-97\ [dBm]$ for 15 minutes without a constant trend, related to the unpredictability of human movements and changing of the objects position. Multipath propagation is the most potential author for these uncertainties from the harsh environment. When the emitted wave by the beacon reach an obstacle it is splitting into several and the mobile node receive many signals with different phases and amplitudes. This gives additional fluctuations to arriving signal.

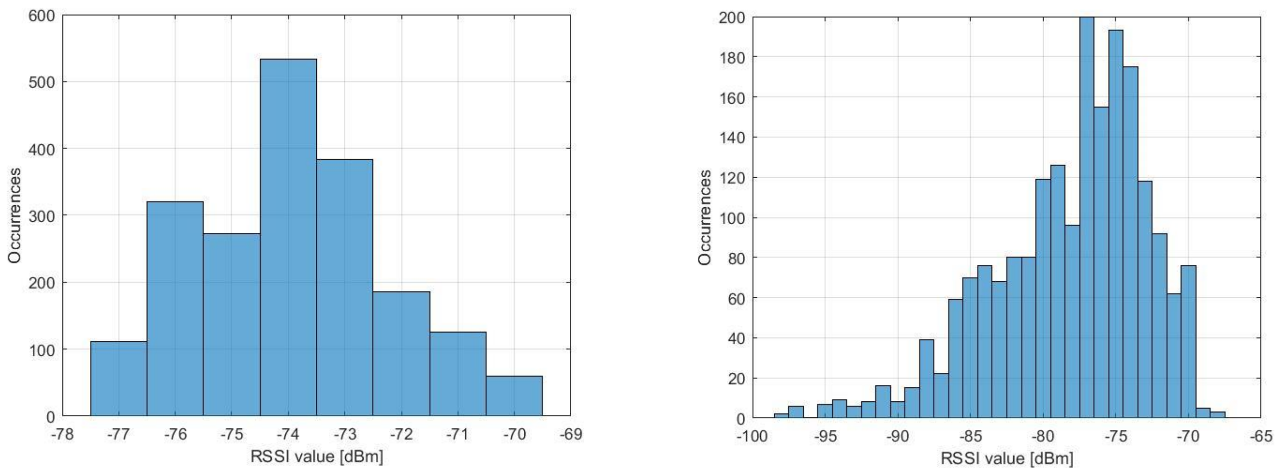


Figure 6.6: Histograms of the RSSI values for static (left) and harsh (right) environment

6.3. Angle variation

In a positioning system it is important to know how RSSI measurements are influenced by BLE beacons` orientation, therefor we made set of tests for a number of different angles between devices. Our aim was firstly to determine how significant the influence is and secondly to find the optimal orientation, in order to simplify the installation and usage of the location system.

We examined the strength of the received signal in three different planes to obtain how large variance the beacon`s orientation introduce. The beacon was placed in three different orientations – horizontal (H), lying down (L) and vertical (V) as it is shown on figure 6.8, while the phone was with static orientation and moved around the beacon by 45 degrees figure 6.7. All the measurements are done at same distance – 1.5m. Beacon was programmed to transmit every 512ms with power of the signal equal to 4dBm.

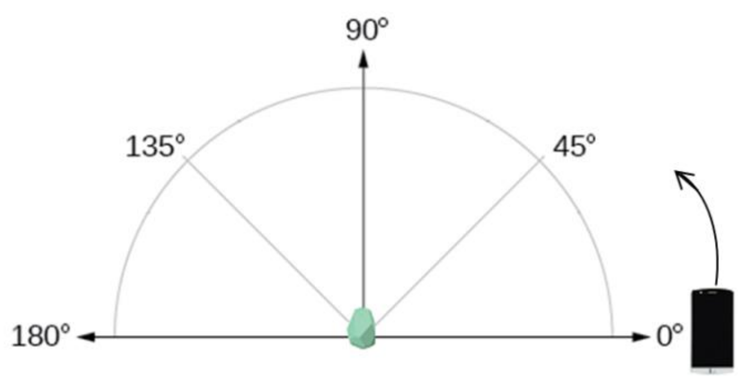


Figure 6.7: Measuring the RSSI variance over different angles

(a) (b) (c)

Figure 6.8: Different orientation of beacon E7:91:97:D9:E4:A8: (a) Horizontal, (b) Lying down, (c) Vertical

On each position and orientation we took 50 individual measurements. To compare the different situations we averaged the values (Figure 6.9) and calculate variance and standard deviation (Table 6.1).

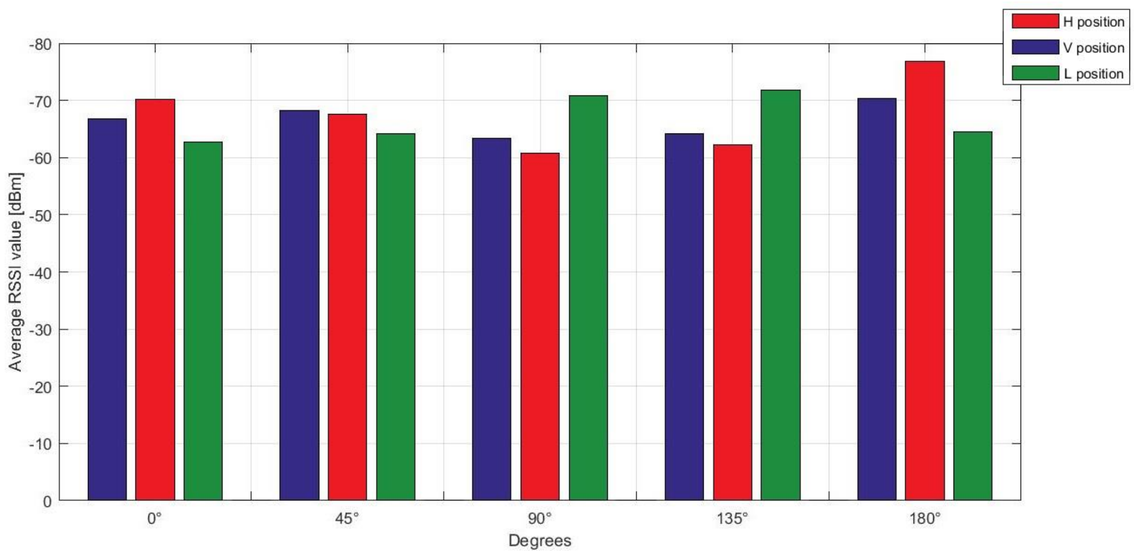


Figure 6.9: Mean RSSI values for different positions and angles at 1,5m

Position	**Variance**	**Standard Deviation**	**Mean [dBm]**
H position	41.8293	6.4676	-67.496
V position	8.1777	2.8597	-66.596
L position	17.4768	4.1805	-66.818

Table 6.1: Comparison of the parameters for three different planes

As we can see at vertical position of the beacon values remain stable whereas the variance for H and L position is around 5 and 2 times more respectively. From the results we concluded as expected maximal RSSI value is obtained when the receiver is located straight against the beacon (90^{o} horizontally and vertically). In both cases the strength of the received signal decreased, when the angle is getting closer to 0^{o} and 180^{o}. However we can see in these orientations the horizontal measurements are worse than the vertical in contrast with all other cases. On the other hand we have the opposite situation with lying position. We have better results when the mobile phone is placed aside from the transmitter and values declined when the angle comes near 90^{o}.

To sum up beacons positioning gains a fundamental role as talking about RSSI readings. Foregoing analysis motivate a conclusion about the best orientation of the beacon. The optimal placement would be if the beacon is on the ceiling in L position, so line of sight will be guaranteed. Thus the signal will spread better over the area. Probably if the top or the bottom of the beacon is faced to the room`s center should give best results, but this will be surveyed in following experiments.

6.4. RSSI vs Distance

After the experiments about the RSSI variation over different angles and orientations of the beacon, our next goal was to determinate how the signal power reacts to changes in the distance. For that purpose we placed one beacon in a static vertical position and without changing the orientation, we move away only the mobile device. We examine the RSSI value from 1 to 10 meter (with step of 1m). A hundred individual measurements were made at every step and the mean value was calculated for more clearly graphical illustration of the results (Figure 6.10).

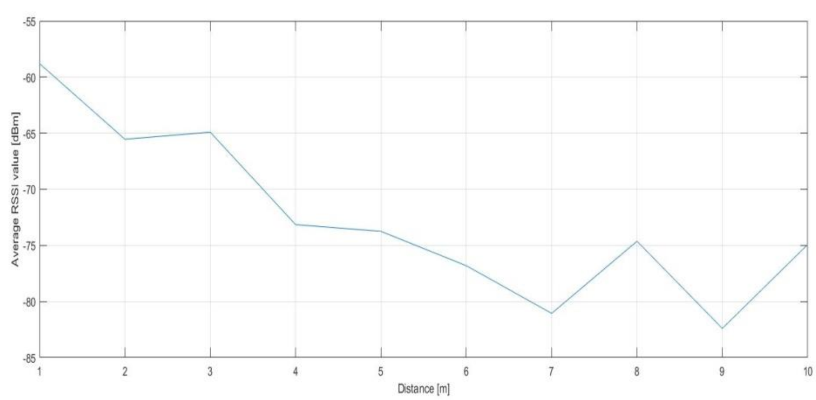
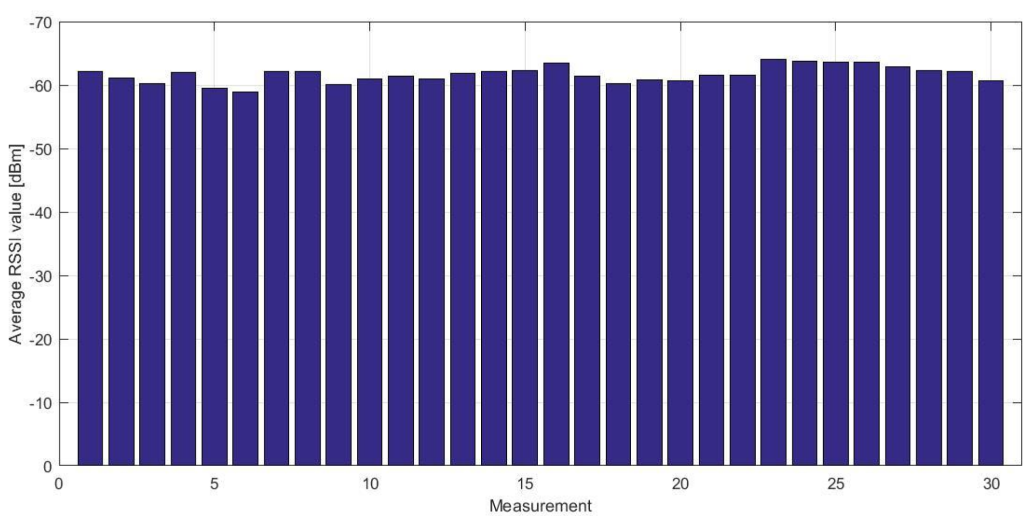


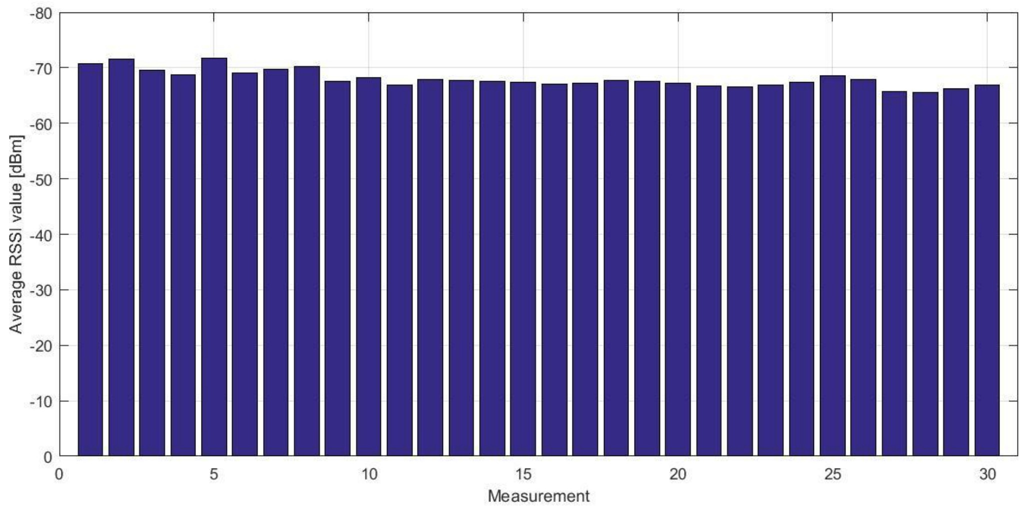
Figure 6.10: Signal strength from 1m to 10m

Initially the measured RSSI values were around -58,5dBm, then by increasing the distance the received signal follows sharp downward trend which continues till the fifth meter where it reaches -73,5dBm. After that the values become unstable and fluctuate in the range of 10dBm (-74dBm to -84dBm). The figure seems to suggest that in the first 5 meters the RSSI values are comparatively predictable and reliable. This is in stark contrast with the following 5 positions, there were several gains and losses and the graph passes through same values more than once. This may lead to wrong determination of the distance between the beacon and the mobile device, caused from the misleading results.

Keeping in mind, our scenario is designed to serve elderly people in their home we considered to make more precise survey for some of the closer positions. To see how much multipath propagation, interference in the radio spectrum and similar disturbances affect the measured results, the same setting (where no external factors are changed) was used to determine how much values differ. Measurements were performed at a distance of 1,5m and 3m. At each of the locations 30 rounds of 50 independent values were made and averaged (Figure 6.11). A comparison between the results from the three distances are presented in Table 6.2



(a)



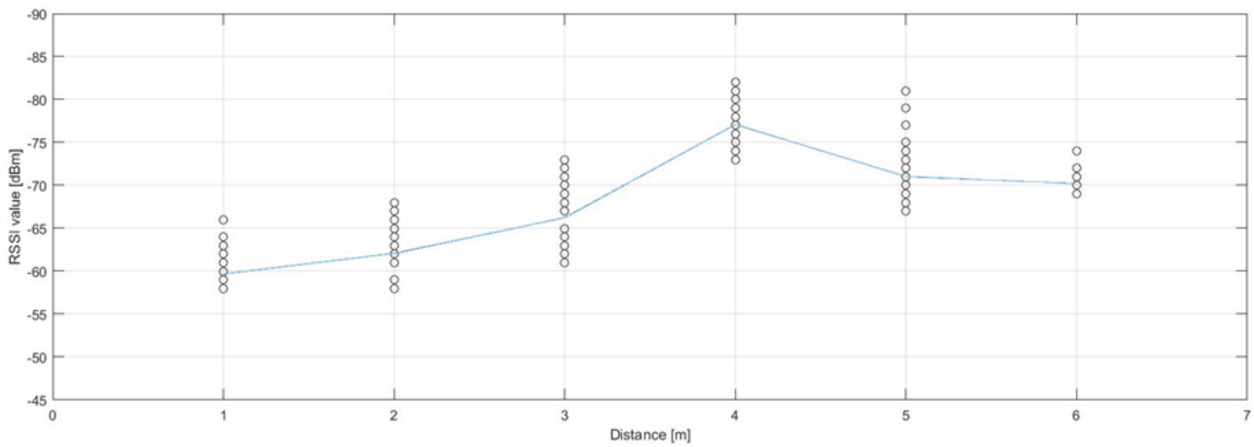
(b)

Figure 6.11: RSSI variance over distance – 1,5m (a) and 3m (b)

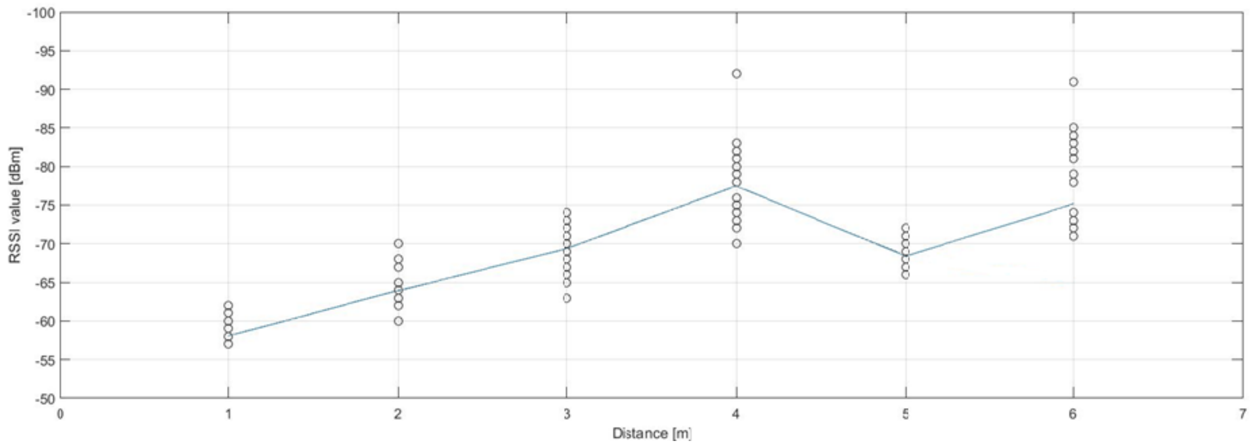
Distance [m]	Variance	Standard deviation	Mean [dBm]
1.5	1.61	1.27	-61.68
3	2.48	1.57	-68

Table 6.2: Comparison of parameters for 3 different distances

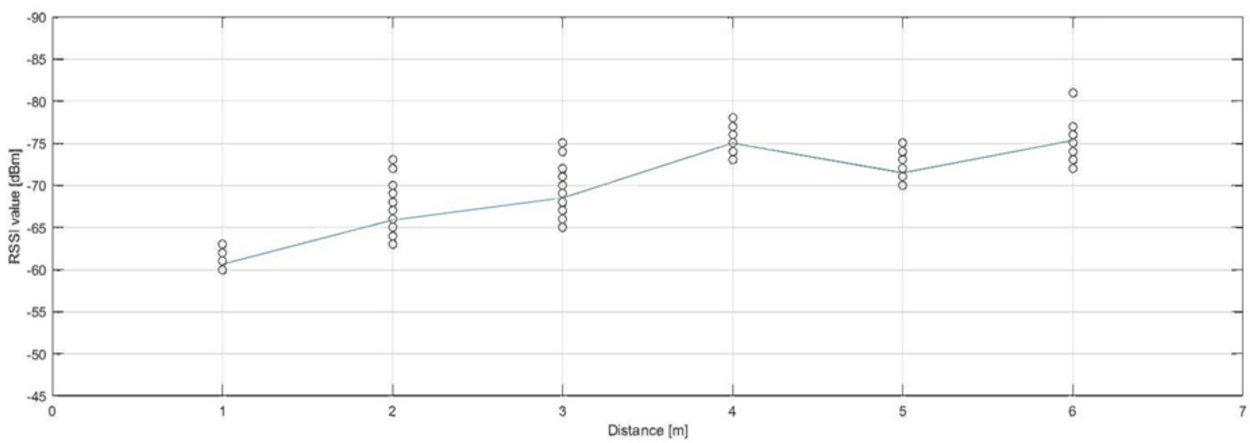
Furthermore the measurements from 1m to 6m were performed with every one of the 3 beacons without any differences during the tests. 50 values were obtained at each distance with every beacon. Overall we can see same trend at each graph, but even though the devices share exactly the same design there are still some distinctions in the results (Figure 6.12). For a system which relies on radio map/fingerprinting technology, this could result in performance degradation.



