Item Tracer

by

Teh Yih Kai

15382

Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Electrical & Electronics)

SEPTEMBER 2015

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzua

CERTIFICATION OF APPROVAL

Item Tracer

by

Teh Yih Kai
15382

A project dissertation submitted to the

Electrical & Electronics Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(ELECTRICAL & ELECTRONICS ENGINEERING)

Approved by,

____

(Assoc Prof Dr Mohd Zuki Bin Yusoff)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK

September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Teh Yih Kai)

ABSTRACT

One of our daily issues for searching indoor lost item remain unresolved until today as there is no any systematic way of locating it. Unaccounted amount of time and energy has been wasted each day trying to retrieve it based on memory. Therefore, in this project, a prototype is proposed to locate indoor lost item utilizing received signal strength (RSS) for distance estimation. The prototype primary consists of a small size tag for attaching on any item and a reader for computing the estimated location of the tag. A positioning algorithm is developed to analyse the behaviour of received signal strength and calculate the probability of the target location. As the nature of indoor environment varies across each location, the prototype is tested at multiple indoor locations for refining the algorithm and verifying its robustness and consistency in estimating the target location. The results obtained showed that the percentage of error for direction probability is 32 % and accuracy of distance is at 0.9m.

ACKNOWLEDGEMENTS

I would like to express my utmost gratitude to Associate Professor Dr. Mohd Zuki B Yusoff for his guidance and care as my supervisor in my final year project, without which I would certainly not have achieved as much.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background

The incapability of global positioning system (GPS) to function indoor due to satellite dependent, has spawned the development of indoor positioning system (IPS). Indoor positioning system is the resolution for real-time tracing of any indoor items or people employing wireless signal for example Wifi, Bluetooth, radio waves, or other sensory information [1]. Considering most of our time spend indoor, the demand for high-precision indoor localization has increased significantly over the past few years across various industry for difference application. However unlike GPS for outdoor localization, contemporary there is no standardized method for indoor localization due to the absent of robust method which work accurately across any indoor environment. The complex nature of indoor environments include inconsistent value of noise interference, multipath effect signal resulted by reflection or attenuation of indoor obstacle, disrupt propagation of electromagnetic waves caused by indoor movement, and so on [2].

In order to achieve high precision of indoor localization, all those uncertainty need to be properly compensated during the development of algorithm. Therefore, lots of research has been done in this field over the past few years to explore ways for eradicating the challenges faced in indoor localization and to bring the power of GPS indoor. Tech giants such as Google, Microsoft and Apple, aside from competing for outdoor street view, are constantly evolving on indoor localization as well because its potential exposed a whole new range of endless application [3]. Ranging from home application for items tracking, healthcare application for patient monitoring, emergency rescue application for victim localizing, commercial application for indoor proximity offer broadcasting, museum application for audio guide replacement and so on [4].

The performance evaluation of localization system can be weighed against the metrics of accuracy, responsiveness, coverage, adaptiveness, scalability, cost and complexity [2]. The high accuracy of localization at present is between 1m to 5m while medium accuracy lays between 6m to 10m and over 11m are considered to be low accuracy [3]. For the rest of the measuring metrics, a balanced should be properly attained across all criteria depending on the system with some tradeoff between metrics.

1.2 Problem Statement

Locating indoor lost item has always been done by either blindly searching based on trial and error from last remembered memory or consulting surrounding people on the possible location when it was last seen. The reliance on memory for item searching is often unreliable and time consuming especially for elderly with the deterioration of memory. Regardless of how organized a person is on all his belongings, items misplace constantly take place sometimes not by ourselves but by family, partners or mostly children. A survey conducted by a British insurance company on 3000 adults discovers that on an average day, 10 minutes are spent on looking for common items such as phones, keys, glasses and paperwork. 9 items are lost on daily basis which is equivalent to closely 3,300 items lost per year and almost 60 hours (2.5 days) spend per year for recovering it. For a typical adult lifespan of 60.5 years, it is comparable to 200,000 items being lost with 3680 hours (153.3 days) wasted on locating them [5].

1.3 Objective

The goals of this project are as follow:

- To develop the positioning algorithm with high accuracy of 1m or less.
- To construct a fully functional prototype for locating indoor lost items.
- To design a small and cost effective tag to attach on indoor item for localization.
- To formula an effective distance representation of item for user.

