<u>ISTANBUL TECHNICAL UNIVERSITY</u>

<u>ELECTRICAL-ELECTRONICS ENGINEERING FACULTY</u>

DISTANCE ESTIMATION USING RECEIVED SIGNAL STRENGTH FOR RFID TRACKING SYSTEM

BSc Thesis by

Ramazan Aktaş

040100521

Department: Electronics and Communication Engineering

Programme: Electronics and Communication Engineering

Supervisor: Assoc. Prof. Dr. S. Berna Örs Yalçın

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ACKNOWLEDGE

First of all, I really want to give my endless thanks to my supervisor, Assoc. Prof. Dr. S. Berna Örs Yalçın for giving advice, sparing her precious time and sharing her knowledge with me. Also, I would like to express my gratitude to my project team members: Oğuzhan Çik, Alp Oran and Onur Azbar for their supports and efforts.

Finally, I really appreciate the efforts of my friends and especially my family who always supported my decisions and stood with me throughout my life.

May, 2015 Ramazan Aktaş

CONTENTS

ABBREVIATIONS

BaaS	: Building as a Service
dBm	: Decibell-milliwatts
FDMA	: Frequency Division Multiple Access
FPGA	: Field Programmable Gate Array
FSK	: Frequency Shift Keying
GFSK	: Gaussian Frequency Shift Keying
GLONASS	: Global Navigation Satellite System
GPS	: Global Positioning System
GUI	: Graphical User Interface
IDE	: Integrated Development Environment
IEEE	: The Institute of Electrical and Electronics Engineers
ISM	: Industrial Scientific and Medical
mW	: Milliwatts
OOK	: On-Off Keying
PCB	: Printed Circuit Board
RF	: Radio Frequency
RFID	: Radio Frequency Identification
RSSI	: Received Signal Strength Indicator
SPI	: Serial Peripheral Interface
SVM	: Support Vector Machine
TDMA	: Time Division Multiple Access
UART	: Universal Asynchronous Receiver Transmitter

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DISTANCE ESTIMATION USING RECEIVED SIGNAL STRENGTH FOR RFID TRACKING SYSTEM

ÖZET

Dış mekanda konum belirlemek için oldukça başarılı sistemler ve teknikler olmasına rağmen bu sistem ve teknikler iç mekanda konum belirlemek için yeterli değildir. Bu başarısızlığın sebebi iç mekandaki materyallerden ve cephe duvarlarından kaynaklı sinyaldeki sönümlenmeler, kırılmalar ve yansımalardır. İç mekanda konum belirlemek popüler bir araştırma konusudur ve bu konuda çeşitli çözümler sunulmuştur. Bunlardan en yaygın olanı radyo frekansıyla haberleşen cihazlar kullanarak konum belirlemektir. Konumu belirleyebilmek için alıcı ve gönderici cihazlar arasındaki mesafe hesaplanmalıdır. Bu hesaplama kesin bir veriden çok yaklaşım şeklinde olmaktadır. Mesafe yaklaşımını yapabilmek için yollanan ve alınan sinyal arasındaki zaman farkından yaklaşım ve alınan sinyalin gücünden yaklaşım gibi farklı yollar kullanılır. Sinyaller arası zaman farkını hesaplamak zor olduğu için sinyal gücünden mesafe kestirimi daha kullanılabilir bir yoldur. Bu amaçla farklı mesafelerde sinyal gücü ölçülür ve ölçüm ortamının yol kaybı katsayısı hesaplanır. Katsayı yardımıyla ortamdaki yol kaybı ve yaklaşık bir mesafe hesaplanır. Hesaplanan bu mesafa konum belirleme algoritmasına sokularak konum belirleme işi gerçeklenir.

DISTANCE ESTIMATION USING RECEIVED SIGNAL STRENGTH FOR RFID TRACKING SYSTEM

SUMMARY

Indoor localization is a problem due to some of reasons: attenuation, refraction, reflection on signal. Most common localization systems are unsuccessful for indoor localization process although they have great success for output localization process. There are various investigations about this problem. Using devices that communicates each other with radio frequencies is the one of the popular ways for solution of the problem. Location can be obtained by using distance between this types of devices, however distance estimation is another problem. There are some different ways to estimate distance like estimation from time difference between sent and received signals and estimation from signal strength of received signal. The way that uses the signal strength of received signal is more suitable for implementation, because calculation of time difference is difficult. The signal strength of received signal is measured for different distances to estimate a path loss exponent for each measurement medium. The path loss exponent is used for calculate path loss in medium. Then, a distance estimation can be realized. After distance is estimated, this data uses for localization in localization algorithms.

1 INTRODUCTION

Localization is one of the most common research topics nowadays. It has two main categories: indoor and outdoor ones [1]. Outdoor localization is realized with high accuracy by using several satellite navigation systems like Global Positioning System (GPS) [2], and GLObal NAvigation Satellite System (GLONASS) [2]. Minimum four satellites are required to detect location in three dimensions. In spite of this success in outdoor localization, GPS is not successful in indoor localization, because it requires a line of sight communication with satellites [1]. However, line of sight communication is hard to achieve due to high interference and shadowing [3]. Radio Frequency IDentification (RFID) based localization systems are designed to handle the communication troubles [3]. Several RFID based positioning methods are used to detect location, but the most common way is triangulation method which based on satellite navigation systems fundamentals. Minimum four tags are needed to detect location in three dimensions. Tags are can be considered as satellites. It will be explained more clearly in next paragraphs.

The European Union carries on a project that is named as Building as a Service (BaaS). BaaS aims creating technologically equipped buildings [4]. According to BaaS, buildings will be controlled, monitored and managed by distinctive systems. The project has some parts like fire detection and alarm, lighting control, and secure access control. Another part of BaaS is evacuation of buildings fast and safely in emergency. Detection of location, determining the number of people in building, and secure communication are basis of this part. Indoor localization is crucial for evacuation of buildings because access to people in emergency is easy if it is known where the people is.

The predicted system includes RFID tags, readers and an operating unit. It is assumed that, tags will be on walls and reader will be mobile as represented in Figure 1.1. Operating unit perform localization process according to taken values from readers. This operating unit can be a computer. However, due to the project is purposed for buildings, high number of readers and tags are required and computer is inadequate. So that, operating unit is planned as a specialized hardware that operates for only localization process. Field Programmable Gate Array (FPGA) is going to be used to overcome this work load.

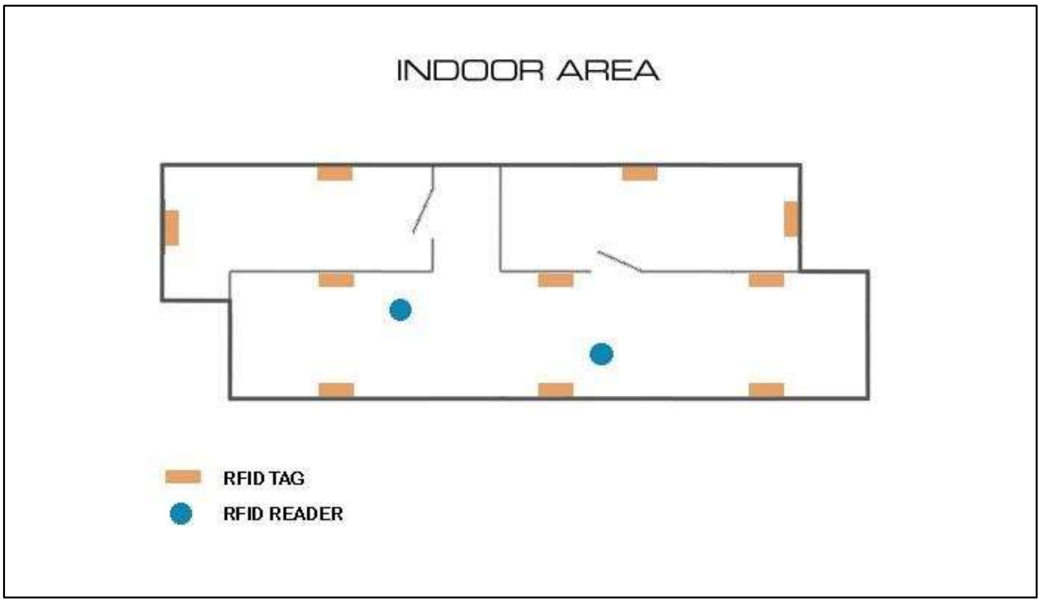

Figure 1.1: System Structure

All of tags and readers are assumed active components, so a microcontroller is required to drive them. These tags and readers have wide communication range which can causes overlapping. Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) modulations are presents as a solution for this problem. A group of tags are driven by a microcontroller and they uses same frequency at different times, which is TDMA modulation [5]. Synchronization problem is prevented by using same microcontroller for tags which are in same group. Frequency of tag groups are different from neighbor tag groups, which is FDMA modulation [5]. So that, overlapping can be prevented and minimum number of microcontroller is used. All system is represented as in Figure 1.2.

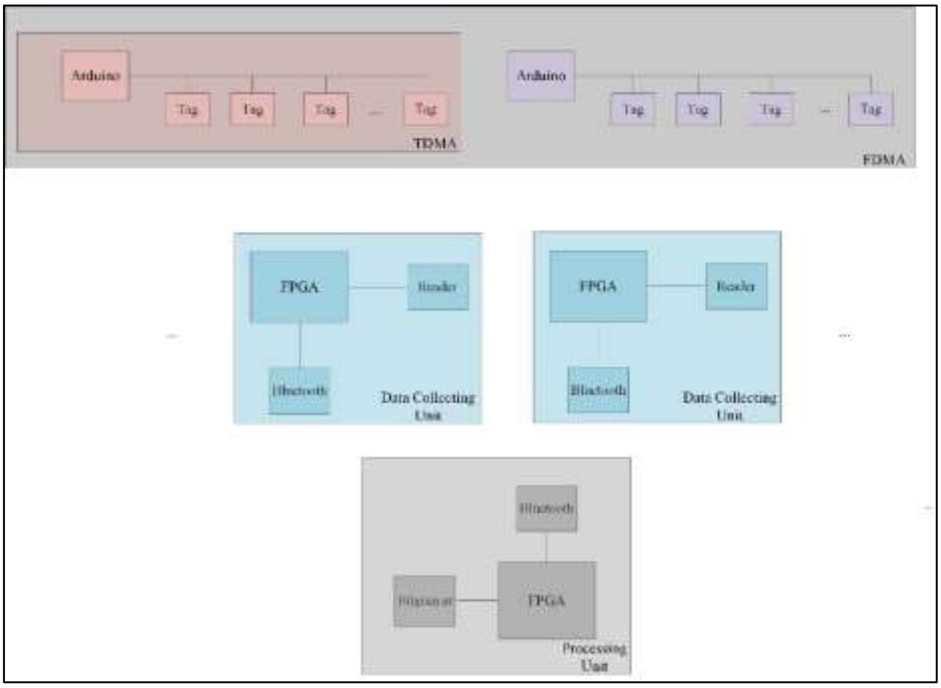

Figure 1.2: All System Work Principle

Work flow of whole project is represented in Figure 1.3 with enumerated blocks. Each block is under responsibility of different team mates. Driving RF (Radio Frequncy) module using Arduino that is the first block is common part. The block enumerated with 2 is part of Oğuzhan Çik. Two distinctive localization algorithms that is enumerated with 4 is realized by Onur Azbar and Alp Oran. The fifth and last block is part of Bahadır Gün. In this case, the block enumerated with 3 is topic of this thesis. This part is about obtain distance from signal power. Work principle of process will be explained in next chapters with details.