RSSI values for node BC



RSSI values for node BF



RSSI values for node BE

Figure 6.12: Comparison of the beacon`s performance from 1m to 6m

6.5. RSSI filtration

6.5.1. Median filter

Nonlinear technique used mostly to reduce single or small area noise - impulse noise. Its main concept is to slide "window" through the signal step by step [48]. With every step it replaces the value in the center of the "window" with the median value of all that are inside in it. When the scanning operator is with odd size the result, $y(i)$ (output signal) is the median of:

$$x\left(i-\frac{(n-1)}{2}:\ i+\frac{(n-1)}{2}\right)$$

Where x, is the input signal and n is the size of the "window". When the scanning operator is even it takes the average of the two middle values after they have been sorted in ascending order, $y(i)$ is the median of:

$$x\left(i-\frac{n}{2}:\ i+\frac{n}{2}-1\right)$$

The advantage of median filter is that it cleans single noises without changing neighboring values it makes correction only to the wrong one (Figure 6.13).

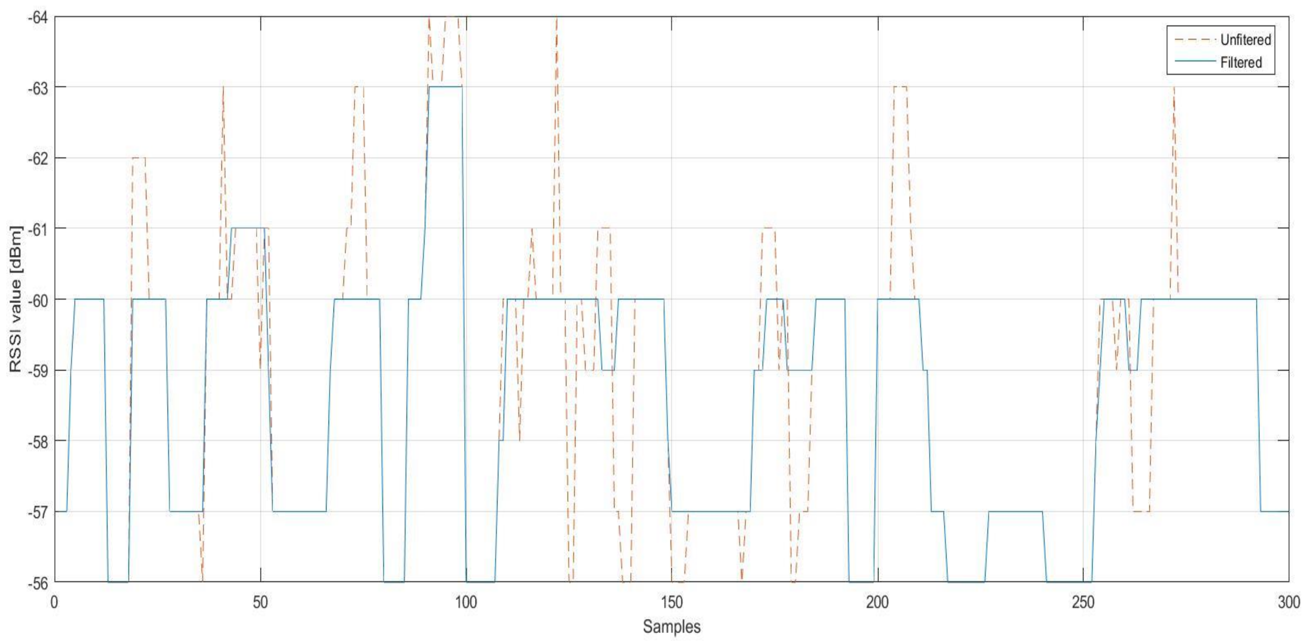


Figure 6.13: Effect of the median filter over RSSI data

As we can see on the figure 1 the input and the filtered data are the same except these undesirable ups and downs (dashed line) which median filter has cut. The used order of the "window" here is 11.

6.5.2. Moving average (MA) filter

This type of linear filters work by averaging set of points of the input signal. Like the median filter the MA filter uses sliding "window", but this time instead of searching for the median value it takes the mean value of the points into the "window". Its common usage is to show the trend of some data. The equation of the MA filter has the following form [49]:

$$y(i) = \frac{1}{M}\sum_{j=0}^{M-1} x(i+j)$$

Where x and y are the input and output signals, respectively, while M is the size of the sliding window. Another way to use the filter is called symmetric (centered) moving average filter, where the considered value is placed in the center of the window, so the limitations of j from the previous equation become: $j = -\frac{(M-1)}{2}$ to $\frac{(M-1)}{2}$. In this situation M should be an odd number. The problem here is that observations in the beginning and at the end of the data staying unfiltered. To overcome this disadvantage it is possible to use asymmetric MA for these parts of the input signal (Figure 6.14).

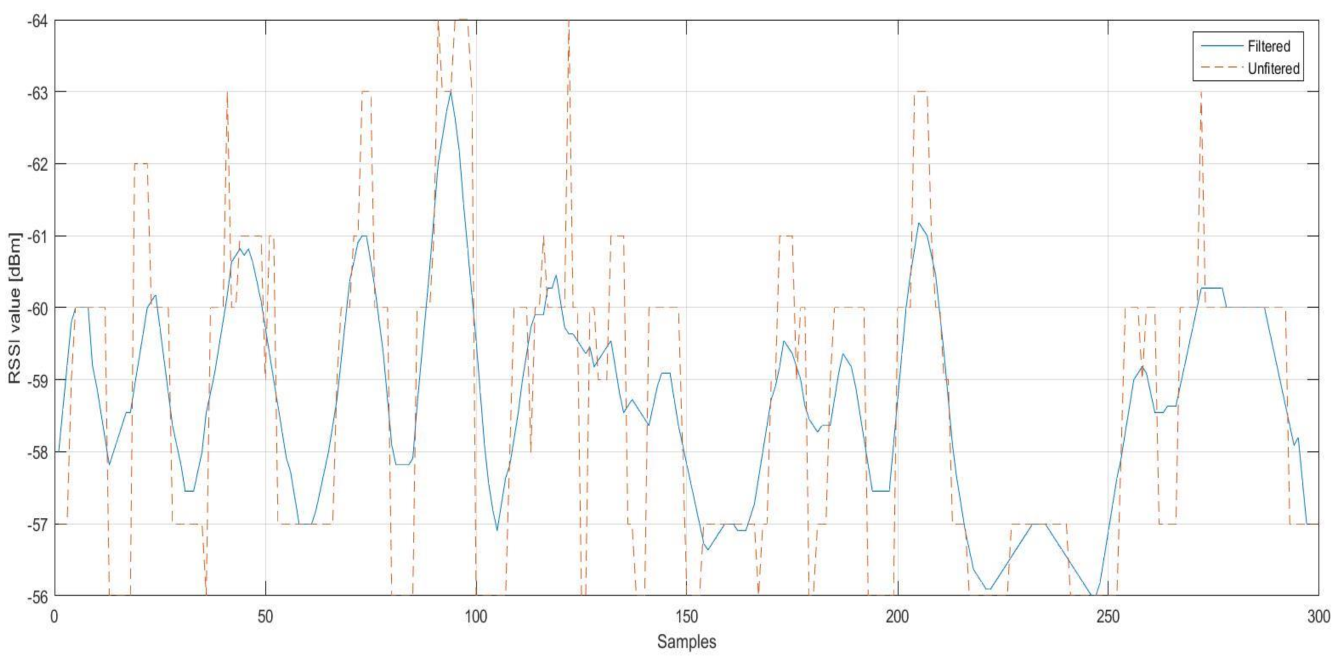


Figure 6.14: Effect of the MA filter over RSSI data

Figure 6.14 shows how the RSSI values look like after the MA filtration with centered “window” size 11 and asymmetric “window” for the ends-size 5. As we can see almost all of the fluctuations are decreased, but in contrast of the median filter, MA filter does not deal very well with these little impulse noises and they appear with delay in in the output signal.

6.5.3. Kalman filter

Almost 60 years old the data fusion algorithm named by Rudolf Kalman is one of the most common decisions for filtering noisy measurements.

At first it starts with formulation of the process. Kalman filter suppose that every next state has relation with the previous one [50]:

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1}$$

and the measurement at time k has the form:

$$z_k = Hx_k + v_k,$$

where A is called transition matrix (model) from $k-1$ to k, B is control matrix (model) which is applied to the optional control vector u_k relating it to the state x, H is the observation matrix (model) that translate the state into measurement, w_k and v_k are independent random variables and are process and measurement noise, respectively. They are assumed to be with normal probability distributions:

$$p(w) \sim N(0, Q),$$

$$p(v) \sim N(0, R).$$

The idea of this recursive method is based on 2 step cycle: prediction (time update) and correction (measurement update). Equations at the first step are:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_{k-1}$$

$$P_k^- = AP_{k-1}A^T + Q$$

Where $\hat{x}_k^-$ is a priori estimated state and P_k^- is a priori error covariance.

Measurement update step is represented as follows:

$$K_k = P_k^- H^T (H P_k^- H^T + R)^{-1}$$

$$\hat{x}_k = \hat{x}_k^- + K_k (z_k - H \hat{x}_k^-)$$

$$P_k = (I - K_k H) P_k^-$$

Here $K_k$is Kalman gain, after its computation come up the update of the state estimate $\hat{x}_k$ with measurement z_k and finally is a posteriori error covariance P_k.

Figure 6.15 illustrates the effect of Kalman filter over the same data as previous two examples. To see how flexible and what time it need to find the pattern of the data the initial prediction of the RSSI value is set $\hat{x}_{k-1}$ -70 [dBm]. Also we have to set P_{k-1}, it should be value different from zero, because if we once set it zero this will have the meaning of no noise in the environment, and every value of $\hat{x}_k$ will stay as the predicted one: here we choose 1 for that value. If we assumed that the process measurements are reliable, since we created the simulation (the process) Q should be zero, but anyway we put here a small value to make the filter easier for later adjusting: $Q = 1e - 6$. Value of R is going to be changed to see how the filter reacts on different measurement noise covariance. Because we have one dimensional data-vector of RSSI values every matrix from the above mentioned equations is going to be just a numerical value. We do not have a control signal u_k, so it is out. Since we get the RSSI directly in dBm the observation model is just $H = 1$. In this situation, because the mobile node is static we expect constant value of the signal, so the transition model is also $A = 1$. All of these values can vary with each measurement, but we assumed they are constant.

Figure 6.15 shows that even if we set the prediction value to -70 dBm when the iterative process starts, by understanding the variation or the uncertainty of the input data, the Kalman filter narrows down to somewhere close to the “true” value very fast [51]. It does not need many points to get there and once it get there and more and more data comes in, the variation becomes smaller and smaller.

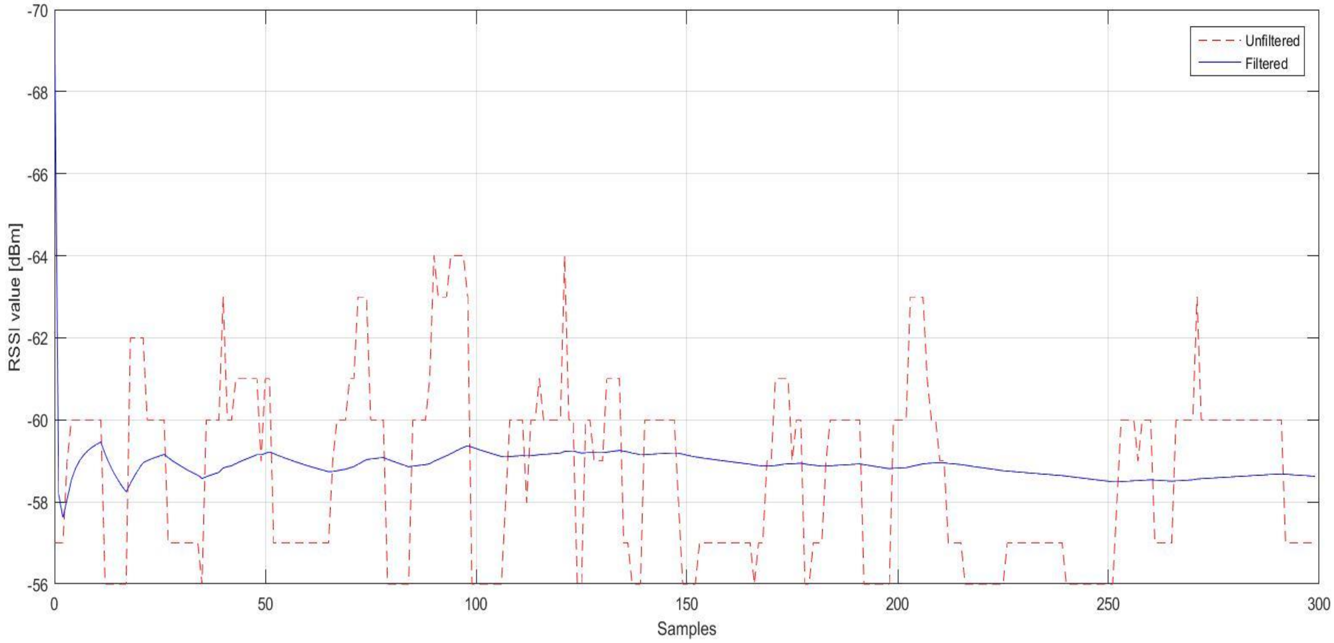


Figure 6.15: Effect of Kalman filter over RSSI data with $R = 0.1$

So if we look up again to the Equations we can easily see how it works (Table 6.3):

<u>Time update:</u>

$$\hat{x}_k^- = \hat{x}_{k-1}$$

$$P_k^- = P_{k-1} + Q$$

<u>Measurement update:</u>

$$K_k = \frac{P_k^-}{P_k^- + R}$$

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - \hat{x}_k^-)$$

$$P_k = (1 - K_k)P_k^-$$

k	z_k	$\hat{x}_{k-1}$	P_k^-	***Time update***	***Measurement Update***
1	-57	-70	1	$\hat{x}_k^- = -70$ $P_k^- = 1$	$K_k = 0.909$ $\hat{x}_k = -58.183$ $P_k = 0.091$

2	-57	-58.183	0.091	$\hat{x}_k^- = -58.183$ $P_k^- = 0.091$	$K_k = 0.476$ $\hat{x}_k = -57.62$ $P_k = 0.048$
3	-57	-57.62	0.048	$\hat{x}_k^- = -57.62$ $P_k^- = 0.048$	$K_k = 0.324$ $\hat{x}_k = -57.42$ $P_k = 0.032$
4	-59	-57.42	0.032	$\hat{x}_k^- = -57.42$ $P_k^- = 0.032$	$K_k = 0.242$ $\hat{x}_k = -57.802$ $P_k = 0.024$
5	-60	-57.802	0.024	$\hat{x}_k^- = -57.802$ $P_k^- = 0.024$	$K_k = 0.194$ $\hat{x}_k = -58.228$ $P_k = 0.019$

Table 6.3: First five iterations of Kalman filter

Some little mistakes are possible due to that the values are rounded up to the third decimal number, so Q is ignored at the calculations in table 1. After we set the initial value of $P_k = 1$, after only 5 steps is down to $P_k = 0.019$.

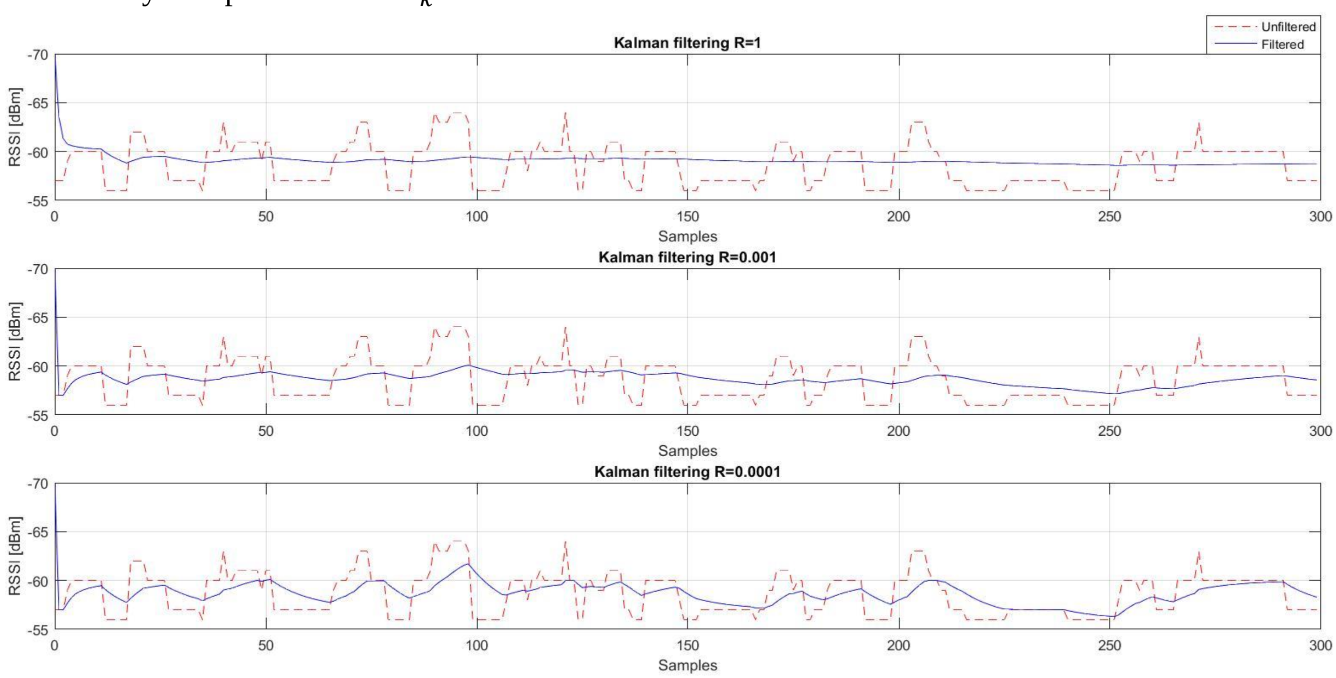


Figure 6.16: Effect of Kalman filter over RSSI data for different values of R

Figure 6.16 compares the output signals when R is changed. When $R = 1$ the signal becomes almost constant very fast, in contrast when $R = 0.0001$ the filter is more trustful to the measurements and the output signal follows the variations of the input.