1.4 Scope of Study

This project will only focus on developing an operational positioning algorithm for indoor localization that has the coverage of a standard room dimension which is generally 4m × 4m. Although the signal coverage for the prototype has the range of a typical house, the location estimation of that scale will not be covered in this project. With the specified confined space the size of a room, emphasis on reaching high location accuracy of 1m or less will be the primary scope of this project study. The performance of the localization hinged on the percentage of error deviation in the result distance estimation of the target location against the real distance measured in real time. As indoor environment varies across difference location depending on the type of object presence, the complexity of the indoor nature will only be studied and tested upon with the prototype in regular room of a living house. Extreme indoor environment for example factory site will not be concerned during the development process.

Similar to any developing process of a functional prototype, an appropriate component which fit the requirement exceedingly is extremely critical towards the success of the product. Therefore for the specification of this prototype, the study on available market model of radio frequency module will be thoroughly reviewed especially module with high sensitivity level on Received Signal Strength (RSS). Bluetooth and wifi module is not examined for this application. For the purpose of the result layout display, the integration into mobile phone application will not be executed but instead only a simple LCD display will be employed.

CHAPTER 2
LITERATURE REVIEW

2.1 Indoor Positioning Systems

To date, the 3 main positioning systems for indoor localization include radio frequency, Wifi and Bluetooth, each with corresponding pros and cons.

2.1.1 Wifi

With the widely accessible Wifi devices and existence of Wifi in almost any premises, most of the studies and development is generally concentrating on Wifi localization. The common localization approaches for Wifi system is mostly fingerprint analysis technique. However as the primitive function of Wifi is intended for communication purpose but not localization, the highest positioning accuracy at present can only reach between 2m to 10m hinged on the technique employed and experimental site [6]. The key element which affect the system accuracy is identified as power transmission, device orientation, hardware specification, Wifi signal fluctuation, and amount of sampling measurement [7]. As a result, the poor accuracy and inadequate scan rate (1Hz) of Wifi restraint the widespread adoption of Wifi as indoor localization system [8]. Nevertheless, one of the recent promising techniques in utilizing Wifi as indoor positioning system is the combination of Pedestrian Dead Reckoning (PDR) with Wifi signal measurement into a sensor fused approach. An average error of 1.3m was able to achieve with the frequent estimation of PDR in between Wifi measurement [9].

2.1.2 Bluetooth

Bluetooth low energy (BLE) is yet another arising low power wireless technology which incorporates in most phone today. There are 3 connection-based signal parameters offer by the specification of Bluetooth, namely RSS, Transmit Power Level (TPL) and Link Quality (LQ). Yet RSS is still considered the best parameter for distance estimation with the most accurate reading among the rest [10]. Recent iPhone framework (iBeacon) released by Apple for developers which offers micro location positioning by utilizing the proximity feature of BLE has generate an enormous amount of interest for this system. Even though both Wifi and Bluetooth are operating at the same frequency band of 2.4 GHz, BLE is shown to have more superior performance over Wifi in indoor localization. The capability of BLE for channel hopping minimizes the encountered channel interference by hopping into a difference channel when the interference is severe. Thus, the RSS value received by BLE is much precise for distance estimation than Wifi. The higher sampling rate and lower transmission power of BLE equally contribute to the enhanced location accuracy over Wifi by eliminate the multipath effect. BLE is proven to surpass Wifi localization accuracy by 27 percent [8]. Since most mobile devices are equipped with build-in functionality of both Wifi and Bluetooth, a hybrid system of indoor positioning system between both systems has been constructed. The main objective behind of the hybrid system is to utilize the advantage of Wifi for wide area coverage combine with the higher positioning accuracy of Bluetooth. The results indicate the improved aspect in term of power consumption and the overall location accuracy with positioning error at approximately 1.75m [11].