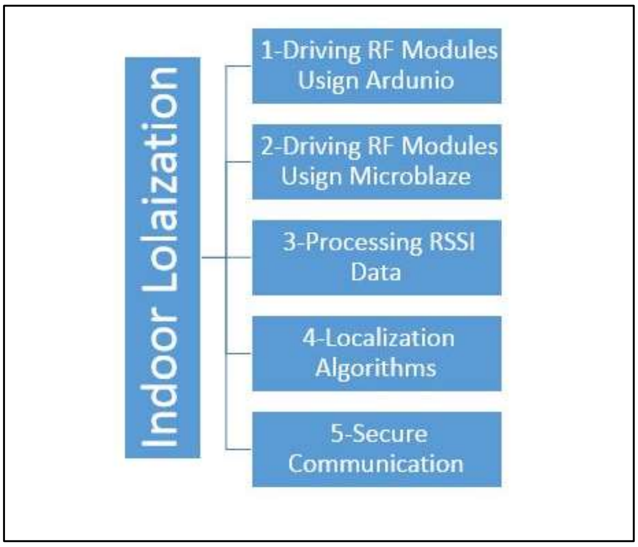

Figure 1.3: Work Flow of Whole Project

2 FUNDAMENTAL DEFINITIONS AND COMPONENTS

All of used applications, components and definitions about process of obtaining distance from received signal strength are explained in this chapter.

2.1 RFM23B

RFM23B is highly integrated, low cost RF transceiver module (Figure 2.1) [6]. Transceiver means that it can act as both of receiver and transmitter. It presents very much features to users. Some of these features are frequency range at 433/470/868/915 MHz ISM (Industrial Scientific and Medical) bands, -121 dBm sensitivity, low power consumption, data rate from 0.123 to 256 kbps, three modulation types that are FSK (Frequency Shift Keying), GFSK (Gaussian Frequency Shift Keying) and OOK (On-Off Keying), digital RSSI (Received Signal Strength Indicator), SPI (Serial Peripheral Interface) communication, wake up timer, configurable packet handler, temperature sensor, temperature range from -40 to +85 °C and on-chip crystal tuning. RFM23B has wide application area because of the abundance of features. Remote control, home security and alarm, home automation and tag readers are only couple of application examples. Digital RSSI output and SPI communication features enable us to prefer RFM23B for this project. The RF module gives an RSSI value between 0 – 255 in decimals which is stored in an 8-bit register with 0.5 dB resolution per bit [6]. The RSSI value is detailed on Section 2.2.

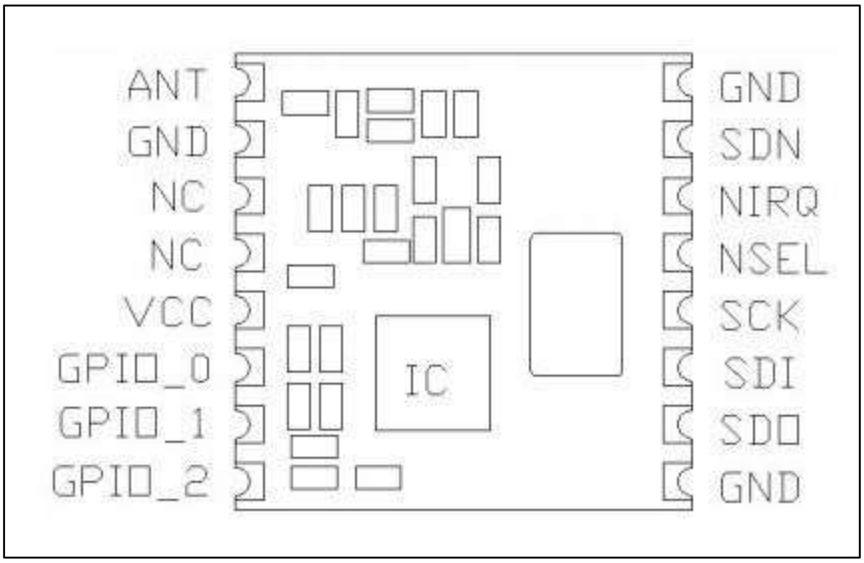

Figure 2.1: RFM23B [6]

This module requires a microcontroller to communicate other modules. Configuration of RF module is controlled by the software on the microcontroller. User can set operating mode, which are transmit and receive modes, modulation types, data rates and so on by the software. The microcontroller communicates with RF module using SPI protocol. Arduino Uno is chosen as a microcontroller because it is programmable and compatible with SPI protocol. Details about Arduino Uno are on Section 2.3.

2.2 RSSI

Received Signal Strength Indicator (RSSI) is a mechanism which is defined by the IEEE 802.11 standard to measure RF signal strength. Although it does not consist any unit, the RSSI represents the strength of RF signal like dBm (decibel-milliwatts) and mW (milliwatts) [7]. RSSI is integer values from 0 to 255 so 256 different signal levels can be defined. However, every producer defines a RSSI_MAX value according to used signal levels. For instance, CISCO uses 101 signal levels that means RSSI_MAX is 100 for CISCO [7].

In this project, distance-RSSI table is estimated according to RSSI of received signals from tags. RSSI changes proportionally to output power of transmitter. For higher output power, the change of RSSI is occurred on longer distances. If the signal strength is required to be in dBm unit, the RSSI can be converted dBm according to producer tables. Firstly RSSI is converted to percentage, then result is searched in the table. As it is stated before, CISCO uses a RSSI_MAX that is 100. Table 2.1 shows dBm conversions of RSSI percentages. Values on the left are RSSI percentage and on the right are dBm.

The RFM23B has no conversion table, however there is a graph in datasheet [6]. This graph is recreated in MATLAB to convert the RSSI value at any point. Original and created graphs can be seen in Figure 2.2 and Figure 2.3 respectively.

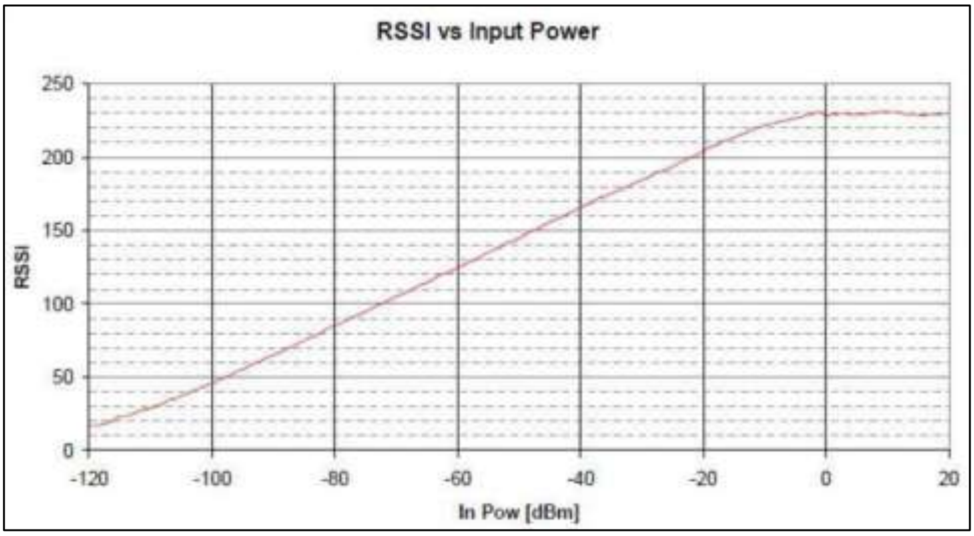

Figure 2.2: RSSI-dBm Graph [6]

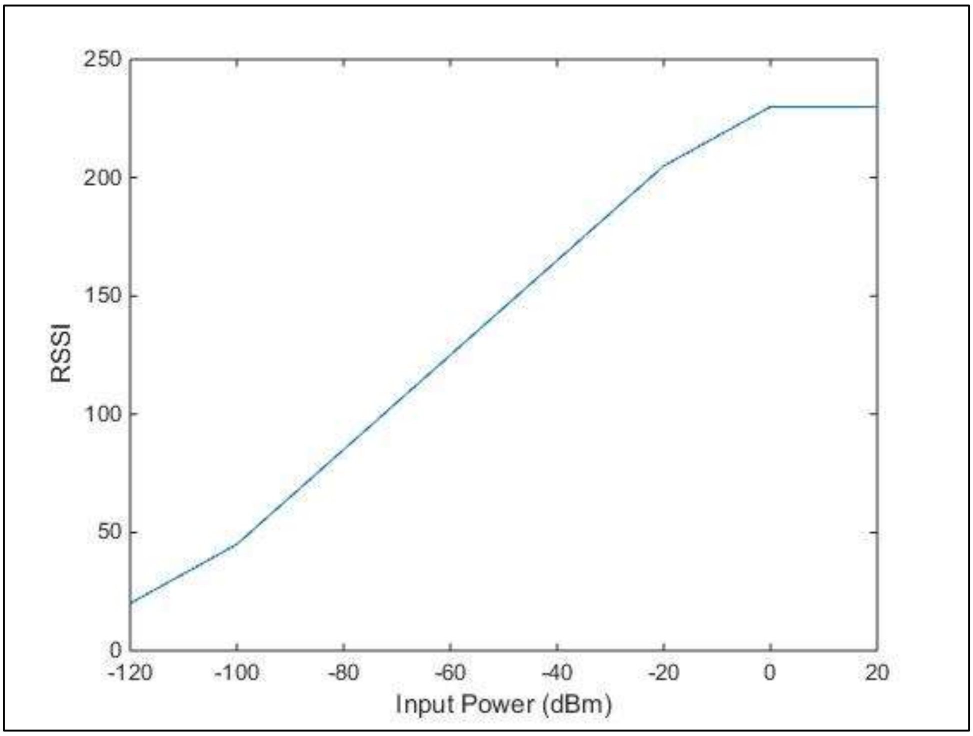

Figure 2.3: Created RSSI-dBm Graph

Table 2.1: CISCO Conversion Table [7]