After the overview of these 3 filters we concluded that the Kalman filter is most appropriate to our needs. By using a Kalman filter we are able to remove noise from a very noisy signal. Its effect is not just to cut unexpected ups and downs (like median filter) or to decrease the fluctuations in the RSSI samples (like MA filter), if you set its parameters well it can eliminate the noise in the measurements and find the “true” value. Last but not least it can do that very fast, after just a few values of our signals. Hence for all following experiments Kalman filter is used to improve the results.

Summary

In this chapter we presented our motivation for work equipment and test environment. We surveyed the behavior of the radio signal and examined its capabilities under different conditions. In this part of our theses we also reviewed several algorithms for filtration of the measured signals.

7. Testing of the BLE Beacons Capabilities as Indoor Positioning Technology

This chapter presents the created from us Indoor Positioning System. In it we describe the algorithm of work in terms of two possible location methods. Trilateration and Fingerprint methodologies are applied for two different scenarios – a small and a big room. In both cases we simulated human's normal behavior and imitate random movements across the areas. The results from the four cases are analyzed and discussed to draw comparison between the methods and conclude appropriate conditions of choosing one of them.

7.1. Indoor Positioning System Algorithm

Our location algorithm stars with collecting the signals from three BLE beacons with a mobile device. The first step is to memorize the new incoming values for additional computations and fall detection check (described in the next chapter). After that a Kalman filtration is applied over the signals. We propose two different methods for positioning and according to them can follow two algorithms of calculations:

Trilateration – If we choose to define the user's position by trilateration method, the RSSI values are computed and transformed to distance measurements by equation number 5 (which is explained in details the following section). Knowing the distances from the mobile device to the beacons, the trilateration method can be applied and the location of the person can be determined.

Fingerprint – We can choose to use fingerprint method. In this case an offline phase is required to create a data set of areas and specifications that describe each of them. During the online step of the method the incoming values are analyzed and compared to the predefined zones' ranges. When the signal rates match to one of the requirements for some area, the algorithm makes a decision that the person is located inside of the corresponding area.

Figure 7.1 clearly illustrates the sequence of steps that our system follows and presents the general idea of project.

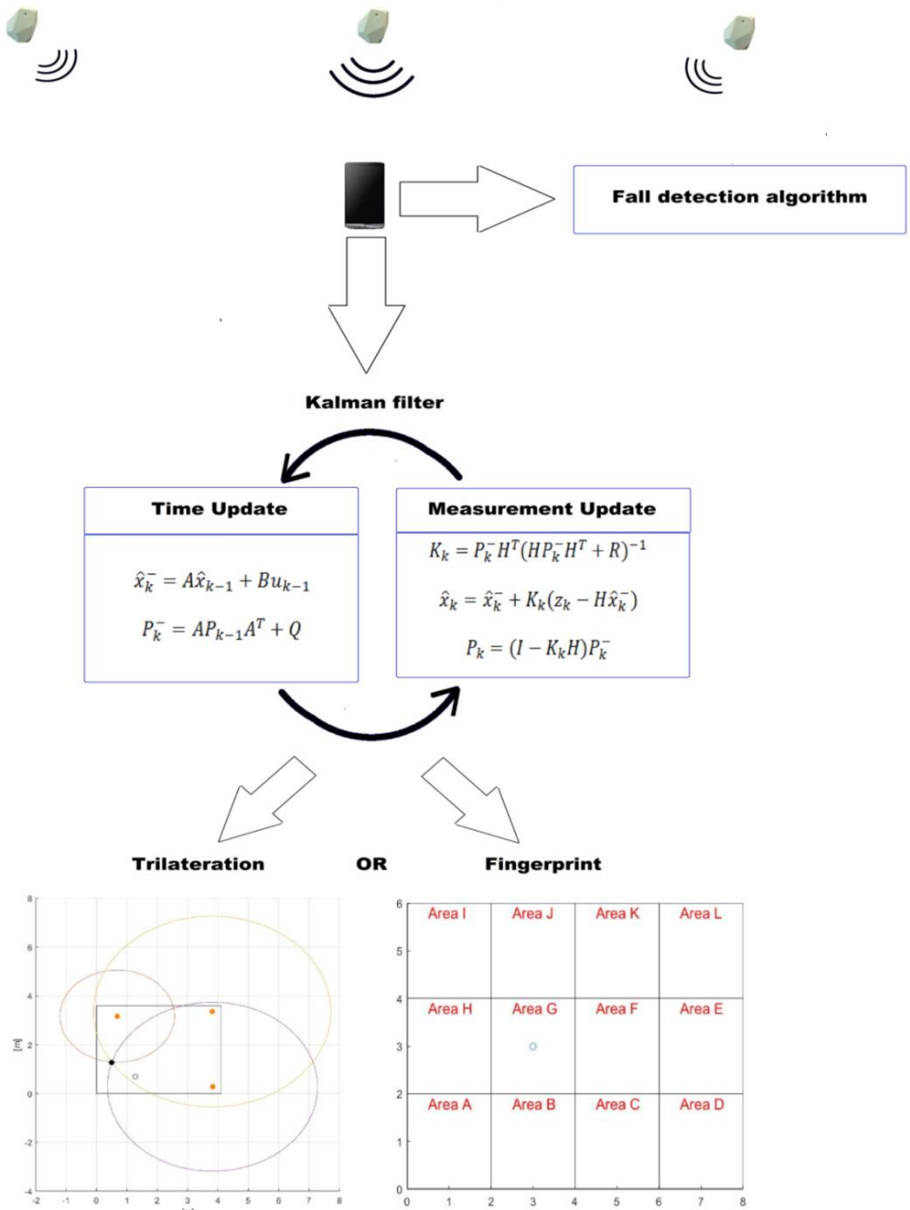
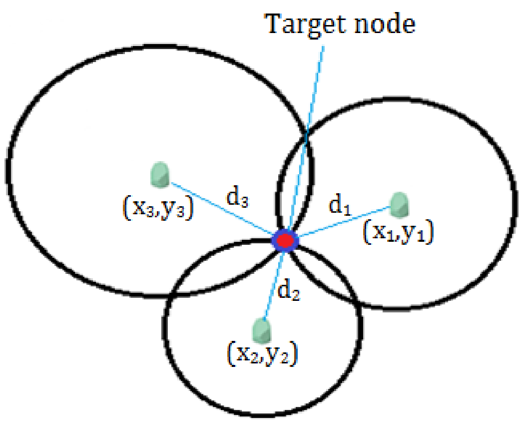


Figure 7.1: Overall view of our location system

7.2. Trilateration

After all the tests and analysis of the results we continued with implementing a location algorithm based on 2D trilateration approach. All the three beacons were placed on the ceiling near the three different corners of the room in L position (Section 6.3), while the top of each beacon is faced to the room`s center. By this placement we avoided the low values of the signal which can be obtained from the both side for every beacon. The mobile node, which was the location target, was put on the shoulder of a person who is moving around the area. The choice of shoulder is due to that most of the time line of sight is guaranteed with two of three beacons. Furthermore, for the purpose of fall detection, the difference in the distances between mobile node and beacons for erect and fallen man will be highest.

Finding the location of target node by trilateration is based on determine the distances to known reference points. For instance the mobile node can localize itself by evaluating distances to certain reference points, e.g. BLE beacons (Figure 7.2). Our beacons are with coordinates $(x_1, y_1), (x_2, y_2)$ and (x_3, y_3), assuming the target is able to exactly determine its distance to each beacon, circle is drawn around each of the three with radii equal to these distances – $d_1,\ d_2$ and d_3. The intersection of the three circles gives the position of the target node. If $(x_1, y_1), (x_2, y_2)$ and (x_3, y_3) are known the target position can be obtained by solving a system of equations [52]:



$$(x - x_1)^2 + (y - y_1)^2 = d_1^2$$

$$(x - x_2)^2 + (y - y_2)^2 = d_2^2$$

$$(x - x_3)^2 + (y - y_3)^2 = d_3^2$$

Figure 7.2: 2D Trilateration

Where x and y are coordinates of the mobile node. Through subtraction this system of quadratic equations can be transformed to a system of linear.

$$2x(x_2 - x_1) + 2y(y_2 - y_1) = (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2) \qquad (1)$$

$$2x(x_3 - x_1) + 2y(y_3 - y_1) = (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \qquad (2)$$

For better visualization and further ease right part of the equations was substitute with Z' and Z'' , respectively. Hence:

$$Z' = (d_1^2 - d_2^2) - (x_1^2 - x_2^2) - (y_1^2 - y_2^2)$$

$$Z'' = (d_1^2 - d_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2)$$

Using matrix operations equations (1) and (2) can be converted into the form:

$$x = f\left(d_{1,}d_2, d_3\right) = \frac{\begin{vmatrix} Z' & 2Y_1^2 \\ Z'' & 2Y_1^3 \end{vmatrix}}{\begin{vmatrix} 2X_1^2 & 2Y_1^2 \\ 2X_1^3 & 2Y_1^3 \end{vmatrix}} \quad (3)$$

$$y = g\left(d_{1,}d_2, d_3\right) = \frac{\begin{vmatrix} 2X_1^2 & Z' \\ 2X_1^3 & Z'' \end{vmatrix}}{\begin{vmatrix} 2X_1^2 & 2Y_1^2 \\ 2X_1^3 & 2Y_1^3 \end{vmatrix}} \quad (4)$$

Where X_j^i and Y_j^i is a represent $(x_i - x_j)$ and $(y_i - y_j)$. After the calculations of (3) and (4) finally we can find the coordinates of the target node (x, y).

Distance formula

In order to implement the trilateration method we need to convert the received signal strength into distance. The most commonly way to do that is based on the formula [6]:

$$RSSI\ [dBm] = RSSI_0 - 10n * lg\left(\frac{d}{d_0}\right). \quad (5)$$

In this equation $RSSI$ is the received signal strength at distance $d\ [m]$, $RSSI_0\ [dBm]$ is received signal strength at some reference distance $d_0\ [m]$ and n is attenuation factor for $RSSI$ which varies from environment to environment. For reference distance we chose $1m$, and as we can see in (Section 6.4) the average value for that distance is equal to $-58.5\ [dBm]$. So formula (5) takes the form:

$$RSSI\ [dBm] = -58.5 - 10n * lg(d)$$

Therefore the distance can be present as:

$$d\ [m] = 10^{\frac{-58.5 - RSSI}{10n}}$$

But with this formulation we find the direct distance from each beacon to the mobile node, which is in three-dimensional space. To find the projection of the target on the ceiling (our 2D coordinate system) we used Pythagorean Theorem presenting d and the distance from person`s shoulder to the ceiling as sides of right triangle: $c = \sqrt{a^2 - b^2}$. a is the measured distance, b is the distance from the shoulder to the ceiling and c is the new distance in our 2D space.

7.2.1. Small Room Scenario

First we started with measurements at 3 fixed static points in the room to adjust the filter parameters and attenuation factor in the distance formula. The coordinates of the beacons in 2d space are as follows: E7:91:97:D9:E4:A8 $(0.68, 3.17)$, F4:0A:08:E6:C0:36 $(3.81, 3.36)$ and CB:BA:B0:9D:61:13 $(3.82, 0.28)$. With purpose to make later mentions of the beacons easier we shortened this addresses to Beacon E, Beacon F and Beacon C, respectively. As we show in (Section 6.5.3) Kalman filter pretty fast removing the noise and narrow down the filtered signal even if the prediction value is not that close to the real one. Here to make it faster we set that initialization value of the filter to be equal to the first value of the unfiltered signal $\hat{x}_0 = z_1$ .With this we decreased the fluctuations in the beginning of the filtered signals. Because our target is not moving in these experiments the transition model is $A = 1$. And the measurement noise covariance is set to $R = 0.1$. About the distance formula after a lot of fixations we get the best results with attenuation factor $n = 2.823$. For these static measurements mobile node was on a stationary holder, imitating ideal conditions – without noise introduced from human presence. It was 1.45 $[m]$ away from the ceiling (Figures 7.3 – 7.5).

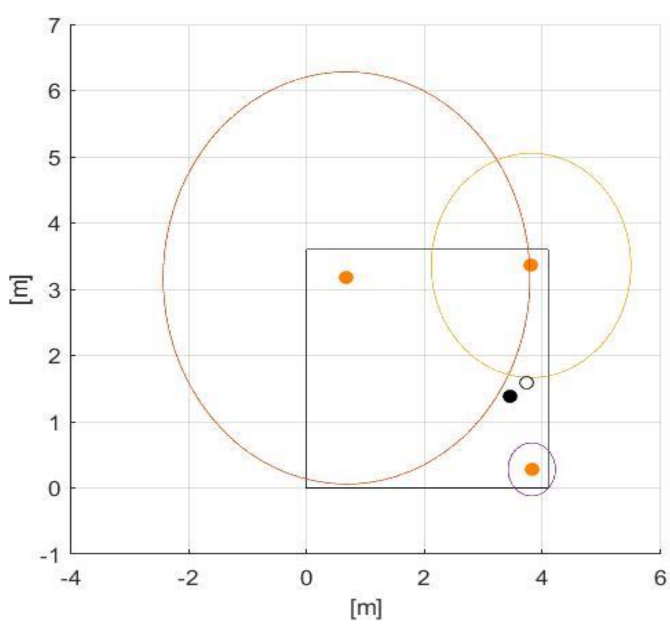


Figure 7.3: BLE beacons locate a target by trilateration method – Position 1

On figure 7.3 the room size is outlined with black rectangle. The position of the beacons is marked with orange dots. Real coordinates of the target are introduces by not-filled black circle while the measured one is shown as a filled one. Circles are with radii equal to the calculated distances. As we can see on the figure 7.5 the three circles do not have common intersection area as in the perfect situation on figure 7.4 due to uncertainties in measurements and of course the transformation from RSSI to distance cannot be 100% accurate. However, the trilateration algorithm compensates the individual mistakes and the combination of the three signals gives us point very close to the real one. The real coordinates of the target are $(3.74, 1.58)$ and the measured ones are $(3.45, 1.38)$. Here we have $30cm$ displacement by x and $20cm$ by y.

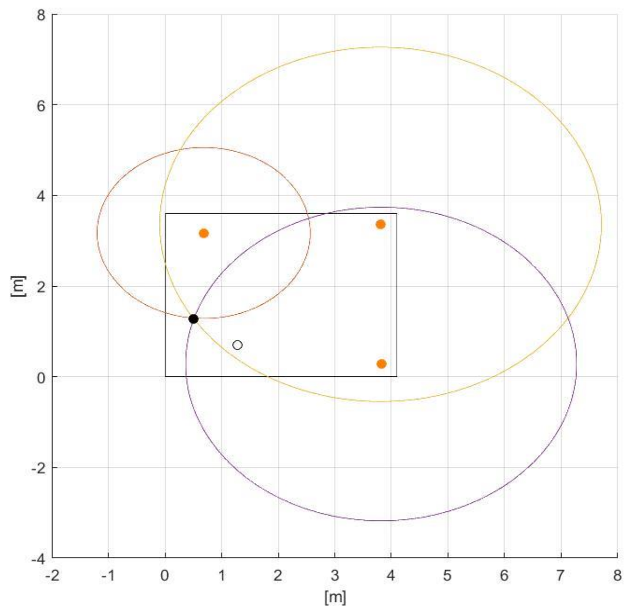


Figure 7.4: BLE beacons locate a target by trilateration method – Position 2

On figure 7.4 our three circles have a common intersection. The distance to the beacons is bigger in this situation and the RSSI values are more unpredictable as when the mobile node is closer. In this test the real coordinates are $(1.275, 0.69)$ and these from location method are $(0.49, 1,27)$. The mistakes are 0.785 $[m]$ and 0.58 $[m]$ by x and y, respectively.

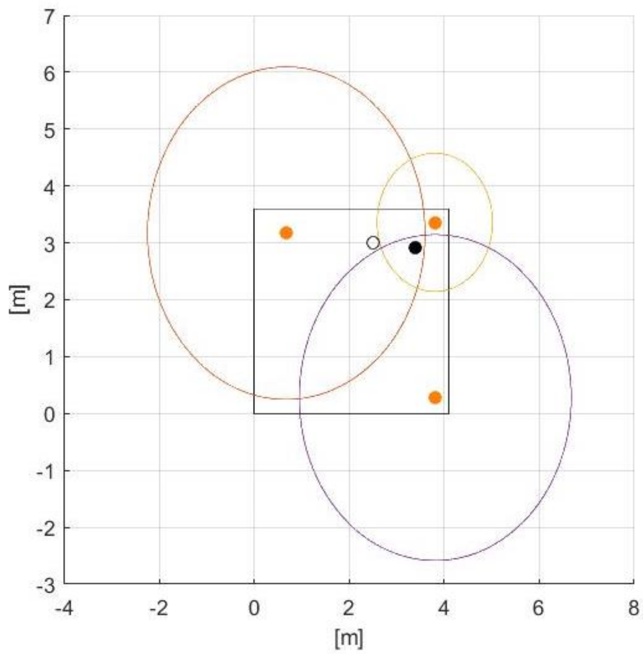


Figure 7.5: BLE beacons locate a target by trilateration method – Position 3

On figure 7.5 the distance measured by the beacon in top right corner which is the nearest to the mobile node present us very good accuracy. In this position of the target the other two beacons import the error and the results are shifted by 0.89 by x and 0.09 by y.The real position is with coordinate $(2.51, 3)$ and the measured $(3.4, 2.91)$.

To see how the algorithm is going to work in real situations the following test are made while the mobile node was on the person`s shoulder and he was walking around the room. For that purpose the transition model of the Kalman filter A has been changed. The value that we conclude fits best is $A = 1.05$. The distance from mobile node to the ceiling here is 0.95 $[m]$. Attenuation factor of the distance formula is taken $n = 3.921$ by testing. All of the other parameters are not changed. Next three figures show one test but it is divided on 3 for better visualization. They are in consecutive order.