2.1.3 Radio Frequency Identifier

Radio frequency identifier (RFID) is another favorable wireless technology of IPS due to the portable tag for asset and people tracking. The tag can be active or passive depend on the presence of power source. Passive tag powers the circuit without the support of power source but only relies on the transmission of energy from reader. Thus passive tag has a limited read range of 1m to 3m in comparison to active tag with the range of more than 10m. The backscatter feature of passive tag offers higher positioning accuracy as it is more sensitive to distance variance. The performance comparison among the three radio frequency systems of Bluetooth, WLAN and RFID, RFID has the highest accuracy followed closely by Bluetooth [12]. One of the adaptive localization algorithm for passive RFID system manages to reach the accuracy of 31 cm within 2.6 seconds [13]. Most of the researches within this field are heavily concentrate on the localization algorithm based on LANDMARC (Location Identification based on Dynamic Active RFID Calibration). The experimented results are improved ranging from 10% to 50%. However the downside of this positioning technology is the requisite of large amount reference tag which is unfeasible for spacious area implementation [14]. As a result the combination of WLAN (Wireless Local Area Network) and RFID hybrid system has been experimented to solve the limited coverage issue of RFID. The obtained findings from the hybrid solution indicate the success in a joint localization algorithm to reach the positioning error of below 2m by analyzing the RSS value from two different systems [15].

2.2 Indoor Localization Techniques

Currently, studies on wireless based indoor localization can be categorized into 3 difference method with each further divided into more thorough technologies [2].

2.2.1 Proximity Detection

It is a range based sensing which does not provide exact location but merely relative location information. This method relies upon a dense network of limited range receivers mounted on the ceiling within an area, each with distinguished position. Once the target's transmitter is sensed by any of the receivers, the target is considered to be located within the detectable range of that receiver. However, if it is picked up by multiple receivers, the target is assumed to be located where the strongest signal is received. The accuracy, coverage and cost of this method depends entirely on the density of deployed receiver within an area and the detectable signal range of receivers. If more receivers with smaller detectable signal range is deployed, the cost of implementation will increase but with higher accuracy and wider coverage. This method requires only simple algorithm and is fairly simple to implement [2].

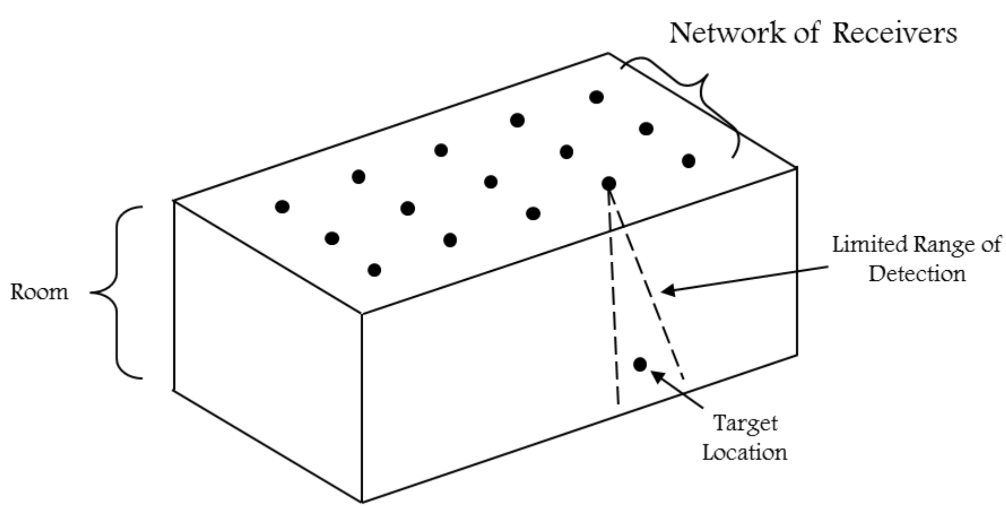


Figure 1: Placement of Receivers for Proximity Detection

2.2.2 Triangulation

Utilizing the geometric property of a triangle for location estimation, this method places three receivers at three difference well-known position and thus forming a triangle. After processing and cross-referencing the data collected from those receivers, an intersection point will be formed by the calculation of triangular relations. That intersection point denotes the probability of where the target will be located. Based on the difference type of data being collected, this method can be further divided into two derivatives namely lateration and angulation. Lateration pinpoints an object by assessing its distance from multiple reference points using time or signal based technique such as round-trip time of flight (RTOF), time difference of arrival (TDOA), time of arrival (TOA) and received signal strength (RSS), while angulation traces an objects by computing its angle from multiple reference points [16, 17].