0	=	-113	34	=	-78	68	=	-41
1	=	-112	35	=	-77	69	=	-40
2	=	-111	36	=	-75	70	=	-39
3	=	-110	37	=	-74	71	=	-38
4	=	-109	38	=	-73	72	=	-37
5	=	-108	39	=	-72	73	=	-35
6	=	-107	40	=	-70	74	=	-34
7	=	-106	41	=	-69	75	=	-33
8	=	-105	42	=	-68	76	=	-32
9	=	-104	43	=	-67	77	=	-30
10	=	-103	44	=	-65	78	=	-29
11	=	-102	45	=	-64	79	=	-28
12	=	-101	46	=	-63	80	=	-27
13	=	-99	47	=	-62	81	=	-25
14	=	-98	48	=	-60	82	=	-24
15	=	-97	49	=	-59	83	=	-23
16	=	-96	50	=	-58	84	=	-22
17	=	-95	51	=	-56	85	=	-20
18	=	-94	52	=	-55	86	=	-19
19	=	-93	53	=	-53	87	=	-18
20	=	-92	54	=	-52	88	=	-17
21	=	-91	55	=	-50	89	=	-16
22	=	-90	56	=	-50	90	=	-15
23	=	-89	57	=	-49	91	=	-14
24	=	-88	58	=	-48	92	=	-13
25	=	-87	59	=	-48	93	=	-12
26	=	-86	60	=	-47	94	=	-10
27	=	-85	61	=	-46	95	=	-10
28	=	-84	62	=	-45	96	=	-10
29	=	-83	63	=	-44	97	=	-10
30	=	-82	64	=	-44	98	=	-10
31	=	-81	65	=	-43	99	=	-10
32	=	-80	66	=	-42	100	=	-10
33	=	-79	67	=	-42			

2.3 Arduino Uno

Arduino is very useful programmable electronic board. It is one the most preferred programmable board due to fact that its platform is open source [8]. So, there are very much example projects for Arduino. It has an integrated development environment (IDE). In addition to IDE, Arduino software includes libraries which are written with C/C++ languages. Because the Arduino can be programmed by using C/C++ language, it presents a simple programmable microcontroller platform and this is another reason of its wide usage. New projects using existing libraries are created in IDE on computer (Figure 2.4). IDE allows to listen the USB port and shows the responses by using its serial monitor. Arduino has some of models: Arduino Uno, Arduino Mega, Arduino Leonardo, Arduino Esplora and Arduino Due [8].

Figure 2.4: Arduino IDE

One of the frequently preferred model is Arduino Uno (Figure 2.5). It includes a microcontroller ATmega238, a USB port that provides a connection to the computer, 14 digital input and output pins, 6 analog inputs and a ceramic crystal with 16 MHz [8].

The fact that RF module has a library and sample application codes for Arduino IDE makes using RF module simple. Because of this simple usage and easily accessible open sources, Arduino is used to drive RF modules.

Figure 2.5: Arduino UNO

2.4 MATLAB

MATLAB is an array-based software for numerical computing [9]. It allows processing and plotting data, matrix calculations and algorithm executions. These are some examples of that MATLAB is able to perform. Additional to computing, visualization is another MATLAB operation which makes easy to understand mathematical data by producing pictures in two dimensions and three dimensions. It has wide usage area from economics to engineering. Some examples of engineering applications are digital signal processing, image processing, neural networks, control systems and fuzzy logic. Each application requires a toolbox. MATLAB is also a programming language. Codes can be written in a script file or MATLAB's command window which can be seen in Figure 2.6.

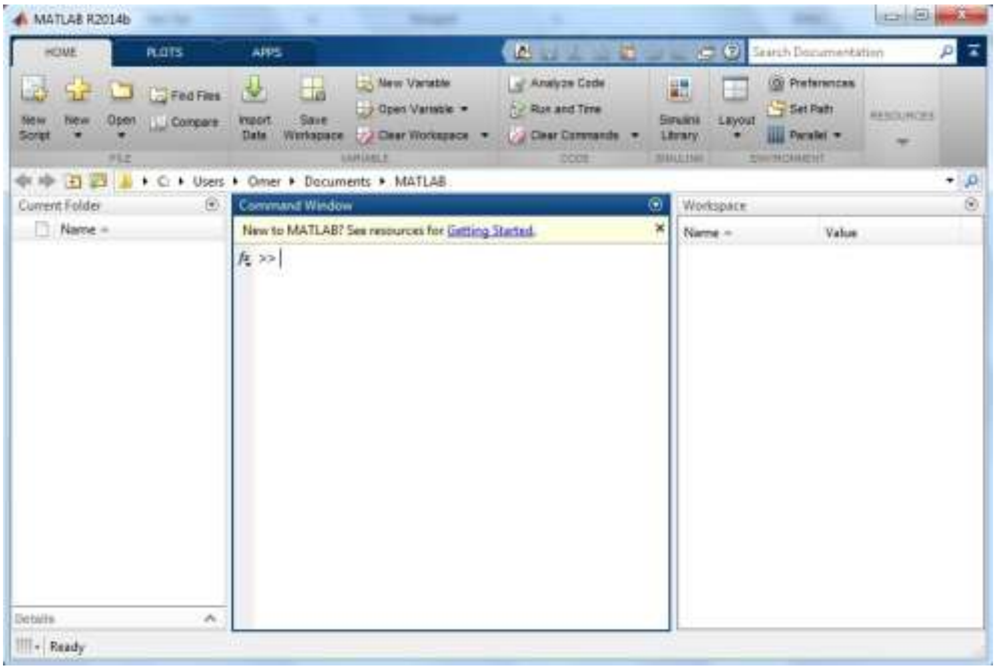

Figure 2.6: MATLAB GUI

In this project, MATLAB is used for distance estimation from RSSI values. One way of distance estimation is tabulating distance according to RSSI values by using mean and variance functions in MATLAB. Another way is calculating path loss of medium according to signal strengths. MATLAB is creating, calculating and monitoring required equations.

2.5 Serial Port Listener Program

A serial port listener program is created by using C# programming language to read, monitor and store RSSI data coming from RF module in Visual Studio IDE as shown in Figure 2.7. The program includes a screen to monitor coming data. Data number can be restricted with number of samples entry. Basically this program listens the communication ports of UART (Universal Asynchronous Receiver Transmitter), monitors data and if needed save data into a .txt file. The program checks whether data count is equal to desired number of samples or not. When it is equal, stops listening the port and asks for saving received data.

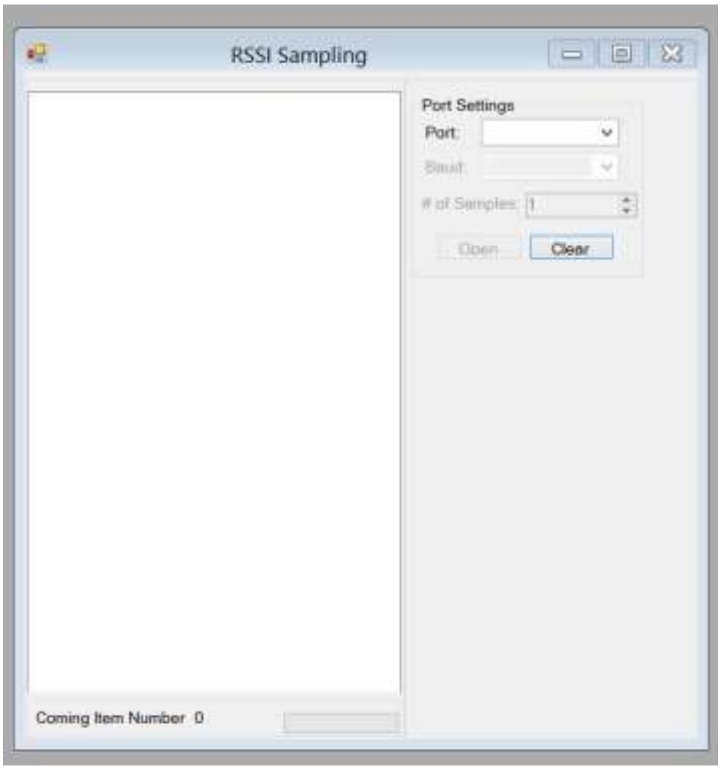

Figure 2.7: Program GUI

2.6 Path Loss

Electromagnetic waves has an attenuation depending on its propagation medium. This attenuation effect is called as path loss of the electromagnetic waves. The calculation of path loss is a tough process due to varying properties of medium such as free space, air, wooden, iron, glass and so on. Path loss has a variable value for indoor environments including different types of materials [11]. So that, the path loss value cannot be known exactly, however it can be estimated by using simple formulations [10]. One of them is given by

$$PL = 10 \times \alpha \times \log_{10}\left(\frac{d}{d_0}\right), \tag{2.1}$$

where d is distance, d_0 is reference distance that is generally 1 meter and α is path loss exponent [10]. The path loss constant α is 2 for free space and it changes depending on medium conditions [11]. where d_{min} and d_{max} are minimum and maximum distances where the received signal strength is measured, $P_r(d_{min})$ and $P_r(d_{max})$ are received signal strengths at this points [10].

Table 2.2 is an example table with measured path loss exponents according to measurement mediums [11]. It can be calculated by using formula that is given by

$$\alpha = \frac{P_r(d_{min}) - P_r(d_{max})}{10 \times \left(\log_{10}\frac{d_{max}}{d_0} - \log_{10}\frac{d_{min}}{d_0}\right)}, \tag{2.2}$$

where d_{min} and d_{max} are minimum and maximum distances where the received signal strength is measured, $P_r(d_{min})$ and $P_r(d_{max})$ are received signal strengths at this points [10].