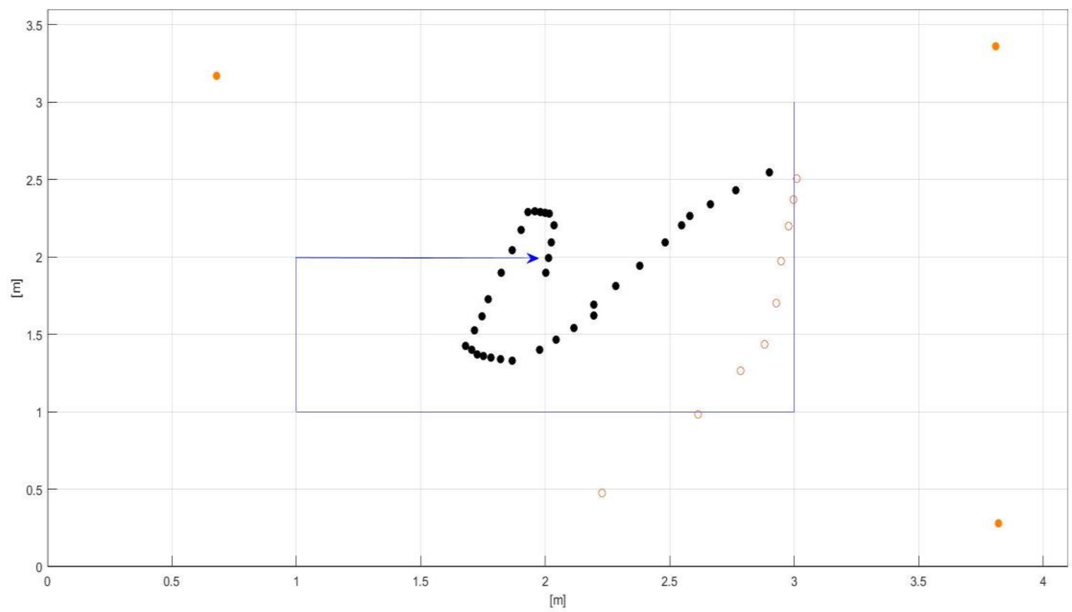


Figure 7.6: First part of our walking test

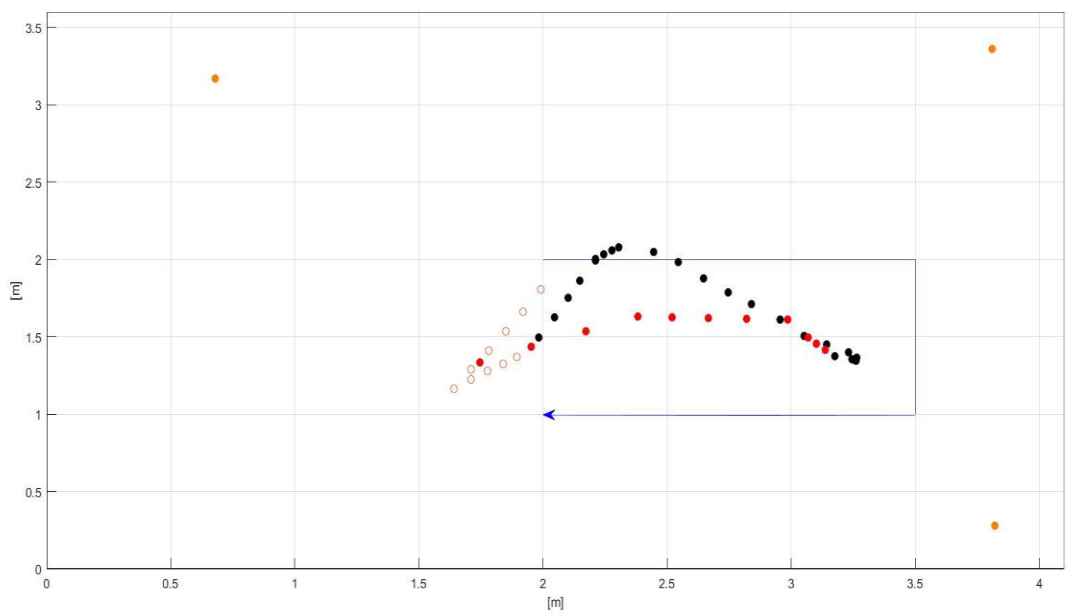


Figure 7.7: Second part of our walking test

On figure 7.6 the three beacons are again marked with orange dots. The blue arrow shows the real path that has been passed through that part of the test. The unfiled red circles here correspond to the first few calculated distance while the Kalman filter searching for the "true" value. They start from the circle at the bottom with coordinate almost 0.5 by y and finish with that with coordinate 2.5 by y which is really close to the real path. The filled black dots illustrate the measured path. We can see that the turns are expressed good and in most of the cases and the mistake is around 1.5m or smaller. Only in the end of that part, where the black dots are near the blue arrow, the calculated values show one wrong turn.

Figure 7.7 illustrates the next part of the experiment. For better understanding of the points on that figure the red unfiled circles show the first 10 values of that part and the red dots are the last 10. All the data is filtered just once, not part by part, so these first 10 values continue the error from the previous figure, which is not due to the filter initialization. This mistake is caused of that the distance is almost equal to all of the beacons and there is no one of them in the vicinity of the mobile node. The real values here are displaced with around 1 meter. After that when the black dots start the mistake decreased to 0.5m and less. The final ten values (red dots) following the direction of the blue line and the inaccuracy remain under 1m.

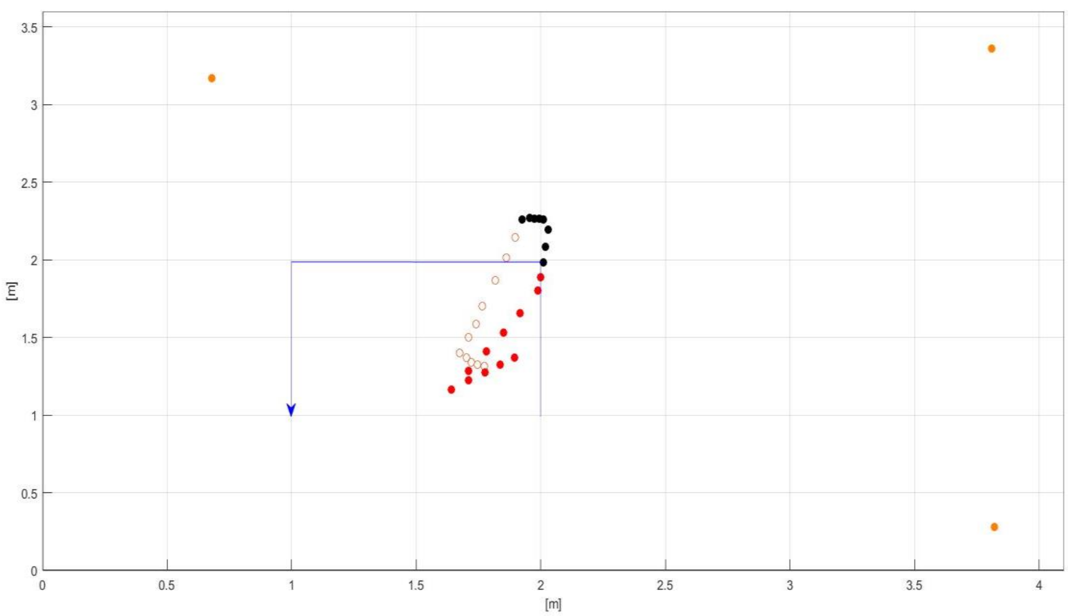


Figure 7.8: Last part of our walking test

In the last part of the experiment when we look at the first points we can find out that after little delay the catch the direction pretty well and get near the blue line. When the black dots start to appear the output signal make a turn into the wrong direction. That does not continue for a long time and after a few points they start to move to the right way. We can see that in the reaction of the red dots. They achieve around $0.6m$ distance away from the real path and then get back again as the final dot of the test is about $1m$ away from the true value.

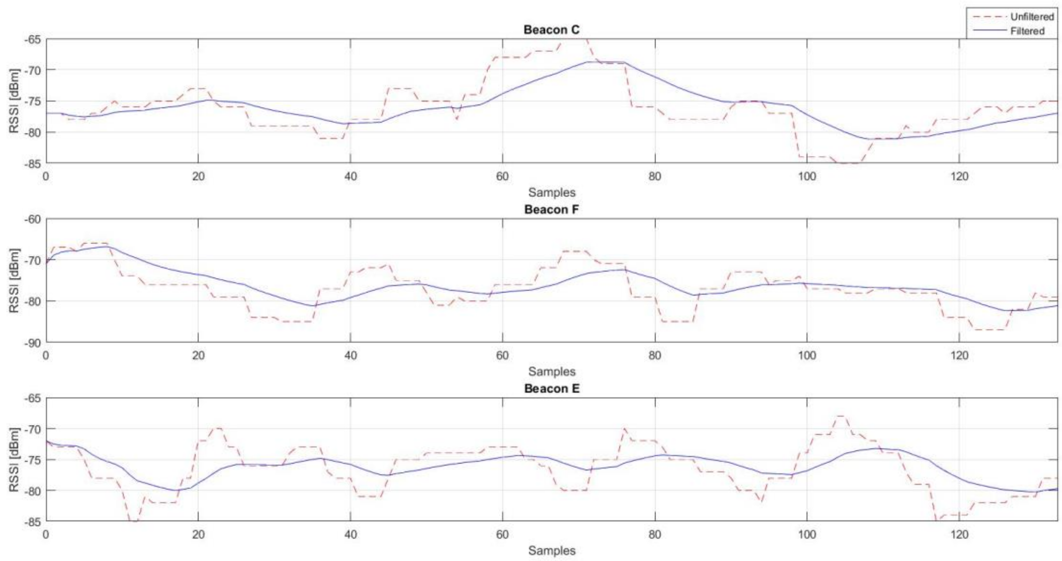


Figure 7.9: The three signals from the whole walking test in filtered and unfiltered form

Figure 7.9 presents the collected received signal strength from all of the three beacons during our experiment. About beacon C which is in the bottom right corner from the previous figures, the moment when the person passing in the vicinity is evident. The filtered signal grows to just over -70 $[dBm]$. The same applies to beacon F which is in the top right corner. Its maximum is in the beginning of the test when the distance between transmitter and receiver is just 1meter. At that moment filtered signal has value of -67 $[dBm]$. In the case of beacon E (top left corner) there is one maximum in the filtered signal when the test starts but it is due to that the Kalman filter still searching for the "true" value. After that the smoothed values plummeted to -80 $[dBm]$ and remain stable between -80 and -75 $[dBm]$ in most of the time. Around 110 sample of that figure there is second maximum equal to -73 $[dBm]$ which gives us the moment of figure 11 when the blue line has coordinates $(1,2)$.

To sum up our trilateration tests in the small area scenario went well. On figures 7.3, 7.4 and 7.5, when there is no movement, noise introduced from human presence and the mobile node is in static position, the measured locations are near to the original location of the target.

Especially, when the coordinates we are searching for are close to some of the beacons (Figure 7.3 and 7.5). The signal in these zones has more fluctuations, but it is still with higher values compared to these zones which are further, where the signal is more stable. With the help of Kalman filter we successfully calm down these ups and downs in the near zones and the results are available. On figure 7.4 the target is not in the vicinity of none of the beacons. The displacement on that figure is bigger compared to the other two. Even if the signal is more steady here the values does not have that big differences with increasing the distance, like in the first few meters, and this leads to some uncertainties in the measurements.

On figures 7.6, 7.7 and 7.8 the mobile node is attached to a person who is moving around the room. As a conclusion to that test we can add that almost all of the time the calculated coordinates catching the correct direction. There is little delay but the turns are clearly expressed. In most of the time the distance between true value and measured one is about 1 meter. Again when the target is moving nearly to some of the beacons the difference between the blue line and the dots is smaller and when the mobile node is going away from that beacon the algorithm pretty fast realize that. This is most distinctly on figure 7.7 when the blue line making its second turn.

7.2.2. Big Room Scenario

When we talk about the bigger area scenario the results cannot be as good as the small one. Here again we started with some static measurements around the room to estimate how our trilateration algorithm with three beacons will manage that time. To cover all the area two of the beacons are close to corners and the third one is placed near the center of the opposite wall. Their coordinates are as follow: Beacon BE $(0.75, 5)$, Beacon BC $(6.98, 4.31)$ and Beacon BF $(3.46, 1.48)$. The transition model of the Kalman filter is $A = 1$. Measurement noise covariance is $R = 0.1$ and the attenuation factor is set $n = 4.127$. The distance mobile node-ceiling is 1.55 $[m]$. Indications in the next figures are as in figures 7.3, 7.4 and 7.5.

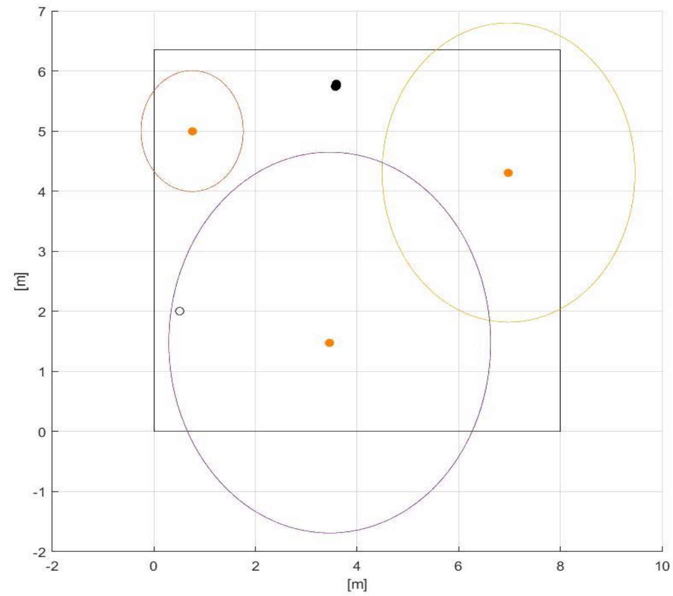


Figure 7.10: BLE beacons locate a target by trilateration method, Second scenario position 1

On the figure above the difference between real and calculated position is really big. This is due to the fact Beacon C is about 7meters away from the target and the mistake that it makes is the biggest. The other 2 beacons give us satisfying results. Furthermore error of the Beacon F is just a few centimeters. The coordinates that the algorithm presents to us are $(3.56, 5.64)$, while the real location is at point $(0.5,2)$.

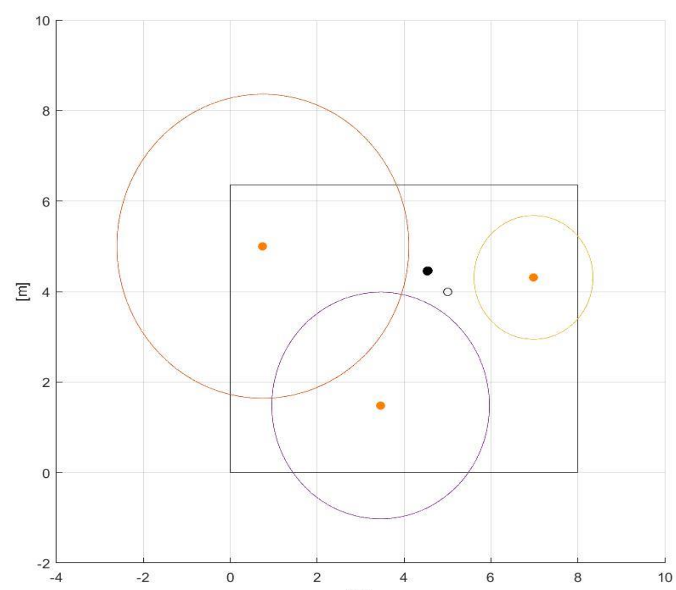


Figure 7.11: BLE beacons locate a target by trilateration method, Second scenario position 2

On figure 7.11 the target is placed have a location $(5, 4)$ in our two-dimensional space. There is no that big distances to each of the beacon in that case, as the previous figure. And that is shown in the results. The unfiled black circle here is less than half meter away from the filled one. The most distant beacon is Beacon E and it is just over 4meters away. We can say that in this situation all the beacons done very good job.

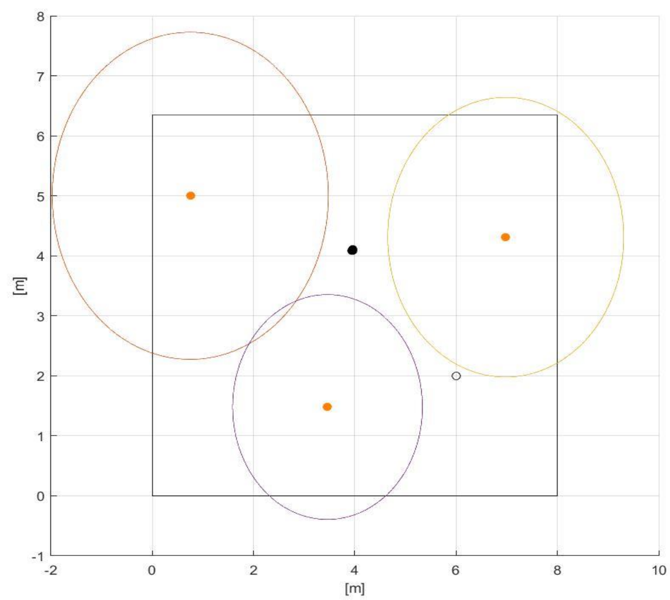


Figure 7.12: BLE beacons locate a target by trilateration method, Second scenario position 3

The situation here on figure 7.12 is similar to that one on figure 7.10. The measurements of the nearest two beacons are really close to the true location. Beacon E which is more than 6meters away from the target import the error here in that situation. The black dot has coordinates $(3.97, 4.06)$, while the real coordinates are $(6,2)$.

After these static experiments, despite of the bad results, we tried a walking test as that one from the first scenario. As we expected the measurements were unsatisfying. The error most of the time was bigger than 2meters. We decided to do not give images or to write more about that test because there were a lot of uncertainties in the output data.

In summary for this second scenario we can say that the trilateration method is not good enough to cope with areas with that size. In the figures 7.10 and 7.12 the dot`s coordinates have too big mistake compared to these of the unfiled circle. Of course this is true for the algorithm when only three beacons are included in it. After the fifth meter away from each beacon as we mentioned in (Section 6.4) the RSSI values become unpredictable and unreliable. For different distances we have the same values. This leads to wrong decisions and most of the time determined distance from mobile node to beacon has big error.

7.3. Fingerprint

We chose to survey and a second location algorithm - the fingerprint method. To present a better analysis and comparison to the two technologies we decided to use the same data sets of measurements. We applied again Kalman filter to the received signals, but we modified the parameters of the filter before process the information.

7.3.1. Small Room Scenario

For the small room scenario we divide the space to squares. Starting from one of the corners of the room and with step of 1 meter we formed 9 useful areas (Figure 7.13 a) and b)):

As part of the offline phase of the fingerprint algorithm (explained in Chapter 3), at each square we performed measurements in all possible orientations of the receiving device. The data was collected in case of standing and fallen position and again processed with Kalman filter (Chapter 6). With the final results a set of information was created to develop radio map of the room. Every area was defined to be characterized by specific values from the different beacons. We also included requirements for every zone to define the existing possible paths to get inside of some area, which eliminated random errors and leaps from distant sectors.