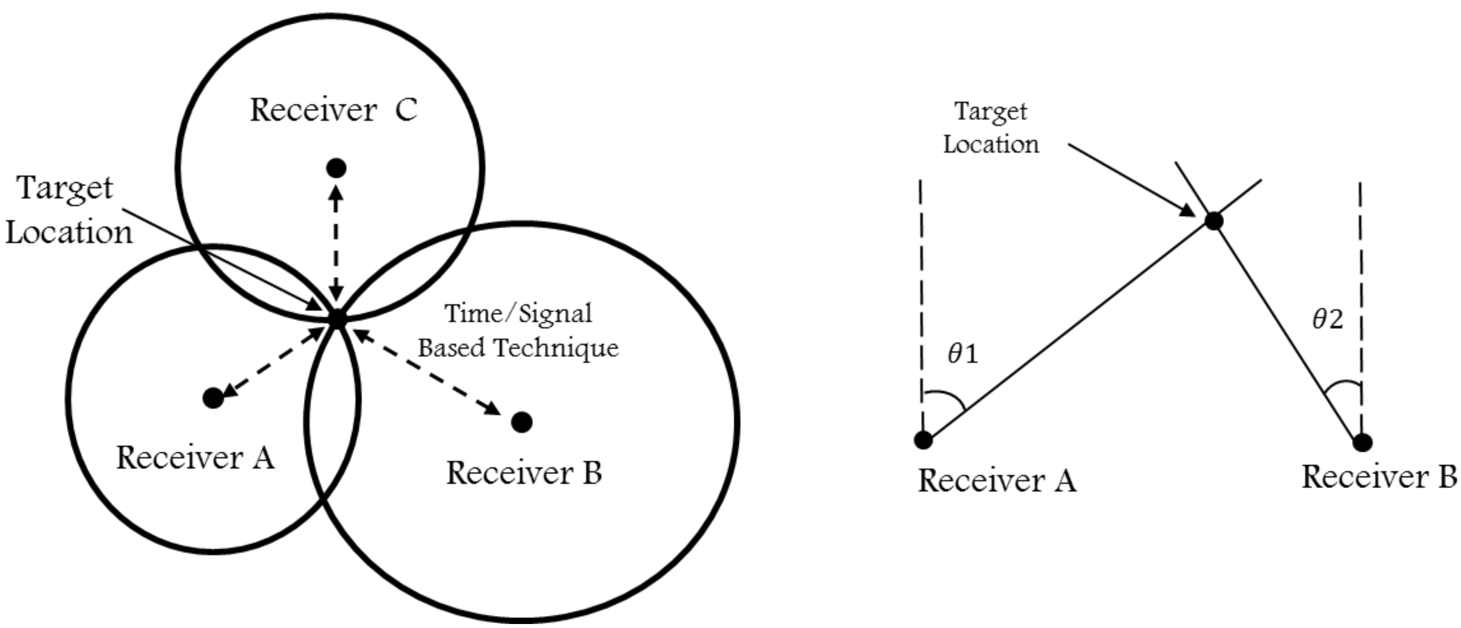


Figure 2: Triangulation method

2.2.2.1 Lateration Method (Time based technique)

Time of arrival (TOA) is the total amount of time required for a signal to propagate from a transmitter to a receiver and is directly proportional to the target distance. To compute this, a timestamp (starting time) signal will be transmitted by the transmitter to the receiver. Upon received, through the calculation of transmission delay and corresponding speed of electromagnetic wave (speed of light), the location of transmitter can be estimated. Nevertheless, the main drawback from this technique is the necessity of absolute synchronization between both transmitter and receiver with a precise time source [16]. TOA is considered to be the most accurate technique used for localization and complex for implementation [18]. This technique is currently being applied by GPS technology for outdoor localization. Though the accuracy is frequently influenced by the effect of multipath within an indoor environment, with the fitting application of temporal or spatial based technique, the effect could be minimized [19].

Time difference of arrival (TDOA) technique is the computation of variation in arrival time of signal at multiple receivers for location estimation. This technique does not require the time synchronization between the transmitter and receiver but only among the receivers. Hence, unlike TOA, a signal with unknown starting time can be received at all receivers and a hyperbolic curve could be drawn at each time variation between two receivers. The intersection of two or more hyperbolic curve alongside with some algorithms for position ambiguity elimination will indicates the target location. This technique is commonly known as multilateration and is relatively simpler to construct without the requisite of common clock [2]. With the same position error estimation for both TOA and TDOA, both measurement are convertible to one another without any loss of positioning information and hence are theoretically equivalent [20].