Table 2.2: Path Loss Exponent for Different Mediums [11]

Environment	*Path Loss Exponent, n*
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

When the path loss is known, received power can be estimated by using formula that is given by

$$P_r(\mathrm{d}) = P_r(d_0) - 10 \times \alpha \times \log_{10}\left(\frac{d}{d_0}\right), \tag{2.3}$$

where $P_r(\mathrm{d})$ is the received signal strength at distance d and $P_r(d_0)$ is the received signal strength at reference point [10].

The distance *d* is formulized from Equation 2.3 and it can be given as

$$\mathrm{d} = 10^{\frac{-(P_r(\mathrm{d}) - P_r(d_0))}{10 \times \alpha}} \times d_0. \tag{2.4}$$

Distance is estimated for each measurement medium using Equation 2.4 after the path loss exponent at the measurement medium is calculated. All of received signal strengths are in unit dBm for equations above.

3 COMMUNICATION of RF MODULE with ARDUINO

The communication between the RF Module and a microcontroller is required to achieve received signal strength. So that, the communication is realized as a first work in two steps: physical set-up and software based configuration.

3.1 Physical Set-Up

The RF module RFM23B is required a microcontroller to be used. As explained before, Arduino Uno is chosen as microcontroller. However, the RF module cannot be drive directly with Arduino when it is purchased because it is a plain module without pin connections. A soldering process is applied to the module and then the module is ready for connecting to Arduino (Figure 3.1). The soldered module had been used for a duration for communication and measurement of signal strength but then a Printed Circuit Board (PCB) was prepared with consideration of measurements can be affected negatively due to soldered ways (Figure 3.2).

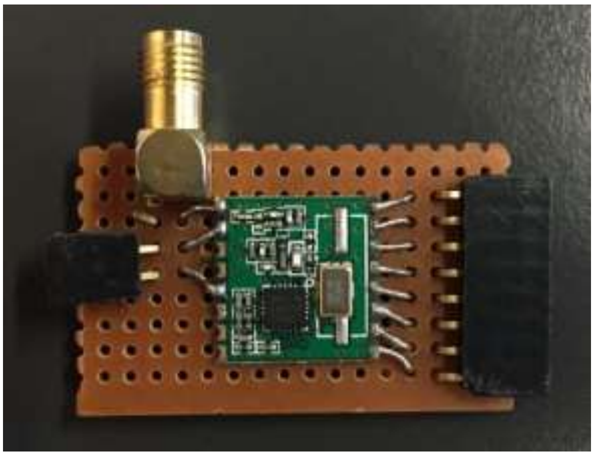

Figure 3.1: RF Module with Soldered Pin Connections

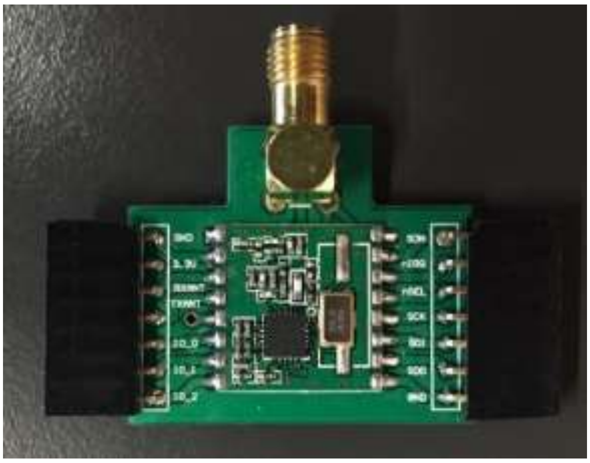

Figure 3.2: RF Module PCB

Arduino Uno and the module communicate with each other by using Serial Peripheral Interface (SPI) protocol [12]. Detailed information about SPI protocol is in part of project that is driving RF modules by using microblaze [13]. Arduino Uno uses 10^{th}, 11^{th}, 12^{th} and 13^{th} pins as SPI pins respectively SS (Slave Select), MOSI (Master Output Slave Input), MISO (Master Input Slave Output) and SCK (Serial Clock) as indicated in Figure 3.3 [14]. SS pin is used to enable or disable slave device, MOSI pin is used to send data to the slave device, MISO pin is used to receive data from slave device and SCK pin is used to synchronize data transmission. SPI pins of Arduino connect related pins in the RF module and this relation can be seen in Figure 3.4.

Arduino Board	MOSI	MISO	SCK	SS (slave)	SS (master)
Uno or Duemilanove	11 or ICSP-4	12 or ICSP-1	13 or ICSP-3	10	-
Mega1280 or Mega2560	51 or ICSP-4	50 or ICSP-1	52 or ICSP-3	53	-
Leonardo	ICSP-4	ICSP-1	ICSP-3	-	-
Due	ICSP-4	ICSP-1	ICSP-3	-	4, 10, 52

Figure 3.3: Arduino SPI Pins for Uno and Other Boards [14]

```
                Arduino      RFM-22B
                GND----------GND-\ (ground in)
                             SDN-/ (shutdown in)
                3V3----------VCC   (3.3V in)
interrupt 0 pin D2-----------NIRQ  (interrupt request out)
         SS pin D10----------NSEL  (chip select in)
        SCK pin D13----------SCK   (SPI clock in)
       MOSI pin D11----------SDI   (SPI Data in)
       MISO pin D12----------SDO   (SPI data out)
                          /--GPIO0 (GPIO0 out to control transmitter antenna TX_ANT
                          \--TX_ANT (TX antenna control in)
                          /--GPIO1 (GPIO1 out to control receiver antenna RX_ANT
                          \--RX_ANT (RX antenna control in)
```

Figure 3.4: RFM22B/23B SPI Pins [12]

3.2 Software Based Configuration

Not only physical connection is not enough for communication between the RF module and Arduino, but a configuration that is created on Arduino IDE is also required. Functions in RF22 library is used for this configuration. The RF22 library includes hardware-SPI and generic-SPI classes. The generic-SPI class is simple base class for SPI interfaces which contains base function definitions for SPI configuration that are illustrated with SPI functions in hardware-SPI class and used in functions of RF22 class. Also RF22 library contains all required functions, register address and mask definitions to make the RF module available. Some important functions with their explanations are given below.

3.2.1 Initialize Function

This function is defined as “init” function and it is for external usage where RF library is included, not used in RF22 library. Every process that can be made by the RF module waits response of init function. If it returns true, that means the initialize is successful and process starts. Otherwise the process does not start.

Initialize function is crucial because all configurations are realized in this function. Frequently spiWrite function is used in init function. Besides, setFrequency, setModemConfig and setTxPower are other functions used in init function.

3.2.2 Write and Read Functions

These functions are used to write values to register address and read values from register address and defined as “spiWrite” and “spiRead”. Defined write mask is put to “logical or” operation with related register address for the writing process and inverse of the write mask is put to “logical and” operation with related register address for reading process. They use transfer function in hardware-SPI class which transfers data via SPI protocol.

3.2.3 Frequency, Modem and Transmitter Power Setting Functions

These functions are used to setting frequency, modem configuration and transmitter signal output power. Decision of data rate and modulation type (FSK, GFSK or OOK) is taken in modem configuration function. They are defined as “setFrequency”, “setModemConfig” and “setTxPower”.

3.2.4 Read RSSI Function

This function reads the RSSI value from related register address where the RF module stores received signal strength by using spiRead function. It is defined as “rssiRead”.

3.3 Operation Phase

The communication between the RF module and Arduino is started when the physical set-up and configuration are built successfully. After that the RF module can be used as desired by writing code in Arduino IDE. For example, the RF module can be used as a transmitter or receiver.

As a first aim two RF module are communicated with each other. Because, precision of communication between two modules is required before obtaining the RSSI value. A message is sent by one of the RF Module and another receives it**.** After the message is received, an answer is sent by the RF module which receives the first message. This communication is represented as in Figure 3.5 and Figure 3.6. Both of RF modules acts as a transceiver for this communication, but the RF module cannot run in both of receiver and transmitter (transceiver) at same time. RF modules are controlled by a software that is written in Arduino IDE. They change operating mode each time after sending and receiving a message. The RSSI of received message can be easily obtained after the communication is realized by using rssiRead function that is created in software.

Figure 3.5: A Received Message from Client

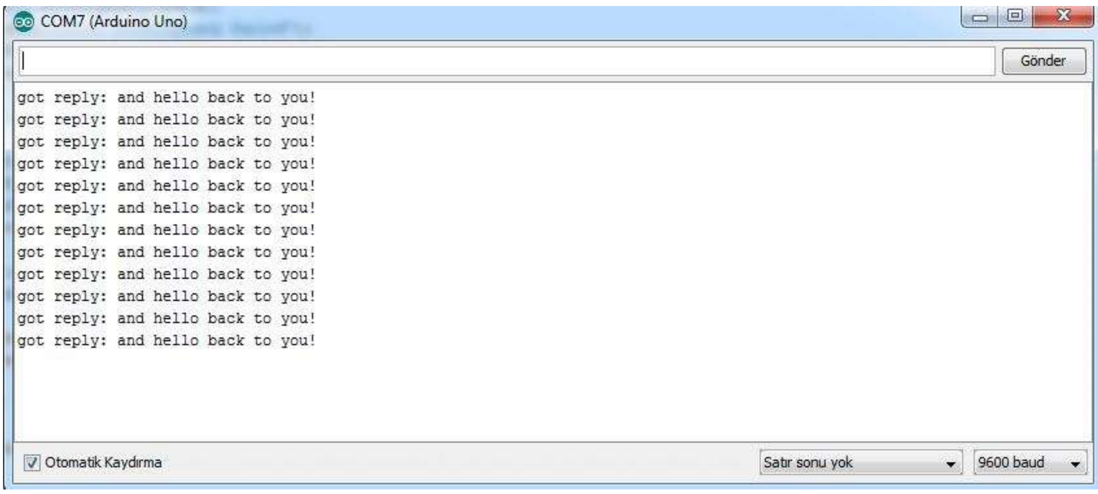

Figure 3.6: Answer of the Server According to Receiving Message

4 PROCESSING THE RSSI VALUES

After the communication between two RF modules is realized, the RSSI values are obtained for different conditions by using codes that are created in Arduino IDE. One of the RF module is set as receiver and another is set as transmitter. There is an infinite loop with a delay in the created code for the transmitter. Delay is measured according to period of the sending signal to prevent overlapping. The RF module which is set as receiver always looks for a message.