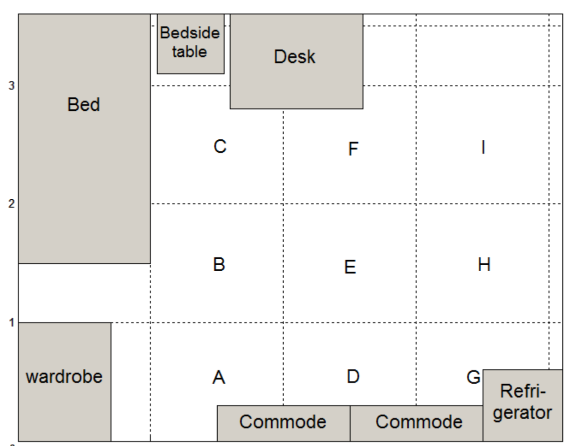


Figure 7.13: a) Small room areas

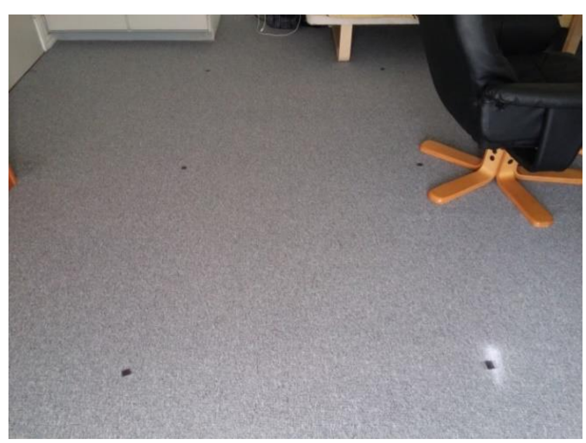


Figure 7.13: b) Small room areas

The online phase of the fingerprint algorithm was created to observe the combination of the current received signals from the three nodes and the previous known location, from where it is possible user had come. So for example if the person is at area A, the algorithm will define him there only if the three signals belong to the allowed ranges for this area and if its previous position was in area A, B, D or E (Figure 7.13a).

During the offline phase, while developing the radio map, we determinate that the RSSI values in the neighbors' areas were too similar and the ranges of some zones overlapped with each other. We tried to adjust the parameters of the Kalman filter, but this didn't introduce any improvements. At the end we observed many to miscalculations in the online process and wrong positioning of the mobile device. This approved that the method is able to find only the approximate location and that step of only 1meter is insufficient, because of the too alike values, which makes the fingerprint algorithm not appropriate and useful in case of room with size $3{,}6m$ to $4{,}1m$.

7.3.2. Big Room Scenario

Relying on the results from the small room scenario, in the case of the big room we decided to create RSSI map based on 2 meters step (Figure 7.14). We designed 12 squares and performed 2 continuous measurements in each of them – one in standing position and one in fallen, while changing the orientation of the person and respectively the orientation of the receiver. Beacons were placed again in area B (BF), area I (BE) and area L (BC). Similar to the previous room we filtered the collected signals and developed radio range for every zone and node. By empirical method we picked transition model $A = 1.08$ for the Kalman filter and measurement noise covariance $R = 0.1$. After that we improved the fingerprint algorithm to fit better to the chamber's particularities and the possible routes in it. We again created a MatLab algorithm, which can monitor for the smooth movement around the room and can detect and correct impossible paths. Thus for example area G is surrounded from eight other zones, but because of an insurmountable obstacle (Figure 6.2) the user is actually allowed to reach it only from areas A, B, C, F, G and H and not from areas I, J and K.

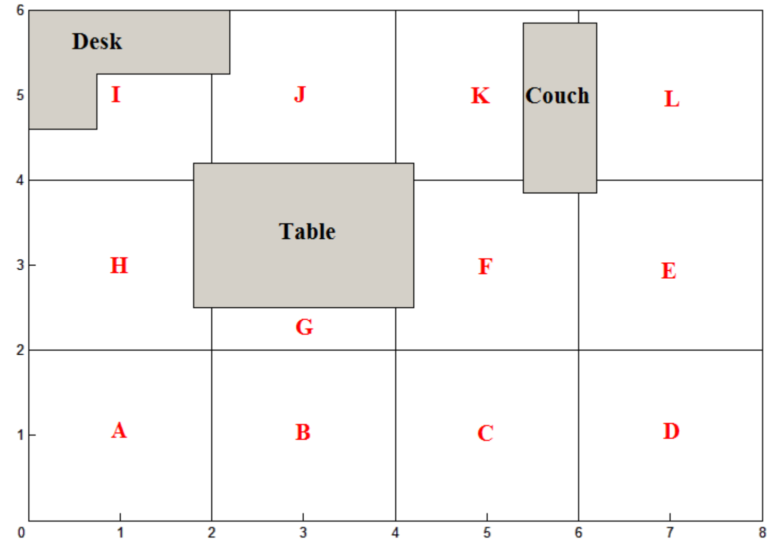


Figure 7.14: Big room areas

While developing the radio map we discovered that in areas B, I and L (where the beacons are placed), the algorithm is highly accurate and defines the right sector correctly. The ranges of values for areas A, C and G are considerably small and predictable, but in some cases they can overlap. The same occasion is repeated and for zones H and J. And for areas F and K the possible values are identical and only the rule about the previous position can define the difference between them (Table 7.1).

Node / Area	F4:0A:08:E6:C0:36		E7:91:97:D9:E4:A8		CB:BA:B0:9D:61:13	
	min, [dBm]	max, [dBm]	min, [dBm]	max, [dBm]	min, [dBm]	max, [dBm]
A				-78	-81	-75
B	-72					
C	-80	-72		-78		
D			-78	-74		-81
E			-74	-68		-81
F			-74	-68	-81	-75
G	-80	-72	-78	-74		
H				-78	-75	-68
I					-68	
J		-80			-75	-68
K	-80	-72	-74	-68		
L			-68			

Table 7.1: Verification values of the areas depending on different beacons

To analyze the capabilities of our algorithm, during the online phase we initiated two occasional paths thought the room. The first one started in area A and passed through areas B, C, D, E, F, G, H, I, J and finished in zone K. And the second went by sectors C, F, K, J, I, H, A, B, C, D, E, L. Although the similar results from the radio map, we confirmed that our algorithm is rather precise, by computing around 80% of accuracy from the simulated routs . At some moments the person was detected to be situated at the nearby zone, but most of the time the computations were correct and presented the true position of the human (Figure 7.15).

On Figure 7.15 we illustrated the first experimental path to represent our idea for an interface of the developed location algorithm. As it can be seen, the system will provide the specified areas and the current human's position. In addition, all furniture and obstacles that characterize the room can be implemented in the user's interface for better representation of the surrounding environment.

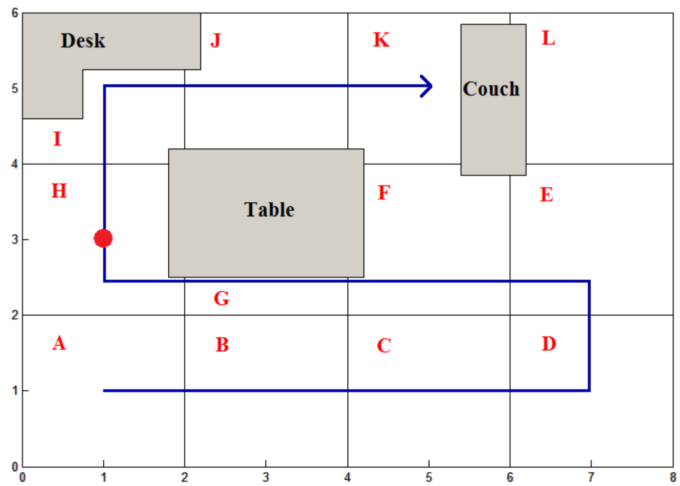


Figure 7.15: Detection for presence in area H

7.4. Results Comparison for Trilateration and Fingerprint Algorithms

Both fingerprint and trilateration use the received signal strength as main tool to find the location of the target. The difference between the two methods is the way they are using it. To estimate the position of a person by fingerprinting two phases has to be passed. It is based on previously collected and stored in database signals, which is very time consuming process. To build precise and reliable radio map that you can use later huge amount of data need to be stored. On the other hand, with trilateration is much more flexible from that viewpoint. It just needs the right coordinates of the beacons, a good distance formula and an algorithm that it can start to locate on.

If we compare the adaptability of the two methods trilateration have better indicators. For example if we want to remove, add or just to move some of the BLE nodes in our system this can be fixed with some little corrections in the trilateration algorithm. When we talk about fingerprint one change like this will lead to re-building of the radio map.

From a view point of correct translation of the signal strength, fingerprinting already has the actual values at each point, even if there is obstruction between the devices. With trilateration the signals are collected and transformed into distance in real time and if there is an obstacle on the path of the radio waves this will give an error in the estimated coordinates. To overcome that negative impact, correction factor can be included in the algorithm but it is always depending from what type of material the signal is passing through**.**

When we talk about accuracy, as we saw in the previous chapters, the trilateration method performs very good results for a small room scenario. In contrast of that when we moved to the bigger room a lot of mistakes in the calculations were fact. Most of the time, the evaluated positions were far from the real ones. The opposite is valid for fingerprinting. In the smaller room we tried with denser boundaries of the areas and this do not give us the expected outcome. The values of neighboring areas were almost the same. It was impossible to define some signal ranges from which the areas can be distinguished one from another. In the big room scenario the implementation of the fingerprint algorithm coped with the localization task much better than the trilateration. It is still gives errors but most of the time the measured position corresponds to the real one.

As a final of that comparison we can say both of the algorithms have pros and cons, but also both are dependent on the number of beacons that are used. All of the experiments and conclusion that we mentioned are result of usage of only three beacons. Of course if that number is increased the results must be much better.

Summary

In the chapter we described our Indoor Positioning Algorithm. We presented the results from applying the algorithm in a small and a big room scenario and evaluated the accuracy and the performance of the two location techniques, that we examined – Trilateration and Fingerprint. Last but not least we compared the advantages of the two methods to determine their specific potential.

8. Fall Detection

In this chapter we present our idea for developing a fall detection algorithm. For this purpose we reinvestigated some of the measurements, made during the indoor location algorithm. Hire we also append our conclusions about the RSSI behavior in occasions of movement and motionless situations. In addition we examined tree cases of simulated falls of a person and analyzed the obtained results. Thanks to these tests we evaluated the performance of the radio signal during fast changes of the user's position and created an algorithm for continuous monitoring and detection of falls.

8.1. Algorithm Modeling

After the evaluation and comparison between the two methods for indoor location that we have used, our final aim was to think about how can we detect falls with the only usage of the received signals from our beacons. As we said in section 7.3, we tried to collect the emitted waves from the three BLE nodes in different areas in the room, while a person with the receiver was walking in that areas or was fallen in them. Even if we assumed that from one area you can fall only in the neighboring squares or in the same one, the signals were too similar. This can lead to misleading in the system, for example it can decide that the person is fallen if he is not or even worst it can skip the falling and to decide he has just moved to another area. This is why we continued to research and try to find something that we can base our algorithm on. For that purpose we simulate real falls in different part of the rooms for both scenarios. For comparison we took results from some of the previous tests where the RSSI values have the biggest variations like test in which the target is moving around and the test with change of the condition: from LoS to NLoS (Figures 8.1 and 6.3 respectively).

On figure 8.1 is illustrated the unfiltered signal from Beacon E from our walking test in Chapter 7. We can see that after big maximum follows a big minimum in the values. And it can be easily seen when the mobile node is closer to the beacon – around 116th sample. The value at that point is $-68\ [dBm]$. After that in the range of 10 samples the signal plummeted with $17\ [dBm]$ to $-85\ [dBm]$. So when the person is moving the variation into the signal are really big, and after every fluctuation follows a new one.

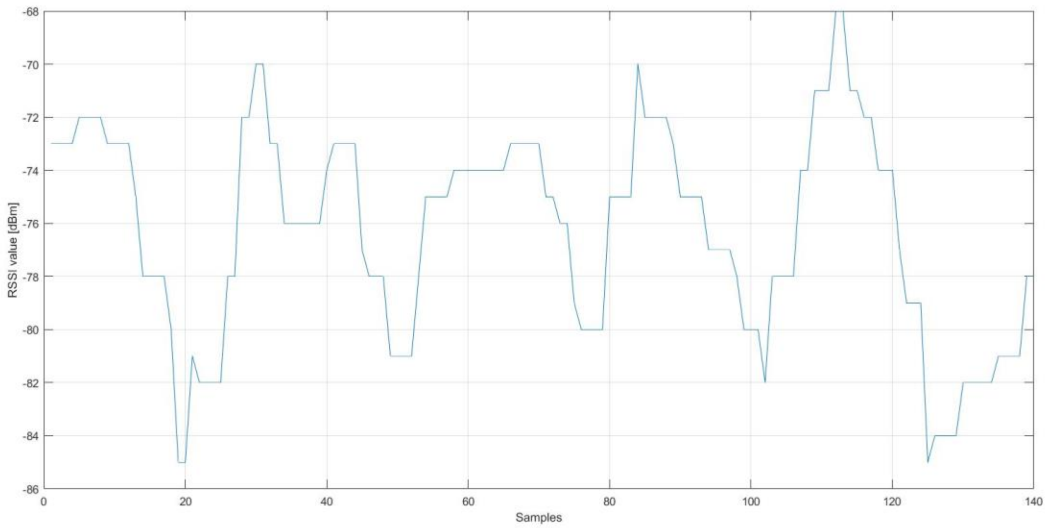


Figure 8.1: Received signal from a beacon while the person is walking

When we look up to the situation from non-line of sight to direct line of sight we can easily observed that the ups and down are fact in both conditions. The difference is that they are in different ranges of the RSSI values. The ranges are changed not that fast, as we can see RSSI grown with more than $20dBm$ for approximately 15 samples.

Now let see what is happening with the signal of the beacons when the person who is tracked fall. The next 3 figures show cases like that:

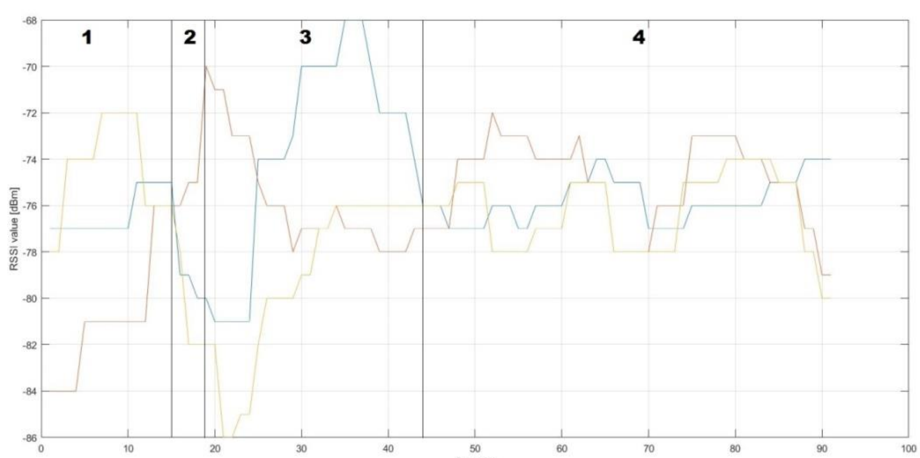


Figure 8.2: Received signals from fall test 1

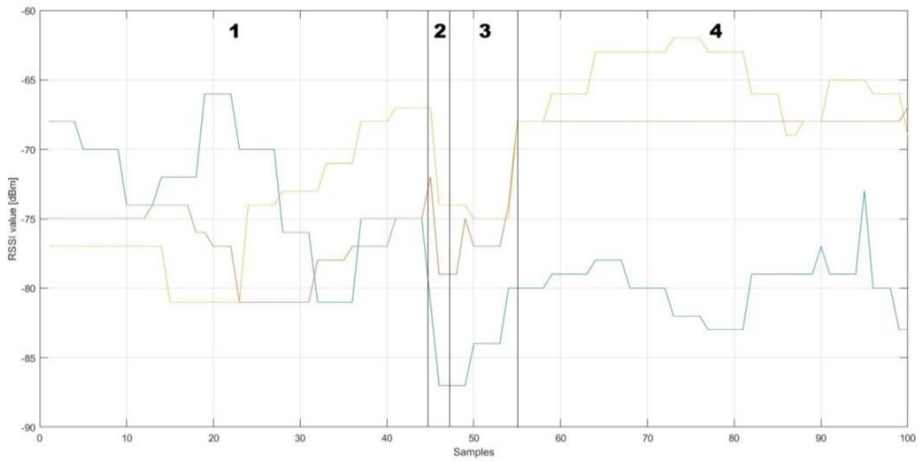


Figure 8.3: Received signals from fall test 2

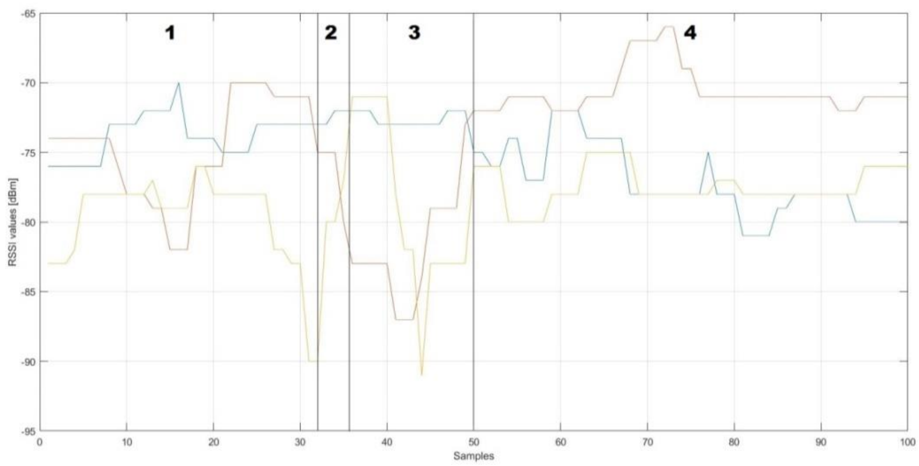


Figure 8.4: Received signals from fall test 3

All of the 3 figures are divided by black lines into 4 periods. With period one is denoted the period when the person is walking. By period 2 we indicate the moment of the fall. On figure 8.2 two of the signals show sharp decrease, while the third one grew suddenly. On the next figure in that period all of the three signals experienced fast drop. On the third image two of the signals demonstrate rapid changes in the values, while the third one remains almost constant. All of these ups and downs happen really fast – for less than 5 samples. In the third period, as we said, after a big maximum or minimum follows the opposite one, so we called this period tune up period, when the system is still confused. The fourth period is when the person is already fallen on the floor. In that period the fluctuations are much smaller. They vary into range of just a few dBm.