The RSSI values are measured in a normal indoor area and a reflectionless room by using the pin soldered RF module that uses cable as an antenna, in a normal indoor area that uses 433 MHz antenna for different transmitter output powers.

Created the serial port listener program is used to save measurements into a txt file and MATLAB is used to calculate mean and variance values from the saved RSSI samples and also it is used for converting the RSSI value to dBm and deriving the distance estimation equation which is given by Equation 2.4.

4.1 Reflectionless Room

Reflectionless room in ITU Electrical and Electronics Faculty Electromagnetic Measurement and Monitoring Laboratory is used to observe changing of signal strength according to distance change. The aim of this measurement is observing the signal reflection effect on measurements. Figure 4.1 shows the experiment medium in the reflectionless room where RF modules are yellow circled. A cable is used as an antenna on the RF module with 7 dBm transmitter signal power in this experiment.

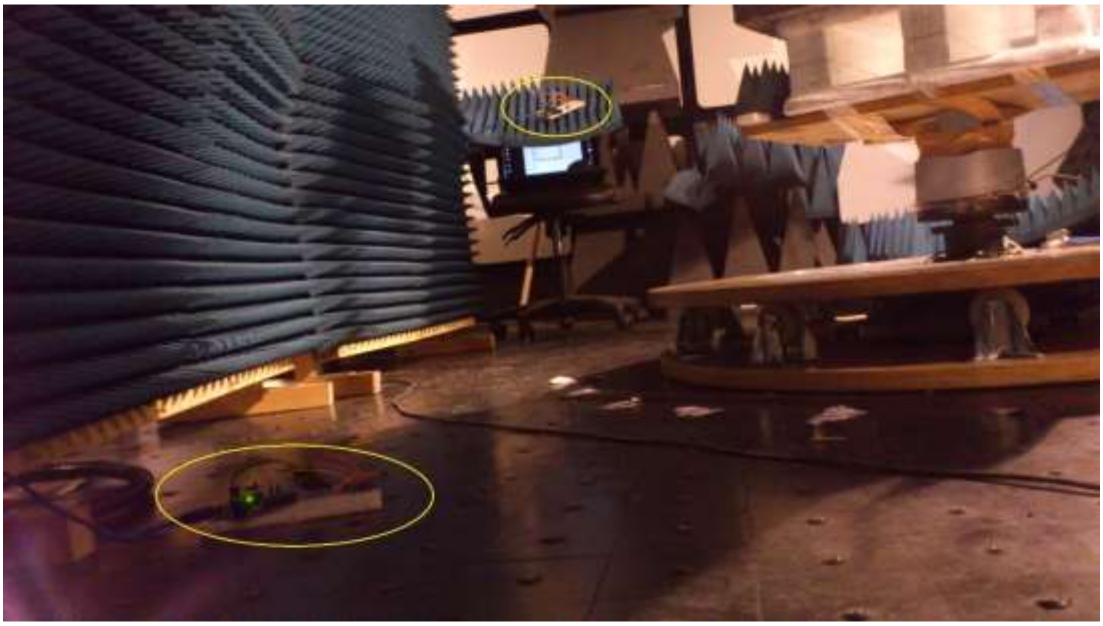

Figure 4.1: Experiment Medium in Reflectionless Room

The RSSI value is measured for three different distances: 5 cm, 100 cm, 150 cm, and 250 cm. Distribution of the RSSI sampling densities at related distances can be seen in Figure 4.2. Because of the limited area, measurements for longer distances cannot be experienced.

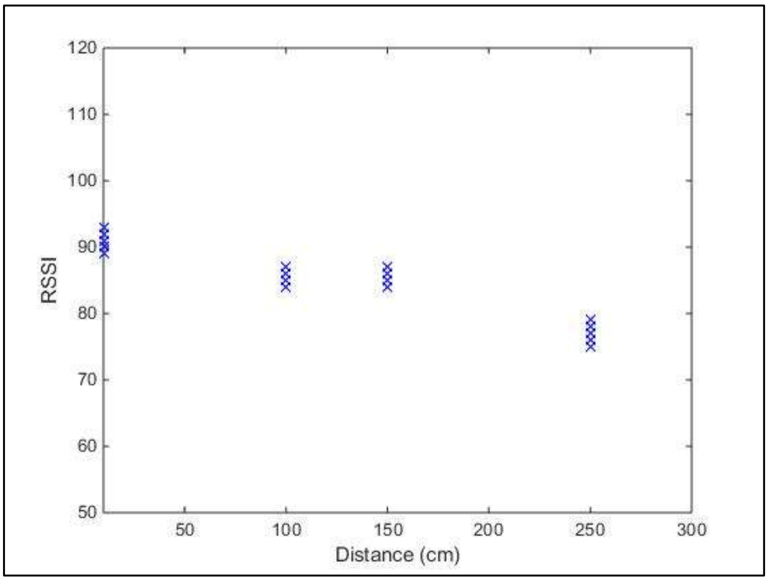

Figure 4.2: RSSI Sampling Density Distribution

According to this experiment, an ordered decreasing on mean of RSSI samples is observed in the reflectionless medium (Figure 4.3). Variance values prove that the RSSI values are scattered in a small region as seen in Figure 4.4.

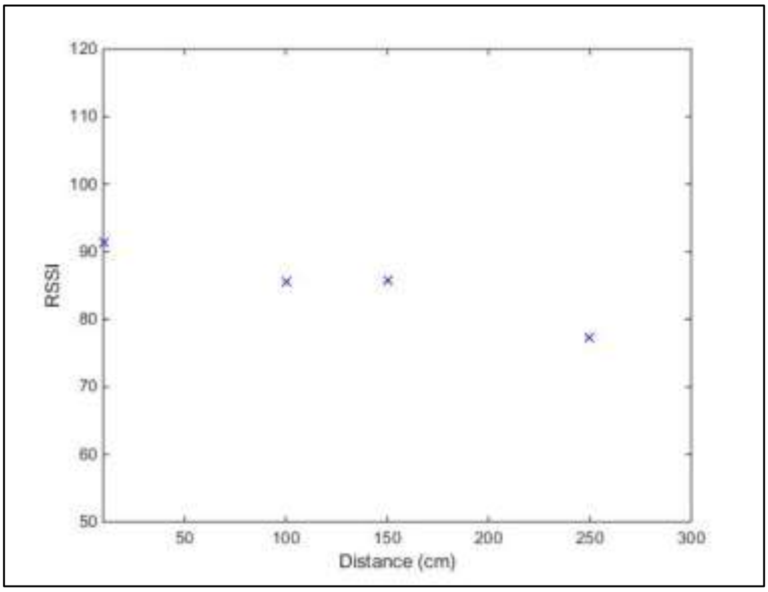

Figure 4.3: Mean of RSSI Samples

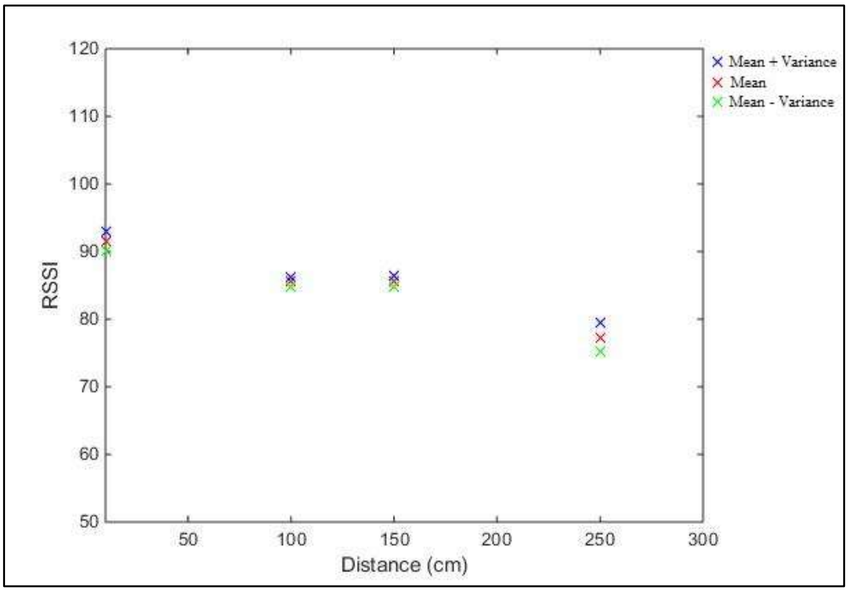

Figure 4.4: Mean with Variance of RSSI Samples

Means and variances are listed in Table 4.1 according to related distance. Figure 4.3 and Table 4.1 show that the RSSI has visible decreasing on 1 meter distance change. It is approximately same at distances 100 cm and 150 cm. However, it decreases at distance 250 cm.

Table 4.1: Distance- RSSI Mean and Variance Table

Distance (cm)	Mean (RSSI)	Mean (dBm)	Variance (RSSI)
10	91.4667	-76.73	1.4095
100	85.5333	-79.73	0.6952
150	85.6667	-79.68	0.8095
250	77.3333	-83.81	2.0952

A measurement at 10 cm is realized outside of the reflectionless room to compare it with the measurement at 10 cm that is realized inside of the reflectionless room. Mean is calculated as 97.200 in this conditions which is more than result in reflectionless room. Reflections can cause this difference.

4.2 7 dBm Signal Output Power

The RF module PCB is used with the 434 MHz antenna and 7 dBm transmitter signal power in this experiment. Received signal strengths are measured in the Electrical and Electronics Faculty corridor (Figure 4.5). 2000 RSSI samples are taken at distances from 50 cm to 500 cm and its distribution is shown in Figure 4.6. Increase and spread in the RSSI is observed. Using antenna caused increment on the RSSI and spread can be caused by reflections.