For better understanding we divided figure 8.4 from the tests to show the beacons' signals separately:

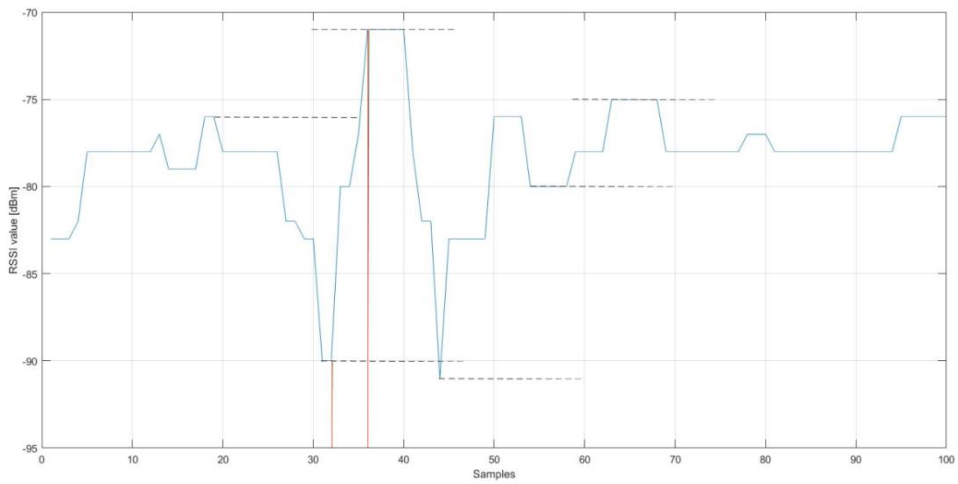


Figure 8.5: Received signal from BE during a fall

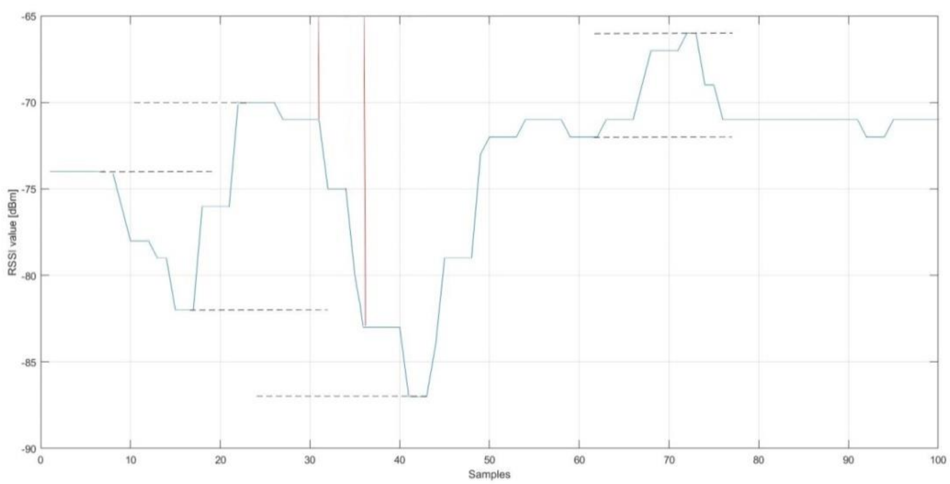


Figure 8.6: Received signal from BE during a fall

The third signal is not object to view because it does not experienced big changes. On the both figures with red lines is shown the moment of the fall and how fast actually the signals jump was. In both cases the graph presents that fast change of the values for around 5 samples. That fact can be used to differentiate a fall from changing the condition from NLoS to LoS. With dashed lines on the figures is shown how big the fluctuations are before, during and after the fall.

To distinguish the case of fall from normal walking situation here can be used that: after the biggest fluctuation (in both cases the signal experience change in the values bigger than $15dBm$) follow a much smaller ones (the signal continue to vary, but in a range of only $5 - 7dBm$). If situation like this occur the system waits 20 seconds to see are these small fluctuations are going to increase. If not the system sends an immediate question to the fallen person: “Are you okay?”. The person has 15 seconds to answer to that question: “Yes, I am.” or “No, I am not”. If after these 15 seconds there is no answer the algorithm automatically took the answer “No, I am not” and contacts with family members or medics, so emergency actions to be taken (Figure 8.7).

Generally the algorithm watches every minimum and maximum of the signal before to be filtered for the positioning algorithm, because if they are filtered they would not be that visible. In particular it is mostly interested by the difference between the maximum and the following minimum or the reverse (on Figure 8.7 mentioned as Range). Also it is looking about how fast are the ups and downs. Thus every time when the signal changes its direction from up to down or from down to up the system saves the value and compare this range to the next similar one. If after fast and big variations in one of the signals follow small fluctuations, with other words the difference |Range1 – Range2| is equal or bigger than 10dBm, the algorithm waits 20 seconds and after that begins the above mentioned process.

If the person sit fast it is possible to give a wrong decision and to decide that he is fallen. To overcome that problem and to improve the algorithm gyroscope can be added to the mobile node on the person shoulder.

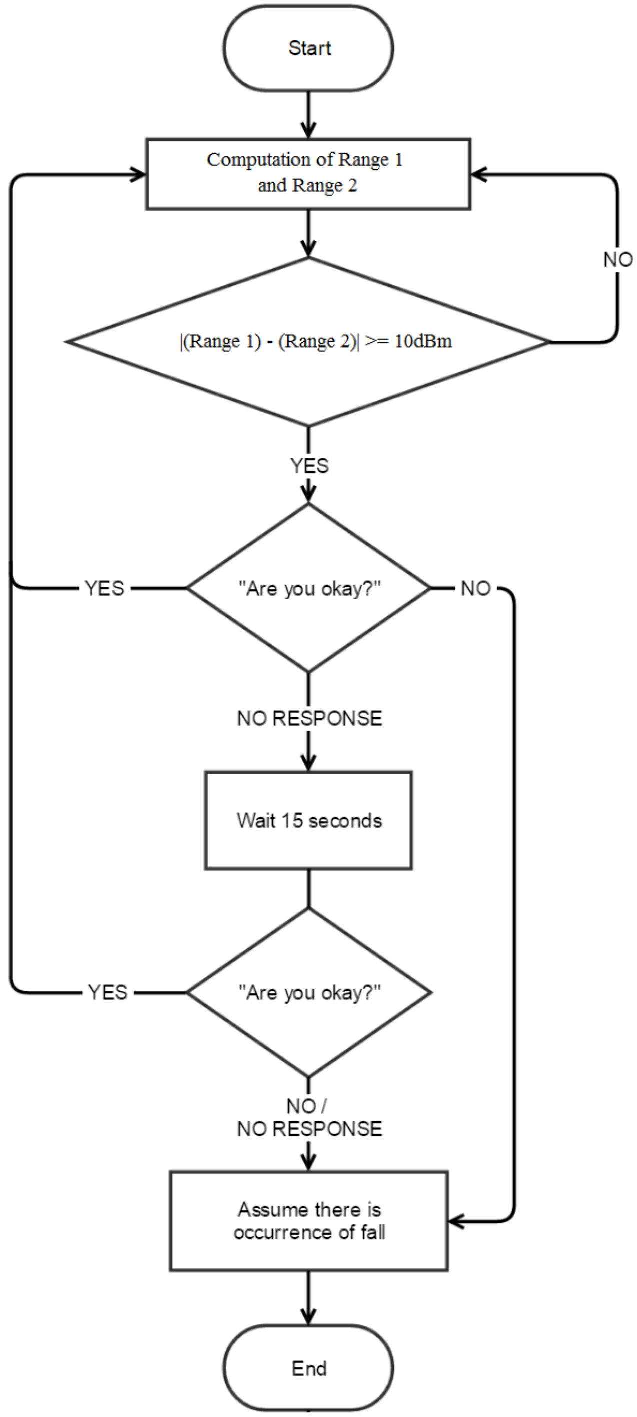


Figure 8.7: Flow chart of the fall detection algorithm

Summary

In this chapter we reviewed some of the results of our previous measurements and presented measurements from simulated falls. We analyzed the RSSI behavior and discovered a pattern in the occasions of falling. We also developed algorithm for monitoring and fall detection.

9. Conclusion and future work

This chapter is organized into two parts. In the first part the results of the experiments are summarized and evaluated to present a conclusion about the value and benefits of the developed positioning algorithm. The selection of location technology and faltering algorithm are also discussed in the following section. The secondpart is dedicated to the still existing limitations of the Indoor Location-Based Systems. In it we proposed some advices for future researches and developments.

9.1. Conclusion

Nowadays the development of indoor location system is a big field of researches. The main objective of this project was to make a comparison of different methods and technologies for indoor localization and to propose an innovative algorithm in the context of healthcare. After an overview Bluetooth Low Energy was picked up as a core technology, due to its good characteristics and since it is increasingly widespread choice. In particular, we have used the beacons made by Estimote Inc. By several experiments the BLE features were studied and applied to obtain the accuracy and precision of the implemented system under different conditions. In this thesis tests were performed for better understanding of the RSSI behavior in indoor environments. Furthermore different techniques as trilateration and fingerprinting have been used in order to present their advantages and disadvantages in various environments. As a summary we can state some of the observations and conclusions that have been made on the basis of the results:

- RSSI of Bluetooth smart presents a lognormal distribution and that gives a chance to calculate distance through a log-distance path loss model. That allows good results for localization algorithm. When the mobile node is in static position the evaluated coordinates are close to the real ones: accuracy of about 1 meter with direct line of sight. When the user is moving the precision is decreasing but it still achieves acceptable outcome.
- After testing, some differences into received signal strength were found, depending on the device orientation. During our work we also discover that even if different devices

but with the same design and hardware are used in the same conditions it is possible to received different output.

- From the signal strength experiments it was observed that when the mobile node is getting away from the beacon the value of the received signal is decreasing. However there are some exceptions to the rule. In some points when the distance is increasing received signal strength gets more unpredictable and experience slight grow. After the 4-5 meter away from the beacon same value can correspond to different distances.
- After evaluating the characteristics of two different localization methods it can be said that for fingerprint system more setup is required. Radio map needs to be created which is a very time consuming process. In the purpose of better accuracy more reference points should be added to the map. When the area of coverage increases that process becomes larger also. For the trilateration algorithm the only setup that is needed is to place the beacons and to use a suitable formula for converting RSSI into distance. When the area is getting bigger just new beacons must be added to the algorithm and the process is continuing.
- Another conclusion from the methods comparison is that, for small areas trilateration method is capable to evaluate the coordinates of a mobile node with big precision. Due to the fact that after few meters away of the beacon RSSI is hardly to be understand, trilateration approach with non-dense placed transmitters in bigger premises is incapable to be used for accurate indoor positioning system (IPS). On the other hand, for the smaller scenario fingerprint algorithm has the possibility to understand in which half of the room is the user but this is not good enough for high precise localization system. It copes much better with bigger areas where the built radio map is clearer and it is a good basis for comparison.
- We provided an example which can be used for the purpose of healthcare. The algorithm can be useful as a remote assisted living service for elderly people or people with different diseases. In case of fall if no urgent measures are taken the consequences can be fatal. With our proposal similar situations can be avoided.

To sum up, even though Bluetooth Low Energy is not a technology created to be used for precise indoor positioning system, but for proximity, we demonstrated it is possible to achieve high accuracy and good results. With taking advantage of Kalman filter the uncertainties in the received signal can be narrowed down and this can lead to better usage of the received values. Bluetooth Smart shows several improvements to inexpensive IPS. It is power efficient, it has fast response time, the beacons support broadcasting mode and last but not least it is already widespread technology which can help to its fast deployment.

9.2. Future Work

In order to improve the system performance some suggestions and ideas for future work are presented in this section.

- For the purpose of our project a log-distance model was used for translating the RSSI to distance. The results that our system showed are good but it can be improved. Also our outcome is taken in only one room scenario. In a multi-room environment it is possible, due to the wall fading and other factors, to have unexpected errors. Hence a good future work would be a total statistical survey on the RSSI behavior to be done.
- A good idea that we have figured out during this project is if there was a direct communication between the beacons. Since we are placing the beacons and their coordinates are known a possible enhancement in the IPS accuracy can be achieved if they are connected to each other. As they will know what is the exact distance to other beacons a calibration algorithm can be created when they start to locate a target together in order to reduce the error.
- Another proposal for improvement of our BLE based indoor location system is to increase the number of beacons. We saw that after the fourth meter away from a beacon the received signal is more unpredictable and it is hard to calculate the real distance by the trilateration method. If more BLE nodes are included in the system the error will decrease drastically. Also if there are more beacons used for fingerprinting there will be more signals to build a radio map on. This will lead to better estimation of the target`s location. Least but not last if there is more than three beacons it would be possible to create a 3 dimensional trilateration algorithm. This can ease the task of the fall detection algorithm.
- For the purpose of our experiments we have used as a mobile node LG G3. In a real exploitation of the system this could be just a BLE tag. If there is per one tag on both of the shoulders, by knowing the distance between them, a correction factor can be

added to improve the calculations. For instance if the person who is located by trilateration turns, so there is no direct visibility between beacon and tag (most of the signal will pass through the person head) this will give us deviations into the signals and wrong decision for the position. In situation like that the system can make a comparison between the two received signals and to take into account the one with better values. When we talk about fingerprinting this additional tag can give us bigger base for comparison and better decision making. The same applies in the case of fall.

- Nowadays the wearable devices become more and more popular. Tools like pedometer, gyroscope, compass or accelerometer can contribute a lot for the localization of a person or for the fall detection algorithm. Another source of data can be also Wi–Fi, Ultrasound or many others. The concept is to use several different technologies together to calculate the coordinates of the target. Even if one of them gives an error, for example if an obstacle is between the tag and the beacon, the mistake that will occurs, can be compensate since the received signal from the Bluetooth Low Energy node is not the only one input for the localization system. The mutual work of different sources of data can warrant bigger reliability and improved accuracy.
- Another idea to make the indoor localization more precise is to use several location methods together. The main here is, if we set some beacons to work with the trilateration algorithm and together with these beacons we can set another to locate the target by the fingerprint algorithm. With appropriate model for comparison between the measurements of the both algorithm the results can be bettered.
- In all of our experiments the only one input that is used is the RSSI values. It is obvious that this is a parameter that is hard to be predicted and the variations even if the tag is close to the beacon are big. In [46] they present another approach to use the BLE technology. With the usage of advanced antennas their innovative idea is to measure the position of the tag by Angle-of-Arrival method. This interesting alternative possibility can compute accurate 3D position with only 2 beacons. Another idea can be the usage of localization build on Time-of-Flight or Time-Difference-of-Arrival-algorithm. Since atomic clocks with highly accurate synchronization of just a few nanoseconds should be embedded, this task will be pretty hard, but anyway it is

not impossible. All of this additional hardware can lead to improvement in the IPS, but because of their high price are not affordable for widespread use.