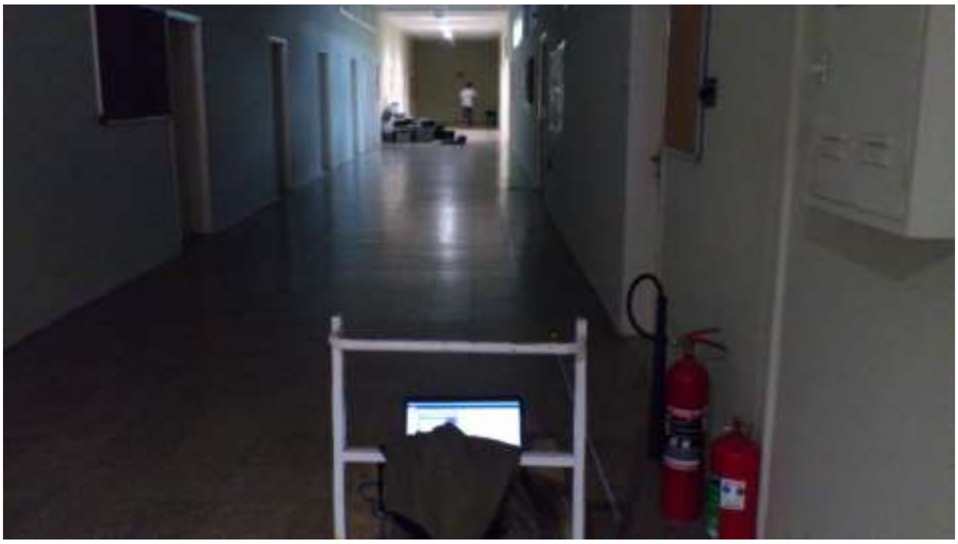

Figure 4.5: The Faculty Corridor

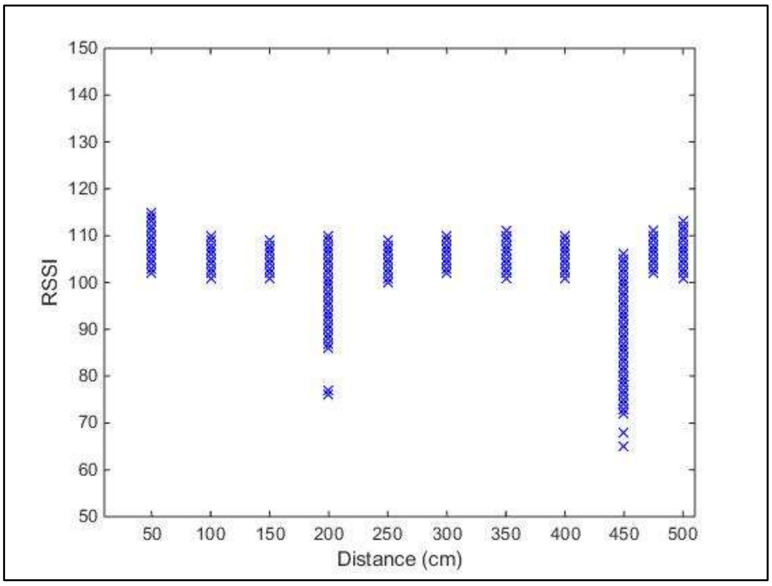

Figure 4.6: RSSI Sampling Density Distribution

Mean is approximately same at all distances except at 450 cm (Figure 4.7). Figure 4.8 shows the means with variance, at 450 cm it spreads in a big region. Because of that communication range of the RF module is longer than 150 m, the RSSI value does not decrease for small distance changes when the transmitter signal power is 7 dBm [2]. It decreased in the reflectionless room because a cable is used as an antenna that caused worse output power performance.

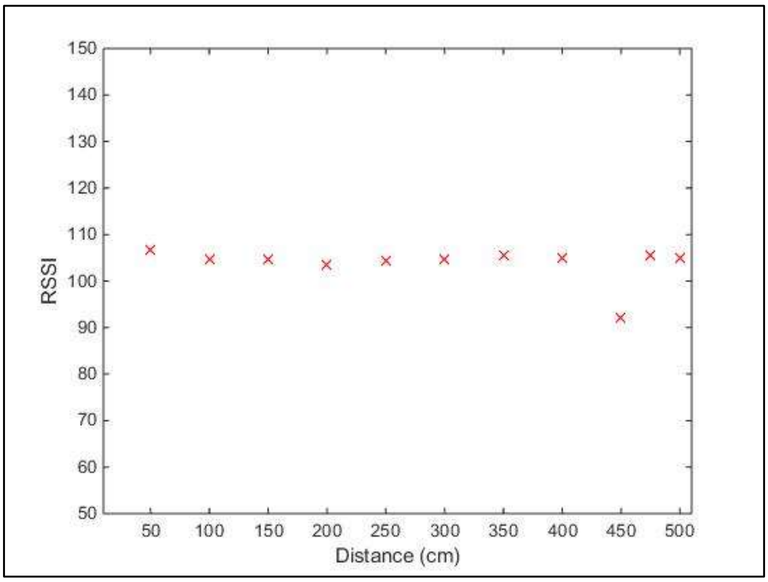

Figure 4.7: Mean of RSSI Samples

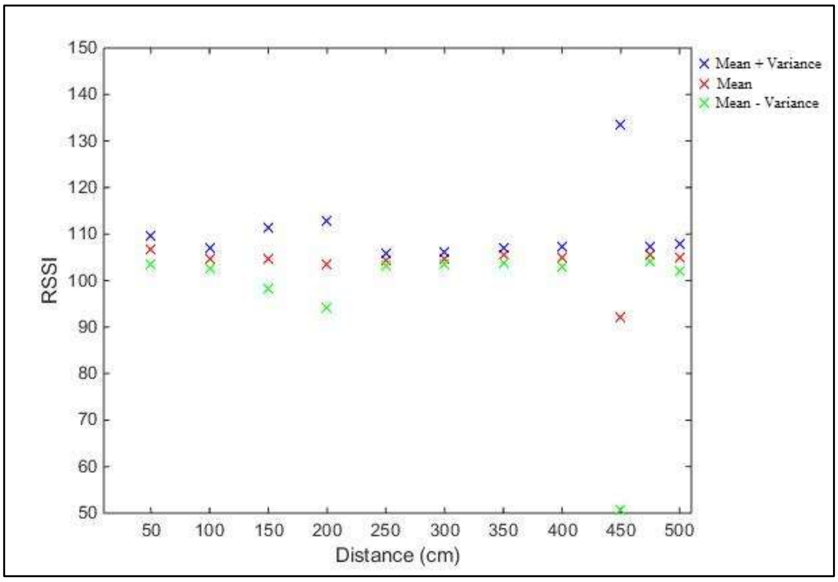

Figure 4.8: Mean with Variance of RSSI Samples

Means and variances are listed in Table 4.2 according to related distance. It shows that distance cannot be estimated when the transmitter signal power is 7 dBm.

Table 4.2: Distance- RSSI Mean and Variance Table

Distance (cm)	**Mean (RSSI)**	**Mean (dBm)**	**Variance (RSSI)**
50	106.6822	-69.21	3.0494
100	104.7084	-70.13	2.1970
150	104.7746	-70.13	6.6327
200	103.5590	-70.7	9.3682
250	104.4200	-70.25	1.3553
300	104.6945	-70.13	1.2838
350	105.4187	-69.8	1.6229
400	104.9945	-70.02	2.1686
450	92.1525	-76.44	41.3149
475	105.6000	-69.66	1.6578
500	104.8475	-70.11	2.9457

4.3 -8 dBm Signal Output Power

Process in section 4.2 is repeated with lower transmitter output power which is -6 dBm in two different mediums: Electricals and Electronics Faculty corridor and the residence. Results are discussed in following subsections.

4.3.1 Measurement in the Faculty Corridor

The RSSI value is measured when the transmitter signal power is -8 dBm in the faculty corridor at distances up to 20 meter. 1000 RSSI values are sampled at each distance (Figure 4.9).

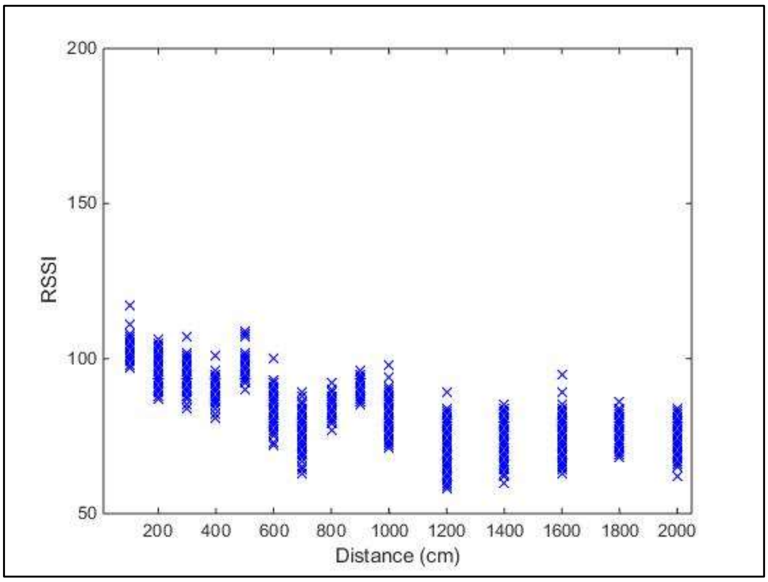

Figure 4.9: RSSI Sampling Density Distribution

When mean values in Figure 4.10 are analyzed, it can be said that the RSSI value decreased at 20 m which is the end point of measurement according to starting point at 50 cm. However, some unordinary increments and decrements are observed, especially at 500 cm, 700 cm and 900 cm. Some unexpected results are observed on RSSI values when samples are being taken under the lamb. The lamb can causes an interference on the signal that is resulted with increment and decrement on RSSI values. According to Figure 4.11, spread on RSSI values is in big regions especially after 10 m.

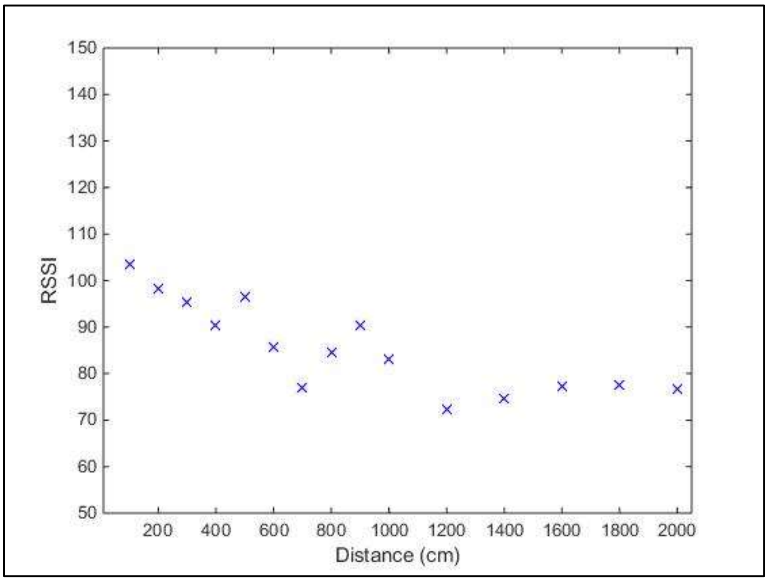

Figure 4.10: Mean of RSSI Samples

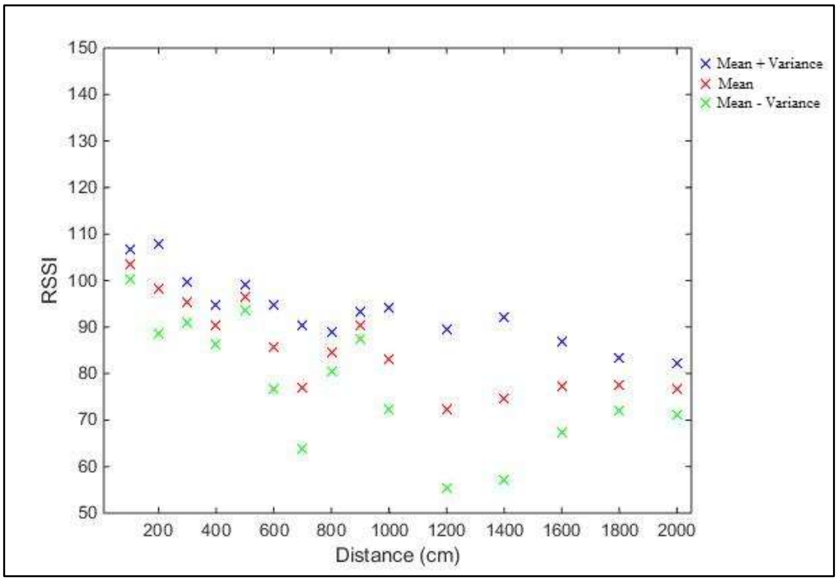

Figure 4.11: Mean with Variance of RSSI Samples

Means and variances are listed in Table 4.3 according to related distance. An exact estimation on distance cannot be realized due to unexpected increments and decrements, however it can be estimated that if the RSSI value is more than 100, the distance is smaller than 2 m and also if it is about 80, probably the distance is in 10 m region.

Table 4.3: Distance- RSSI Mean and Variance Table

Distance (cm)	Mean (RSSI)	Mean (dBm)	Variance (RSSI)
100	103.5800	-70.74	3.2629
200	98.2150	-73.36	9.6624
300	95.2710	-74.83	4.4160
400	90.4980	-77.22	4.1722
500	96.4290	-74.3	2.7897
600	85.7530	-79.71	9.1271
700	77.0820	-83.99	13.2946
800	84.6020	-80.19	4.2679
900	90.3150	-77.38	2.8827
1000	83.1280	-80.97	10.9045
1200	72.4230	-86.33	17.0491
1400	74.7050	-85.18	17.4855
1600	77.2350	-83.9	9.7635
1800	77.5990	-83.69	5.6799
2000	76.6890	-84.2	5.4998

4.3.2 Measurement in the Residence

Measurements are repeated for different medium to observe if there is diversity in results. Figure 4.12 shows the residence medium and experiment devices. 1000 RSSI values are sampled at each distances from 50 cm to 1000 cm (Figure 4.13). A regular decrement can be seen in Figure 4.13, it can be seen in Figure 4.14 more clearly.

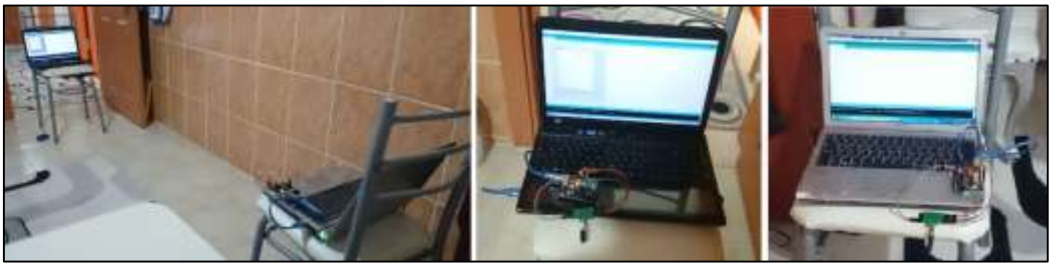

Figure 4.12: Measurement Medium

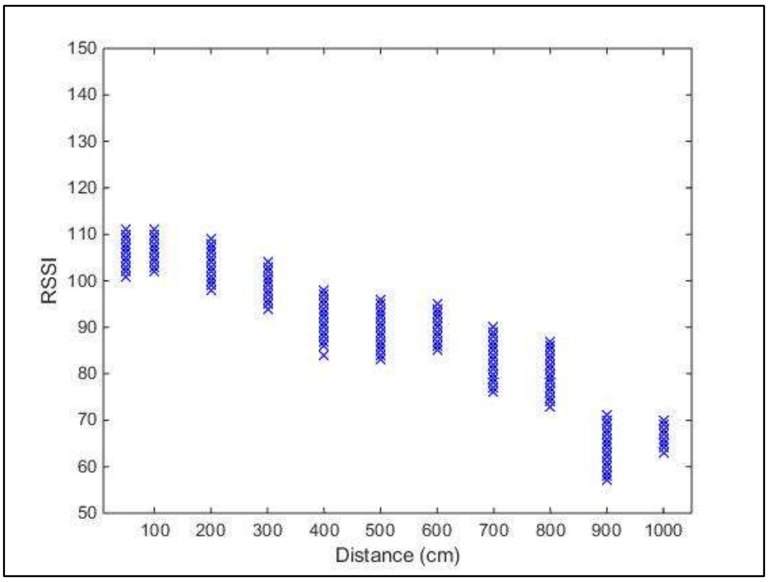

Figure 4.13: RSSI Sampling Density Distribution

Mean values of RSSI values decreased at every 1 m change except 10 m according to Figure 4.14, and also shows that RSSI values are approximately same in 1 m region. As can be seen in Figure 4.15, spread is in a small region for this medium. RSSI values has maximum spreading at 9 m where the decrement order is disorganized.

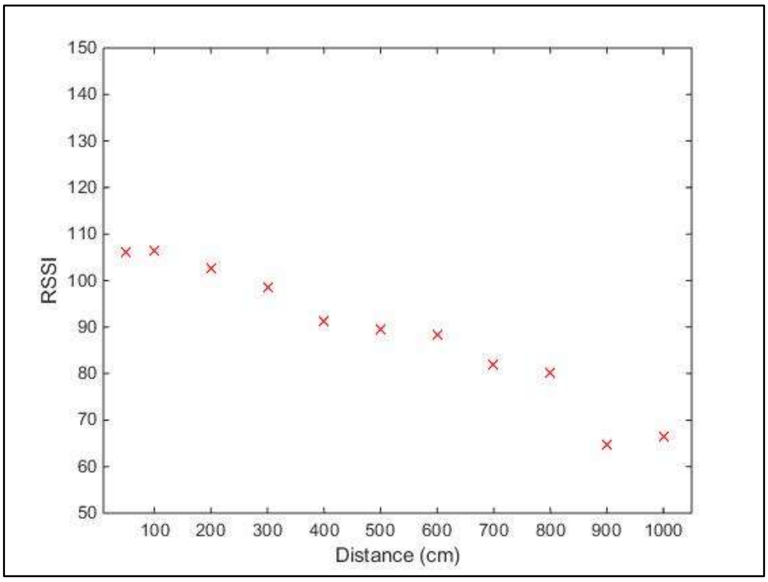

Figure 4.14: Mean of RSSI Samples

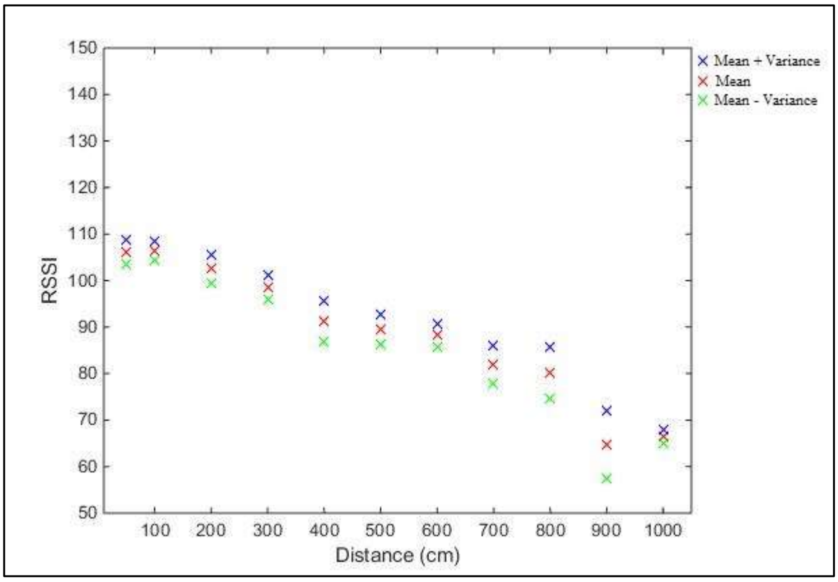

Figure 4.15: Mean with Variance of RSSI Samples

Means and variances are listed in Table 4.4 according to related distance. The distance can be estimated easily at medium of residence with 2 m resolution. There is distinct decrement on the RSSI value at every 2 m.

When Subsections 4.3.1 and 4.3.2 are compared, difference on the change of the RSSI value according to distance can be seen. The residence medium is more proper to make distance estimation.