10. Appendixes

10.1. 2D Trilateration Function for 100 consecutive position estimations in Matlab based on the algorithm in Chapter 7

```
function [x,y] = Two_d_trilateration(x1, x2, x3, y1, y2, y3, d1, d2, d3)


Z_1 = (d1.^2 - d2.^2) - (x1.^2 - x2.^2) - (y1.^2 - y2.^2);

Z_2 = (d1.^2 - d3.^2) - (x1.^2 - x3.^2) - (y1.^2 - y3.^2);

Y_21 = 2.*(y2-y1);

Y_31 = 2.*(y3-y1);

X_21 = 2.*(x2-x1);

X_31 = 2.*(x3-x1);

x_F = [Z_1, Y_21; Z_2, Y_31];

d = [X_21, Y_21; X_31, Y_31];

x = [(x_F([1 2],[1 101]))/(d([1 2],[1 101])),(x_F([1 2],[2 102]))/(d([1 2],[2 102])),...

   (x_F([1 2],[3 103]))/(d([1 2],[3 103])),(x_F([1 2],[4 104]))/(d([1 2],[4 104])),...

   (x_F([1 2],[5 105]))/(d([1 2],[5 105])),(x_F([1 2],[6 106]))/(d([1 2],[6 106])),...

   (x_F([1 2],[7 107]))/(d([1 2],[7 107])),(x_F([1 2],[8 108]))/(d([1 2],[8 108])),...

   (x_F([1 2],[9 109]))/(d([1 2],[9 109])),(x_F([1 2],[10 110]))/(d([1 2],[10 110])),...

   (x_F([1 2],[11 111]))/(d([1 2],[11 111])),(x_F([1 2],[12 112]))/(d([1 2],[12 112]))...

   ,(x_F([1 2],[13 113]))/(d([1 2],[13 113])),(x_F([1 2],[14 114]))/(d([1 2],[14 114]))...

   ,(x_F([1 2],[15 115]))/(d([1 2],[15 115])),(x_F([1 2],[16 116]))/(d([1 2],[16 116]))...

   ,(x_F([1 2],[17 117]))/(d([1 2],[17 117])),(x_F([1 2],[18 118]))/(d([1 2],[18 118]))...
```

```
,(x_F([1 2],[19 119]))/(d([1 2],[19 119])),(x_F([1 2],[20 120]))/(d([1 2],[20 120]))...
,(x_F([1 2],[21 121]))/(d([1 2],[21 121])),(x_F([1 2],[22 122]))/(d([1 2],[22 122]))...
,(x_F([1 2],[23 123]))/(d([1 2],[23 123])),(x_F([1 2],[24 124]))/(d([1 2],[24 124]))...
,(x_F([1 2],[25 125]))/(d([1 2],[25 125])),(x_F([1 2],[26 126]))/(d([1 2],[26 126]))...
,(x_F([1 2],[27 127]))/(d([1 2],[27 127])),(x_F([1 2],[28 128]))/(d([1 2],[28 128]))...
,(x_F([1 2],[29 129]))/(d([1 2],[29 129])),(x_F([1 2],[30 130]))/(d([1 2],[30 130]))...
,(x_F([1 2],[31 131]))/(d([1 2],[31 131])),(x_F([1 2],[32 132]))/(d([1 2],[32 132]))...
,(x_F([1 2],[33 133]))/(d([1 2],[33 133])),(x_F([1 2],[34 134]))/(d([1 2],[34 134]))...
,(x_F([1 2],[35 135]))/(d([1 2],[35 135])),(x_F([1 2],[36 136]))/(d([1 2],[36 136]))...
,(x_F([1 2],[37 137]))/(d([1 2],[37 137])),(x_F([1 2],[38 138]))/(d([1 2],[38 138]))...
,(x_F([1 2],[39 139]))/(d([1 2],[39 139])),(x_F([1 2],[40 140]))/(d([1 2],[40 140]))...
,(x_F([1 2],[41 141]))/(d([1 2],[41 141])),(x_F([1 2],[42 142]))/(d([1 2],[42 142]))...
,(x_F([1 2],[43 143]))/(d([1 2],[43 143])),(x_F([1 2],[44 144]))/(d([1 2],[44 144]))...
,(x_F([1 2],[45 145]))/(d([1 2],[45 145])),(x_F([1 2],[46 146]))/(d([1 2],[46 146]))...
,(x_F([1 2],[47 147]))/(d([1 2],[47 147])),(x_F([1 2],[48 148]))/(d([1 2],[48 148]))...
,(x_F([1 2],[49 149]))/(d([1 2],[49 149])),(x_F([1 2],[50 150]))/(d([1 2],[50 150]))...
,(x_F([1 2],[51 151]))/(d([1 2],[51 151])),(x_F([1 2],[52 152]))/(d([1 2],[52 152]))...
,(x_F([1 2],[53 153]))/(d([1 2],[53 153])),(x_F([1 2],[54 154]))/(d([1 2],[54 154]))...
,(x_F([1 2],[55 155]))/(d([1 2],[55 155])),(x_F([1 2],[56 156]))/(d([1 2],[56 156]))...
,(x_F([1 2],[57 157]))/(d([1 2],[57 157])),(x_F([1 2],[58 158]))/(d([1 2],[58 158]))...
,(x_F([1 2],[59 159]))/(d([1 2],[59 159])),(x_F([1 2],[60 160]))/(d([1 2],[60 160]))...
,(x_F([1 2],[61 161]))/(d([1 2],[61 161])),(x_F([1 2],[62 162]))/(d([1 2],[62 162]))...
,(x_F([1 2],[63 163]))/(d([1 2],[63 163])),(x_F([1 2],[64 164]))/(d([1 2],[64 164]))...
```

```
    ,(x_F([1 2],[65 165]))/(d([1 2],[65 165])),(x_F([1 2],[66 166]))/(d([1 2],[66 166]))...
    ,(x_F([1 2],[67 167]))/(d([1 2],[67 167])),(x_F([1 2],[68 168]))/(d([1 2],[68 168]))...
    ,(x_F([1 2],[69 169]))/(d([1 2],[69 169])),(x_F([1 2],[70 170]))/(d([1 2],[70 170]))...
    ,(x_F([1 2],[71 171]))/(d([1 2],[71 171])),(x_F([1 2],[72 172]))/(d([1 2],[72 172]))...
    ,(x_F([1 2],[73 173]))/(d([1 2],[73 173])),(x_F([1 2],[74 174]))/(d([1 2],[74 174]))...
    ,(x_F([1 2],[75 175]))/(d([1 2],[75 175])),(x_F([1 2],[76 176]))/(d([1 2],[76 176]))...
    ,(x_F([1 2],[77 177]))/(d([1 2],[77 177])),(x_F([1 2],[78 178]))/(d([1 2],[78 178]))...
    ,(x_F([1 2],[79 179]))/(d([1 2],[79 179])),(x_F([1 2],[80 180]))/(d([1 2],[80 180]))...
    ,(x_F([1 2],[81 181]))/(d([1 2],[81 181])),(x_F([1 2],[82 182]))/(d([1 2],[82 182]))...
    ,(x_F([1 2],[83 183]))/(d([1 2],[83 183])),(x_F([1 2],[84 184]))/(d([1 2],[84 184]))...
    ,(x_F([1 2],[85 185]))/(d([1 2],[85 185])),(x_F([1 2],[86 186]))/(d([1 2],[86 186]))...
    ,(x_F([1 2],[87 187]))/(d([1 2],[87 187])),(x_F([1 2],[88 188]))/(d([1 2],[88 188]))...
    ,(x_F([1 2],[89 189]))/(d([1 2],[89 189])),(x_F([1 2],[90 190]))/(d([1 2],[90 190]))...
    ,(x_F([1 2],[91 191]))/(d([1 2],[91 191])),(x_F([1 2],[92 192]))/(d([1 2],[92 192]))...
    ,(x_F([1 2],[93 193]))/(d([1 2],[93 193])),(x_F([1 2],[94 194]))/(d([1 2],[94 194]))...
    ,(x_F([1 2],[95 195]))/(d([1 2],[95 195])),(x_F([1 2],[96 196]))/(d([1 2],[96 196]))...
    ,(x_F([1 2],[97 197]))/(d([1 2],[97 197])),(x_F([1 2],[98 198]))/(d([1 2],[98 198]))...
    ,(x_F([1 2],[99 199]))/(d([1 2],[99 199])),(x_F([1 2],[100 200]))/(d([1 2],[100 200]))];
x100 = det(x(:,1:2));
x200 = det(x(:,3:4));
x300 = det(x(:,5:6));
x4 = det(x(:,7:8));
x5 = det(x(:,9:10));
```

```
x6 = det(x(:,11:12));

x7 = det(x(:,13:14));

x8 = det(x(:,15:16));

x9 = det(x(:,17:18));

x10 = det(x(:,19:20));

x11 = det(x(:,21:22));

x12 = det(x(:,23:24));

x13 = det(x(:,25:26));

x14 = det(x(:,27:28));

x15 = det(x(:,29:30));

x16 = det(x(:,31:32));

x17 = det(x(:,33:34));

x18 = det(x(:,35:36));

x19 = det(x(:,37:38));

x20 = det(x(:,39:40));

x21 = det(x(:,41:42));

x22 = det(x(:,43:44));

x23 = det(x(:,45:46));

x24 = det(x(:,47:48));

x25 = det(x(:,49:50));

x26 = det(x(:,51:52));

x27 = det(x(:,53:54));

x28 = det(x(:,55:56));
```

```
x29 = det(x(:,57:58));
x30 = det(x(:,59:60));
x31 = det(x(:,61:62));
x32 = det(x(:,63:64));
x33 = det(x(:,65:66));
x34 = det(x(:,67:68));
x35 = det(x(:,69:70));
x36 = det(x(:,71:72));
x37 = det(x(:,73:74));
x38 = det(x(:,75:76));
x39 = det(x(:,77:78));
x40 = det(x(:,79:80));
x41 = det(x(:,81:82));
x42 = det(x(:,83:84));
x43 = det(x(:,85:86));
x44 = det(x(:,87:88));
x45 = det(x(:,89:90));
x46 = det(x(:,91:92));
x47 = det(x(:,93:94));
x48 = det(x(:,95:96));
x49 = det(x(:,97:98));
x50 = det(x(:,99:100));
x51 = det(x(:,101:102));
```

```
x52 = det(x(:,103:104));

x53 = det(x(:,105:106));

x54 = det(x(:,107:108));

x55 = det(x(:,109:110));

x56 = det(x(:,111:112));

x57 = det(x(:,113:114));

x58 = det(x(:,115:116));

x59 = det(x(:,117:118));

x60 = det(x(:,119:120));

x61 = det(x(:,121:122));

x62 = det(x(:,123:124));

x63 = det(x(:,125:126));

x64 = det(x(:,127:128));

x65 = det(x(:,129:130));

x66 = det(x(:,131:132));

x67 = det(x(:,133:134));

x68 = det(x(:,135:136));

x69 = det(x(:,137:138));

x70 = det(x(:,139:140));

x71 = det(x(:,141:142));

x72 = det(x(:,143:144));

x73 = det(x(:,145:146));

x74 = det(x(:,147:148));
```

```
x75 = det(x(:,149:150));

x76 = det(x(:,151:152));

x77 = det(x(:,153:154));

x78 = det(x(:,155:156));

x79 = det(x(:,157:158));

x80 = det(x(:,159:160));

x81 = det(x(:,161:162));

x82 = det(x(:,163:164));

x83 = det(x(:,165:166));

x84 = det(x(:,167:168));

x85 = det(x(:,169:170));

x86 = det(x(:,171:172));

x87 = det(x(:,173:174));

x88 = det(x(:,175:176));

x89 = det(x(:,177:178));

x90 = det(x(:,179:180));

x91 = det(x(:,181:182));

x92 = det(x(:,183:184));

x93 = det(x(:,185:186));

x94 = det(x(:,187:188));

x95 = det(x(:,189:190));

x96 = det(x(:,191:192));

x97 = det(x(:,193:194));
```

```
x98 = det(x(:,195:196));

x99 = det(x(:,197:198));

x101 = det(x(:,199:200));

x=[x100,x200,x300,x4,x5,x6,x7,x8,x9,x10,x11,x12,x13,x14,x15,x16,x17,x18,x19,x20,x21,x22...
    ,x23,x24,x25,x26,x27,x28,x29,x30,x31,x32,x33,x34,x35,x36,x37,x38,x39,x40,x41,x42,x43,...
    x44,x45,x46,x47,x48,x49,x50,x51,x52,x53,x54,x55,x56,x57,x58,x59,x61,x61,x62,x63,x64,...
    x65,x66,x67,x68,x69,x70,x71,x72,x73,x74,x75,x76,x77,x78,x79,x80,x81,x82,x83,x84,x85,...
    x86,x87,x88,x89,x90,x91,x92,x93,x94,x95,x96,x97,x98,x99,x101];

y_G = [X_21, Z_1; X_31, Z_2];

y = [(y_G([1 2],[1 101]))/(d([1 2],[1 101])),(y_G([1 2],[2 102]))/(d([1 2],[2 102])),...
    (y_G([1 2],[3 103]))/(d([1 2],[3 103])),(y_G([1 2],[4 104]))/(d([1 2],[4 104])),...
    (y_G([1 2],[5 105]))/(d([1 2],[5 105])),(y_G([1 2],[6 106]))/(d([1 2],[6 106])),...
    (y_G([1 2],[7 107]))/(d([1 2],[7 107])),(y_G([1 2],[8 108]))/(d([1 2],[8 108])),...
    (y_G([1 2],[9 109]))/(d([1 2],[9 109])),(y_G([1 2],[10 110]))/(d([1 2],[10 110])),...
    (y_G([1 2],[11 111]))/(d([1 2],[11 111])),(y_G([1 2],[12 112]))/(d([1 2],[12 112]))...
    ,(y_G([1 2],[13 113]))/(d([1 2],[13 113])),(y_G([1 2],[14 114]))/(d([1 2],[14 114]))...
    ,(y_G([1 2],[15 115]))/(d([1 2],[15 115])),(y_G([1 2],[16 116]))/(d([1 2],[16 116]))...
    ,(y_G([1 2],[17 117]))/(d([1 2],[17 117])),(y_G([1 2],[18 118]))/(d([1 2],[18 118]))...
    ,(y_G([1 2],[19 119]))/(d([1 2],[19 119])),(y_G([1 2],[20 120]))/(d([1 2],[20 120]))...
    ,(y_G([1 2],[21 121]))/(d([1 2],[21 121])),(y_G([1 2],[22 122]))/(d([1 2],[22 122]))...
    ,(y_G([1 2],[23 123]))/(d([1 2],[23 123])),(y_G([1 2],[24 124]))/(d([1 2],[24 124]))...
    ,(y_G([1 2],[25 125]))/(d([1 2],[25 125])),(y_G([1 2],[26 126]))/(d([1 2],[26 126]))...
    ,(y_G([1 2],[27 127]))/(d([1 2],[27 127])),(y_G([1 2],[28 128]))/(d([1 2],[28 128]))...
```

```
,(y_G([1 2],[29 129]))/(d([1 2],[29 129])),(y_G([1 2],[30 130]))/(d([1 2],[30 130]))...
,(y_G([1 2],[31 131]))/(d([1 2],[31 131])),(y_G([1 2],[32 132]))/(d([1 2],[32 132]))...
,(y_G([1 2],[33 133]))/(d([1 2],[33 133])),(y_G([1 2],[34 134]))/(d([1 2],[34 134]))...
,(y_G([1 2],[35 135]))/(d([1 2],[35 135])),(y_G([1 2],[36 136]))/(d([1 2],[36 136]))...
,(y_G([1 2],[37 137]))/(d([1 2],[37 137])),(y_G([1 2],[38 138]))/(d([1 2],[38 138]))...
,(y_G([1 2],[39 139]))/(d([1 2],[39 139])),(y_G([1 2],[40 140]))/(d([1 2],[40 140]))...
,(y_G([1 2],[41 141]))/(d([1 2],[41 141])),(y_G([1 2],[42 142]))/(d([1 2],[42 142]))...
,(y_G([1 2],[43 143]))/(d([1 2],[43 143])),(y_G([1 2],[44 144]))/(d([1 2],[44 144]))...
,(y_G([1 2],[45 145]))/(d([1 2],[45 145])),(y_G([1 2],[46 146]))/(d([1 2],[46 146]))...
,(y_G([1 2],[47 147]))/(d([1 2],[47 147])),(y_G([1 2],[48 148]))/(d([1 2],[48 148]))...
,(y_G([1 2],[49 149]))/(d([1 2],[49 149])),(y_G([1 2],[50 150]))/(d([1 2],[50 150]))...
,(y_G([1 2],[51 151]))/(d([1 2],[51 151])),(y_G([1 2],[52 152]))/(d([1 2],[52 152]))...
,(y_G([1 2],[53 153]))/(d([1 2],[53 153])),(y_G([1 2],[54 154]))/(d([1 2],[54 154]))...
,(y_G([1 2],[55 155]))/(d([1 2],[55 155])),(y_G([1 2],[56 156]))/(d([1 2],[56 156]))...
,(y_G([1 2],[57 157]))/(d([1 2],[57 157])),(y_G([1 2],[58 158]))/(d([1 2],[58 158]))...
,(y_G([1 2],[59 159]))/(d([1 2],[59 159])),(y_G([1 2],[60 160]))/(d([1 2],[60 160]))...
,(y_G([1 2],[61 161]))/(d([1 2],[61 161])),(y_G([1 2],[62 162]))/(d([1 2],[62 162]))...
,(y_G([1 2],[63 163]))/(d([1 2],[63 163])),(y_G([1 2],[64 164]))/(d([1 2],[64 164]))...
,(y_G([1 2],[65 165]))/(d([1 2],[65 165])),(y_G([1 2],[66 166]))/(d([1 2],[66 166]))...
,(y_G([1 2],[67 167]))/(d([1 2],[67 167])),(y_G([1 2],[68 168]))/(d([1 2],[68 168]))...
,(y_G([1 2],[69 169]))/(d([1 2],[69 169])),(y_G([1 2],[70 170]))/(d([1 2],[70 170]))...
,(y_G([1 2],[71 171]))/(d([1 2],[71 171])),(y_G([1 2],[72 172]))/(d([1 2],[72 172]))...
,(y_G([1 2],[73 173]))/(d([1 2],[73 173])),(y_G([1 2],[74 174]))/(d([1 2],[74 174]))...
```

```
    ,(y_G([1 2],[75 175]))/(d([1 2],[75 175])),(y_G([1 2],[76 176]))/(d([1 2],[76 176]))...
    ,(y_G([1 2],[77 177]))/(d([1 2],[77 177])),(y_G([1 2],[78 178]))/(d([1 2],[78 178]))...
    ,(y_G([1 2],[79 179]))/(d([1 2],[79 179])),(y_G([1 2],[80 180]))/(d([1 2],[80 180]))...
    ,(y_G([1 2],[81 181]))/(d([1 2],[81 181])),(y_G([1 2],[82 182]))/(d([1 2],[82 182]))...
    ,(y_G([1 2],[83 183]))/(d([1 2],[83 183])),(y_G([1 2],[84 184]))/(d([1 2],[84 184]))...
    ,(y_G([1 2],[85 185]))/(d([1 2],[85 185])),(y_G([1 2],[86 186]))/(d([1 2],[86 186]))...
    ,(y_G([1 2],[87 187]))/(d([1 2],[87 187])),(y_G([1 2],[88 188]))/(d([1 2],[88 188]))...
    ,(y_G([1 2],[89 189]))/(d([1 2],[89 189])),(y_G([1 2],[90 190]))/(d([1 2],[90 190]))...
    ,(y_G([1 2],[91 191]))/(d([1 2],[91 191])),(y_G([1 2],[92 192]))/(d([1 2],[92 192]))...
    ,(y_G([1 2],[93 193]))/(d([1 2],[93 193])),(y_G([1 2],[94 194]))/(d([1 2],[94 194]))...
    ,(y_G([1 2],[95 195]))/(d([1 2],[95 195])),(y_G([1 2],[96 196]))/(d([1 2],[96 196]))...
    ,(y_G([1 2],[97 197]))/(d([1 2],[97 197])),(y_G([1 2],[98 198]))/(d([1 2],[98 198]))...
    ,(y_G([1 2],[99 199]))/(d([1 2],[99 199])),(y_G([1 2],[100 200]))/(d([1 2],[100 200]))];
y100 = det(y(:,1:2));
y200 = det(y(:,3:4));
y300 = det(y(:,5:6));
y4 = det(y(:,7:8));
y5 = det(y(:,9:10));
y6 = det(y(:,11:12));
y7 = det(y(:,13:14));
y8 = det(y(:,15:16));
y9 = det(y(:,17:18));
y10 = det(y(:,19:20));
```

```
y11 = det(y(:,21:22));

y12 = det(y(:,23:24));

y13 = det(y(:,25:26));

y14 = det(y(:,27:28));

y15 = det(y(:,29:30));

y16 = det(y(:,31:32));

y17 = det(y(:,33:34));

y18 = det(y(:,35:36));

y19 = det(y(:,37:38));

y20 = det(y(:,39:40));

y21 = det(y(:,41:42));

y22 = det(y(:,43:44));

y23 = det(y(:,45:46));

y24 = det(y(:,47:48));

y25 = det(y(:,49:50));

y26 = det(y(:,51:52));

y27 = det(y(:,53:54));

y28 = det(y(:,55:56));

y29 = det(y(:,57:58));

y30 = det(y(:,59:60));

y31 = det(y(:,61:62));

y32 = det(y(:,63:64));

y33 = det(y(:,65:66));
```

```
y34 = det(y(:,67:68));

y35 = det(y(:,69:70));

y36 = det(y(:,71:72));

y37 = det(y(:,73:74));

y38 = det(y(:,75:76));

y39 = det(y(:,77:78));

y40 = det(y(:,79:80));

y41 = det(y(:,81:82));

y42 = det(y(:,83:84));

y43 = det(y(:,85:86));

y44 = det(y(:,87:88));

y45 = det(y(:,89:90));

y46 = det(y(:,91:92));

y47 = det(y(:,93:94));

y48 = det(y(:,95:96));

y49 = det(y(:,97:98));

y50 = det(y(:,99:100));

y51 = det(y(:,101:102));

y52 = det(y(:,103:104));

y53 = det(y(:,105:106));

y54 = det(y(:,107:108));

y55 = det(y(:,109:110));

y56 = det(y(:,111:112));
```

```
y57 = det(y(:,113:114));
y58 = det(y(:,115:116));
y59 = det(y(:,117:118));
y60 = det(y(:,119:120));
y61 = det(y(:,121:122));
y62 = det(y(:,123:124));
y63 = det(y(:,125:126));
y64 = det(y(:,127:128));
y65 = det(y(:,129:130));
y66 = det(y(:,131:132));
y67 = det(y(:,133:134));
y68 = det(y(:,135:136));
y69 = det(y(:,137:138));
y70 = det(y(:,139:140));
y71 = det(y(:,141:142));
y72 = det(y(:,143:144));
y73 = det(y(:,145:146));
y74 = det(y(:,147:148));
y75 = det(y(:,149:150));
y76 = det(y(:,151:152));
y77 = det(y(:,153:154));
y78 = det(y(:,155:156));
y79 = det(y(:,157:158));
```

```
y80 = det(y(:,159:160));

y81 = det(y(:,161:162));

y82 = det(y(:,163:164));

y83 = det(y(:,165:166));

y84 = det(y(:,167:168));

y85 = det(y(:,169:170));

y86 = det(y(:,171:172));

y87 = det(y(:,173:174));

y88 = det(y(:,175:176));

y89 = det(y(:,177:178));

y90 = det(y(:,179:180));

y91 = det(y(:,181:182));

y92 = det(y(:,183:184));

y93 = det(y(:,185:186));

y94 = det(y(:,187:188));

y95 = det(y(:,189:190));

y96 = det(y(:,191:192));

y97 = det(y(:,193:194));

y98 = det(y(:,195:196));

y99 = det(y(:,197:198));

y101 = det(y(:,199:200));

y=[y100,y200,y300,y4,y5,y6,y7,y8,y9,y10,y11,y12,y13,y14,y15,y16,y17,y18,y19,y20,y21,y22...

  ,y23,y24,y25,y26,y27,y28,y29,y30,y31,y32,y33,y34,y35,y36,y37,y38,y39,y40,y41,y42,y43,...
```

```
    y44,y45,y46,y47,y48,y49,y50,y51,y52,y53,y54,y55,y56,y57,y58,y59,y60,y61,y62,y63,y64,...
    y65,y66,y67,y68,y69,y70,y71,y72,y73,y74,y75,y76,y77,y78,y79,y80,y81,y82,y83,y84,y85,...
    y86,y87,y88,y89,y90,y91,y92,y93,y94,y95,y96,y97,y98,y99,y101];
end
```

10.2. Kalman Filter Matlab Function based on Chapter 6

```
function [Y,KG,P]= Kalman_Filter( X, Q )
%Q-process noise covariance
N=length(X);
X(isinf(X))=[];
X(isnan(X))=[];
%% Filter parameters
A    = 1;                        % (State) transition model
B   = 0;                         % Control model (added for future works if needed)
P    = zeros(1,N);               %Inserting variable P for the error covariance
P(1) = 0.1;                      % a priori error covariance
R    = 0.1;                      % Measurement noise covariance
Y    = zeros (1, N);             % Inserting variable Y for the output data
Y(1)=X(1);                       % initialization of the filter
KG   = zeros (1, N);             % Inserting variable for the Kalman gain vector
H=1;                             %Observation matrix (added for future works if needed)

%% Filter Loop
for i=2:N
 % time update
   X_pred =Y(i-1);               %Predictions for state vector
   P_pred =(A*P(i-1)*A')+Q;      %and error covariance
   K      = P_pred./(P_pred + R);   %Computing the Kalman Gain
% measurment update
   Y(i)   = X_pred + (K*(X(i)-X_pred));  %Filtered data
   P(i)   = (1-K) * P_pred;              %A postreori error covariance
% Saving the Kalman Gain values
   KG(i)  = K ;
end
```

10.3. Trilateration Algorithm. Example based on the small room scenario with the usage of Kalman filter

```
%% Collecting the data from the beacons and filtration
%loading the measurements from the three beacons
load('RSSI_values.mat')
%Parameters
t=0:99;
n=length(t);
Q=1e-6; %process noise covariance

%first beacon
%Adding the corresponding values of the beacon
X1=RSSI_values(1,:);
%Filtration of the data with Kalman Filter
[Y1,KG1,P1]=Kalman_Filter(X1,Q);
% figure of the first beacon signal (filtered and Unfiltered)
subplot(3,1,1)
 plot(t,X1,'r--','MarkerSize',1.2), hold on, plot(t,Y1,'b'),title('Beacon C'),
legend('Unfiltered''Filtered'), grid on,
 hold on

 %second beacon
 %Adding the corresponding values of the beacon
X2= RSSI_values (2,:);
%Filtration of the data with Kalman Filter
[Y2,KG2,P2]=Kalman_Filter(X2,Q);
% figure of the second beacon signal (filtered and Unfiltered)
subplot(3,1,2)
 plot(t,X2,'r--','MarkerSize',1.2), hold on, plot(t,Y2,'b'),title('Beacon F'),
legend('Unfiltered','Filtered'), grid on,
```

```
 hold on

 %third beacon
  %Adding the corresponding values of the beacon
X3= RSSI_values (1,:);
%Filtration of the data with Kalman Filter
[Y3,KG3,P3]=Kalman_Filter(X3,Q);
% figure of the third beacon signal (filtered and Unfiltered)
subplot(3,1,3)
 plot(t,X3,'r--','MarkerSize',1.2), hold on, plot(t,Y3,'b'),title('Beacon E'),
legend('Unfiltered','Filtered'), grid on,

%% Convert the RSSI to distance
d1 = (10.^((-58.5 - Y1)/(10*3.921)));
d2 = (10.^((-58.5 - Y2)/(10*3.921)));
d3 = (10.^((-58.5 - Y3)/(10*3.921)));
height=0.95; %Distance from mobile node to the ceiling
%Find the projection of the mobile node in 2d plane
err1=((sqrt((d1).^2-height^2)));
err2=((sqrt((d2).^2-height^2)));
err3=((sqrt((d3).^2-height^2)));

%% Trilateration Algorithm
%Adding Beacons coordinates
Reader = [0.68, 3.17; 3.81, 3.36; 3.82, 0.28];
%Adding room`s size
figure
rectangle('Position',[0 0 4.1 3.6])
hold on
%Plotting beacons position
scatter(getcolumn(Reader(1:3,1:2),1),getcolumn(Reader(1:3,1:2),2), 'MarkerEdgeColor', ...
```

```
 [1 0.5 0], 'MarkerFaceColor', [1 0.5 0]);figure(gcf), hold on
grid on;
hold on
%plot of the circles around the beacons
Distance = [(err1); (err2); (err3)];
%http://www.mathworks.com/matlabcentral/fileexchange/2876-draw-a-circle
circle([0.68, 3.17],Distance(1), 1000,'-');figure(gcf)
circle([3.81, 3.36],Distance(2),1000, '-');figure(gcf)
circle([3.82, 0.28],Distance(3), 1000, '-');figure(gcf)
x = zeros(1,50);
y = zeros(1,50);

[x,y] = Two_d_trilateration(repmat(Reader(1,1),1, 100), repmat(Reader(2, 1),1, 100),...
repmat(Reader(3,1),1, 100) , repmat(Reader(1, 2),1, 100), repmat(Reader(2, 2),1, 100),...
repmat(Reader(3, 2),1, 100), Distance(1,:), Distance(2,:), Distance(3,:));
```

10.4. Fingerprint algorithm in practice – Example based on the big room scenario with the usage of Kalman filter

```
%Loading the RSSI values from the beacons
load('RSSI_values.mat')
Q=1e-6; %process noise covariance
%Giving the corresponding values from each beacon as e_UN is unfiltered
%data from beacon E
e_UN=RSSI_values(1,:);
c_UN=RSSI_values(3,:);
f_UN=RSSI_values(2,:);
%Filtration of the data
[f,Kf_kk1,Pf_kk1]=Kalman1D(f_UN,Q);
[c,Kf_kk2,Pf_kk2]=Kalman1D(c_UN,Q);
[e,Kf_kk3,Pf_kk3]=Kalman1D(e_UN,Q);

n=numel(e);
%Assigning RSSI ranges for all of the 12 areas from the scenario
for ii=1:n
   %Area A
   if (e(ii)>=-81) && (e(ii)<=-75)  && (c(ii)<=-78)
      y(ii)=1;
      b(ii)=1;
   %Area B
   elseif  (f(ii)>=-74)
      y(ii)=2;
      b(ii)=2;
   %Area C
   elseif  (c(ii)<=-78) && (f(ii)>=-80) && (f(ii)<=-72)
      y(ii)=3;
      b(ii)=3;

   %Area D
   elseif (e(ii)<=-81) && (c(ii)<=-74) && (c(ii)>=-78)
      y(ii)=4;
      b(ii)=4;
   %Area E
   elseif (e(ii)<=-81) && (c(ii)<=-68) && (c(ii)>=-74)
      y(ii)=5;
      b(ii)=5;
   %Area F
   elseif (e(ii)<=-75) && (e(ii)>=-81) && (c(ii)<=-68) && (c(ii)>=-74)  && (e(ii)<=-75) ...
&& (e(ii)>=-81)
       y(ii)=6;
```

```
        b(ii)=6;
    %Area G
    elseif (c(ii)<=-74) && (c(ii)>=-78) && (f(ii)>=-80) && (f(ii)<=-72)
        y(ii)=7;
        b(ii)=7;
    %Area H
    elseif (e(ii)<=-68) && (e(ii)>=-75) && (c(ii)<=-78)
        y(ii)=8;
        b(ii)=8;
    %Area I
    elseif (e(ii)>=-67)
        y(ii)=9;
        b(ii)=9;
    %Area J
    elseif (e(ii)<=-68) && (e(ii)>=-75) && (f(ii)<=-80)
        y(ii)=10;
        b(ii)=10;
    %Area K
    elseif (c(ii)<=-68) && (c(ii)>=-74) && (f(ii)<=-72)  && (f(ii)>=-80) && (e(ii)<=-75) ...
&& (e(ii)>=-81)
        y(ii)=11;
        b(ii)=11;
    %Area L
    elseif  (c(ii)>=-69)
        y(ii)=12;
        b(ii)=12;
    else
        y(ii)=y(ii-1);
        b(ii)=b(ii-1);
    end
end

%Creating a figure with the 12 areas
txt1 = 'Area A';
t = text(0.5,1.8,txt1);
t(1).Color = 'red';
t(1).FontSize = 14;
txt2 = 'Area B';
t1 = text(2.5,1.8,txt2);
t1(1).Color = 'red';
t1(1).FontSize = 14;
txt3 = 'Area C';
t3 = text(4.5,1.8,txt3);
t3(1).Color = 'red';
t3(1).FontSize = 14;
txt4 = 'Area D';
```

```
t4 = text(6.5,1.8,txt4);
t4(1).Color = 'red';
t4(1).FontSize = 14;
txt5 = 'Area E';
t5 = text(6.5,3.8,txt5);
t5(1).Color = 'red';
t5(1).FontSize = 14;
txt6 = 'Area F';
t6 = text(4.5,3.8,txt6);
t6(1).Color = 'red';
t6(1).FontSize = 14;
txt7 = 'Area G';
t7 = text(2.5,3.8,txt7);
t7(1).Color = 'red';
t7(1).FontSize = 14;
txt8 = 'Area H';
t8 = text(0.5,3.8,txt8);
t8(1).Color = 'red';
t8(1).FontSize = 14;
txt9 = 'Area I';
t9 = text(0.5,5.8,txt9);
t9(1).Color = 'red';
t9(1).FontSize = 14;
txt10 = 'Area J';
t10 = text(2.5,5.8,txt10);
t10(1).Color = 'red';
t10(1).FontSize = 14;
txt11 = 'Area K';
t11 = text(4.5,5.8,txt11);
t11(1).Color = 'red';
t11(1).FontSize = 14;
txt12 = 'Area L';
t12 = text(6.5,5.8,txt12);
t12(1).Color = 'red';
t12(1).FontSize = 14;
hold on
rectangle('Position',[0 0 8 6]);
rectangle('Position',[0 0 2 2]);
rectangle('Position',[2 0 2 2]);
rectangle('Position',[4 0 2 2]);
rectangle('Position',[6 0 2 2]);
rectangle('Position',[0 2 2 2]);
rectangle('Position',[2 2 2 2]);
rectangle('Position',[4 2 2 2]);
rectangle('Position',[6 2 2 2]);
rectangle('Position',[0 4 2 2]);
```

```
rectangle('Position',[2 4 2 2]);
rectangle('Position',[4 4 2 2]);
rectangle('Position',[6 4 2 2]);
hold on



p=numel(y);
%possibilities for scatter plot for later ease
for i=3:p
    if b(i)==1
        n=1;
        m=1;
    elseif b(i)==2
        n=3;
        m=1;
    elseif b(i)==3
        n=5;
        m=1;
    elseif b(i)==4
        n=7;
        m=1;
    elseif b(i)==5
        n=7;
        m=3;
    elseif b(i)==6
        n=5;
        m=3;
    elseif b(i)==7
        n=3;
        m=3;
    elseif b(i)==8
        n=1;
        m=3;
    elseif b(i)==9
        n=1;
        m=5;
    elseif b(i)==10
        n=3;
        m=5;
    elseif b(i)==11
        n=5;
        m=5;
    elseif b(i)==12
        n=7;
        m=5;
```

```
    end
end


%Plotting the coordinates from the corresponding filtered signals
for i=3:p
%Area A
    if y(i)==1
        if  y(i-1)==1 || y(i-1)==2 || y(i-1)==7 || y(i-1)==8
            scatter(1,1)  ,hold on
            pause(1)
            scatter(1,1,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaB
    elseif y(i)==2
        if (y(i-1)==1 || y(i-1)==2 || y(i-1)==3 || y(i-1)==6 || y(i-1)==7 || y(i-1)==8)
            scatter(3,1)  ,hold on
            pause(1)
            scatter(3,1,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaC
    elseif y(i)==3
        if (y(i-1)==2 || y(i-1)==3 || y(i-1)==4 || y(i-1)==5 || y(i-1)==6 || y(i-1)==7)
            scatter(5,1)  ,hold on
            pause(1)
            scatter(5,1,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaD
    elseif y(i)==4
        if (y(i-1)==3 || y(i-1)==4 || y(i-1)==5 || y(i-1)==6)
            scatter(7,1)  ,hold on
```

```
            pause(1)
            scatter(7,1,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(0.2)
            scatter(n,m,'w')  ,hold on
        end
%areaE
    elseif y(i)==5
        if  (y(i-1)==3 || y(i-1)==4 || y(i-1)==5 || y(i-1)==6 || y(i-1)==12)
            scatter(5,3)  ,hold on
            pause(1)
            scatter(5,3,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaF
    elseif y(i)==6
        if (y(i-1)==2 || y(i-1)==3 || y(i-1)==4 || y(i-1)==5 || y(i-1)==6 || y(i-1)==7 || y(i-1)==11 )
            scatter(5,3)  ,hold on
            pause(1)
            scatter(5,3,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaG
    elseif y(i)==7
        if (y(i-1)==1 || y(i-1)==2 || y(i-1)==3 || y(i-1)==6 || y(i-1)==7 || y(i-1)==8)
            scatter(3,3)  ,hold on
            pause(1)
            scatter(3,3,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaH
    elseif y(i)==8
```

```
        if (y(i-1)==1 || y(i-1)==2 || y(i-1)==7 || y(i-1)==8 || y(i-1)==9)
            scatter(1,3)  ,hold on
            pause(1)
            scatter(1,3,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaI
    elseif y(i)==9
        if (y(i-1)==8 || y(i-1)==9 || y(i-1)==10)
            scatter(1,5)  ,hold on
            pause(1)
            scatter(1,5,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaJ
    elseif y(i)==10
        if (y(i-1)==9 || y(i-1)==10 || y(i-1)==11)
            scatter(3,5)  ,hold on
            pause(1)
            scatter(3,5,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
%areaK
    elseif y(i)==11
        if(y(i-1)==6 || y(i-1)==10 || y(i-1)==11)
            scatter(5,5)  ,hold on
            pause(1)
            scatter(5,5,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end
```

```
%areaL
    elseif y(i)==12
        if (y(i-1)==5 || y(i-1)==12)
            scatter(7,5)  ,hold on
            pause(1)
            scatter(7,5,'w')  ,hold on
        else
            b(i)=b(i-1);
            scatter(n,m)
            pause(1)
            scatter(n,m,'w')  ,hold on
        end

        %Constrains for the possible movement from area to another area
    elseif  y(i-2)==1 && y(i-1)==1 && y(i)~=1 && y(i)~=2 && y(i)~=8 && y(i)~=7
        scatter (2,2), hold on
        pause(1)
        scatter (2,2,'w'), hold on
    elseif  y(i-2)==2 && y(i-1)==2 && y(i)~=1 && y(i)~=2 && y(i)~=3 && y(i)~=6...
 && y(i)~=7 && y(i)~=8
        scatter (3,2), hold on
        pause(1)
        scatter (3,2,'w'), hold on
    elseif  y(i-2)==3 && y(i-1)==3 && y(i)~=2 && y(i)~=3 && y(i)~=4 && y(i)~=5...
 && y(i)~=6 && y(i)~=7
        scatter (5,2), hold on
        pause(1)
        scatter (5,2,'w'), hold on
    elseif  y(i-2)==4 && y(i-1)==4 && y(i)~=3 && y(i)~=4 && y(i)~=5 && y(i)~=6
        scatter (6,2), hold on
        pause(1)
        scatter (6,2,'w'), hold on
    elseif  y(i-2)==5 && y(i-1)==5 && y(i)~=3 && y(i)~=4 && y(i)~=5 && y(i)~=6...
 && y(i)~=12
        scatter (6,3), hold on
        pause(1)
        scatter (6,3,'w'), hold on
    elseif y(i-2)==6 && y(i-1)==6 && y(i)~=2 && y(i)~=3 && y(i)~=4 && y(i)~=5 &&...
y(i)~=6 && y(i)~=7  && y(i)~=11 && y(i)~=12
        scatter (5,3.5), hold on
        pause(1)
        scatter (5,3.5,'w'), hold on
    elseif  y(i-2)==7 && y(i-1)==7 && y(i)~=1 && y(i)~=2 && y(i)~=3 && y(i)~=6...
 && y(i)~=7 && y(i)~=8
        scatter (3,3.5), hold on
        pause(1)
```

```
        scatter (3,3.5,'w'), hold on
    elseif  y(i-2)==8 && y(i-1)==8 && y(i)~=1 && y(i)~=2 && y(i)~=7 && y(i)~=8...
 && y(i)~=9
        scatter (2,3), hold on
        pause(1)
        scatter (2,3,'w'), hold on
    elseif  y(i-2)==9 && y(i-1)==9 && y(i)~=8 && y(i)~=9 && y(i)~=10
        scatter (2,4), hold on
        pause(1)
        scatter (2,4,'w'), hold on
    elseif  y(i-2)==10 && y(i-1)==10 && y(i)~=7  && y(i)~=9 && y(i)~=10 && y(i)~=11
        scatter (3,4), hold on
        pause(1)
        scatter (3,4,'w'), hold on
    elseif  y(i-2)==11 && y(i-1)==11  && y(i)~=6 &&  y(i)~=10
        scatter (5,4), hold on
        pause(1)
        scatter (5,4,'w'), hold on
    elseif  y(i-2)==12 && y(i-1)==12 && y(i)~=5  && y(i)~=12
        scatter (6,4), hold on
        pause(1)
        scatter (6,4,'w'), hold on
    end
end
```

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