Table 4.4: Distance- RSSI Mean and Variance Table

Distance (cm)	Mean (RSSI)	Mean (dBm)	Variance (RSSI)
50	106.0780	-69.49	2.5485
100	106.3423	-69.33	2.0530
200	102.5390	-71.23	3.0475
300	98.4925	-73.29	2.6791
400	91.2040	-76.85	4.4488
500	89.4795	-77.73	3.2699
600	88.3280	-78.42	2.4869
700	82.0490	-81.48	4.0887
800	80.2480	-82.37	5.4840
900	64.8158	-90.1	7.2526
1000	66.3620	-89.37	1.4924

4.4 Distance Estimation Using Path Loss Exponent

The path loss exponent of all measurement mediums are calculated using Equation 2.2 and listed in Table 4.5. These path loss exponents are used in Equation 2.4 to estimate distances.

Table 4.5: Path Loss Exponent

Measurement Medium	Path Loss Exponent, α
Free Space [7]	2
The Reflectionless Room (Subsection 4.1)	0.5065
The Faculty Corridor 1 (Subsection 4.2)	0.09
The Faculty Corridor 2 (Subsection 4.3.1)	1.0346
The Residence (Subsection 4.3.2)	1.5280

The path loss exponent is very low for results of the measurement in Subsection 4.2 that means distance estimation is hard in this medium. Measured distance-RSSI and calculated distance-RSSI graphs for this measurement is represented in Figure 4.16. Signal is approximately same while the distance is going to infinite. As a result, an efficient distance estimation cannot be realized if the RF module with 7 dBm transmitter output power is used.

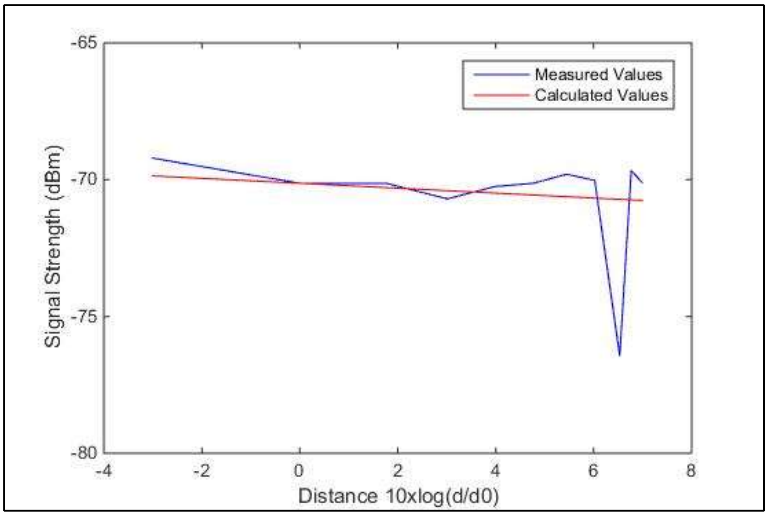

Figure 4.16: Distance-Signal Strength Graph for the Faculty Corridor 1st Measurement

Measured distance-RSSI and calculated distance-RSSI graphs for measurement in the reflectionless room is represented in Figure 4.17. Estimated distances are tabulated in Table 4.6 to have a clear view of Figure 4.17. When the Table 4.6 and Table 4.1 are compared, it can be seen that the distance can be estimated very close to exact value until -82 dBm. For lower signal strengths, there is big deflection. If measurement area was wider, more measurements on different distances can improve the success of estimation.

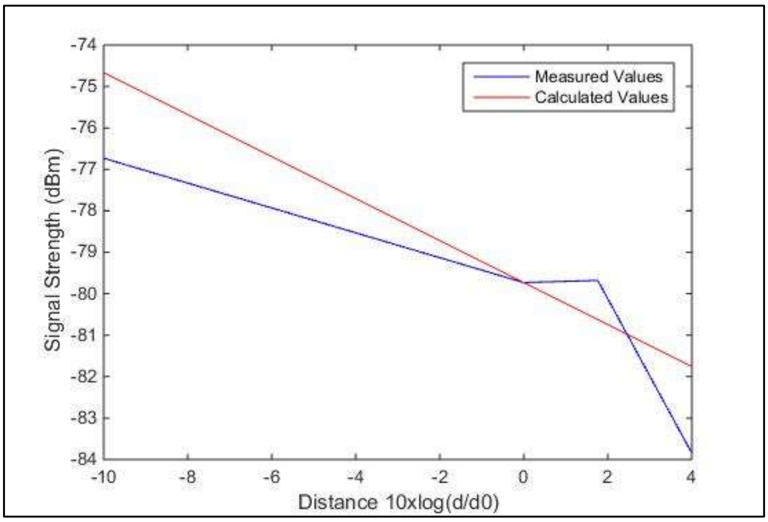

Figure 4.17: Distance-Signal Strength Graph for the Measurement in the Reflectionless Room

Table 4.6: Estimated Distances

Estimated Distances (m)	**Received Signal Strength (dBm)**
0.045	-73
0.07	-74
0.11	-75
0.46	-78
0.72	-79
1.13	-80
1.78	-81
2.81	-82
4.42	-83

The measurement in Subsection 4.3.1 is compared with calculated distance-RSSI relation in Figure 4.18. The path loss exponent is 1.0346 for the medium in Subsection 4.3.1. Decreasing the transmitter output power to -8 dBm is improved the estimation success. Calculated and measured values are nearly same until 4 meter. Table 4.7 lists estimated distances according to RSSI values. When the signal strength is high, estimation is close to the exact value.

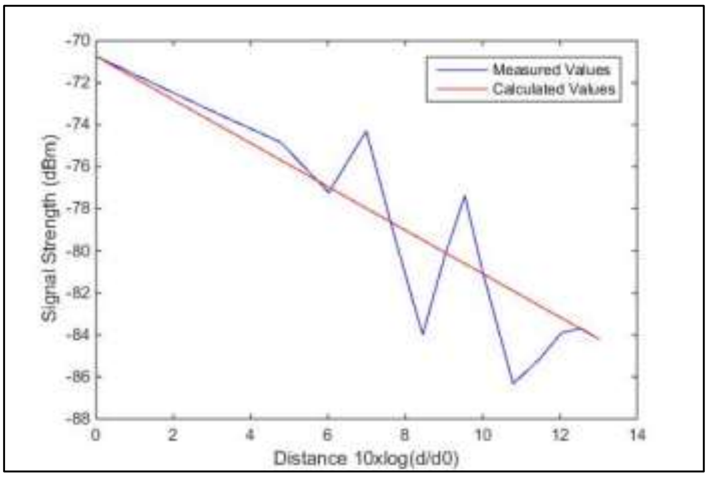

Figure 4.18: Distance-Signal Strength Graph for the Faculty Corridor 2nd Measurement

Table 4.7: Estimated Distances

Estimated Distances (m)	**Received Signal Strength (dBm)**
0.85	-70
1.05	-71
1.32	-72
1.65	-73
2.07	-74
2.58	-75
3.22	-76
4.02	-77
5.03	-78
6.29	-79
7.85	-80
9.81	-81
12.25	-82
15.31	-83
19.13	-84
29.85	-86
46.59	-88
72.72	-90

Figure 4.19 represents the comparison of measured and calculated values of distance-RSSI relation in the residence. The path loss exponent is 1.5280 in this medium. Calculated values are very close to measured values according to Figure 4.19.

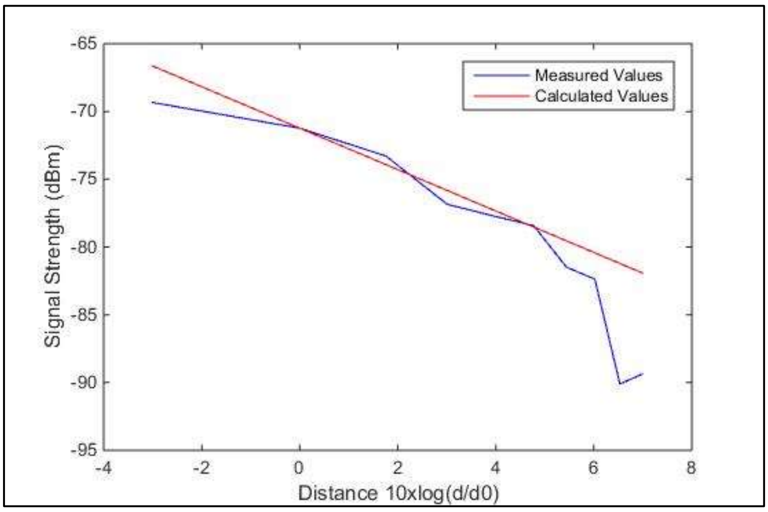

Figure 4.19: Distance-Signal Strength Graph for the Measurements in the Residence

Comparison of Table 4.8 and Table 4.4 show that estimation is very successful until a signal power: -80 dBm and also, estimation in Table 4.8 and in Table 4.7 are very close to each other until the -80 dBm. For high signal strengths, estimation is acceptable. However, the distance estimation formula is unsuccessful for lower signal strengths.

Table 4.8: Estimated Distances

Estimated Distances (m)	Received Signal Strength (dBm)
0.9	-66
1.2	-68
1.66	-70
1.93	-71
2.25	-72
2.61	-73
3.04	-74
3.53	-75
4.10	-76
4.77	-77
5.55	-78
6.45	-79
7.50	-80
8.72	-81
10.14	-82
11.78	-83
13.70	-84
18.52	-86
25.03	-88
33.84	-90

5 CONCLUSION

Measurements are realized for different medium conditions for 7 dBm and -8 dBm. According to measurements, path loss exponent is calculated for all mediums. Distance is estimated by using path loss exponent. Estimation is successful for some conditions, however it is not successful for all conditions. When the transmitter output power is high, estimation cannot be realized and also when the received signal strength is under a threshold that is approximately -80 dBm, estimation is unsuccessful.

Consequently, the RF module must be used with -8 dBm transmitter output power to realize an efficient estimation. Distance estimation formulas are successful for high signal strength levels. When the path loss exponent which is special to measurement medium is calculated, the distance can be efficiently estimated up to 7 m if the received signal strength is above the threshold. Estimated distance is a vital input for localization algorithms created by teammates Alp Oran and Onur Azbar [15, 16].

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RESUME

Ramazan Aktaş, was born in Kadıköy, İstanbul in 1992. He completed high school at Haydarpaşa High School in 2010. He has started Electronics and Communication Engineering programme in Istanbul Technical University. He is currently studying undergraduate programme in Istanbul Technical University.