Round-trip time of flight (RTOF) is the complete propagation time of signal from transmitter to receiver and return. This measuring technique is almost identical to TOA except it resolves the synchronization constraint of TOA. Therefore, the localization algorithm from TOA is accurately fitting for this technique. The downside of this technique is the latency processing time during the transmission and receive of signal which is substantial for short range localization [2].

2.2.2.2 Lateration Method (Signal based technique)

With the property of wireless signal strength that attenuates (reduce in power density) as it propagates over distance, it formed the basic of localization algorithm using received signal strength (RSS). Contrary to all of the time based technique which require advanced hardware, RSS is cost effective and easily obtainable off the shelves. Theoretical and empirical models are established to decipher the received signal strength value into distance estimation. However, direct mapping is occasionally ambiguous and susceptible to error due to the variance multipath effect indoor and wireless interference in the same frequency band [21]. As a result, most of the developed models are location specific and not robust to the dynamics of any indoor environment [2]. To resolve the dynamic profile of indoor environment, a heavy runtime calibration process is employed to constantly compute the conversion between RSS value and distance measurement. The accuracy of RSS measurement can also be further enhanced with a fuzzy logic algorithm or custom directional antenna [16, 21].

2.2.2.3 Angulation Method

Angle of arrival (AOA) technique evaluate the angle entry of signal at a receiver using distinctly directional antenna. Through the geometric association, the target location can be identified via the intersection of two lines of bearing for 2D location and more intersection for accuracy improvement. Nonetheless, the multipath effect indoor causes scenario where signal received are not direct but reflection from transmitter. This greatly impacts the location accuracy with positioning error equal to a segment of communication range and therefore incompatible for indoor localization [22]. The additional requirement for antenna with the capability of angle measurement increase the system operational cost [2].

2.2.3 Scene Analysis

This localization method is based on location matching and composed of two segments. Begin with the gathering of surrounding characteristics within the corresponding area, a database is compiled with the collected information of radio signal features such as RSS value, propagation time or signal angle from all receivers at a respectively coordinate. Each coordinate with the recorded information is defined as a fingerprint. The measurement of the target is then compare against the constructed database for the closest fingerprint match to pinpoint the target. Since this method offers an exceedingly improve accuracy with no sophisticated hardware required neither in transmitter or receiver, it is adopted into the basic layout for majority of indoor localization method. The cost and complexity of the system is minimized as the whole implementation is entirely on software [2]. The commonly employed technique for this fingerprinting method is RSS [16]. The downside of this approach is the tedious and time consuming calibration process which has to be carried out periodically for preserving the positioning accuracy by reassessing the information collected in database. The existing matching technique used in this localization algorithm include probabilistic approach, Bayesian deduction, k nearest neighbor (kNN), support vector machine (SVN), artificial neural networks (ANN) and compressive sensing (CS) based method [2]. Among the performance evaluation of those existing techniques, CS based method has the highest positioning accuracy of 1m - 3m with the trade off at higher conducting complexity and lower time-efficiency [23].

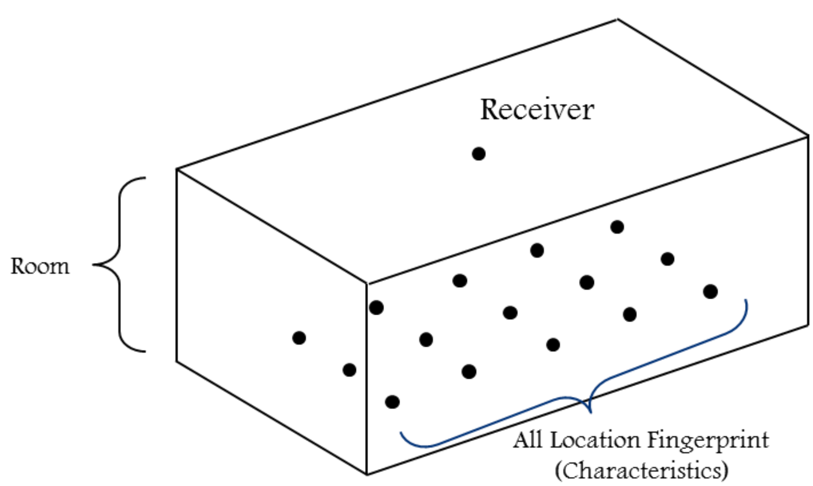


Figure 3: Placement of Receivers for Scene Analysis

CHAPTER 3

METHODOLOGY

3.1 Tools and Software

<u>Hardware</u>

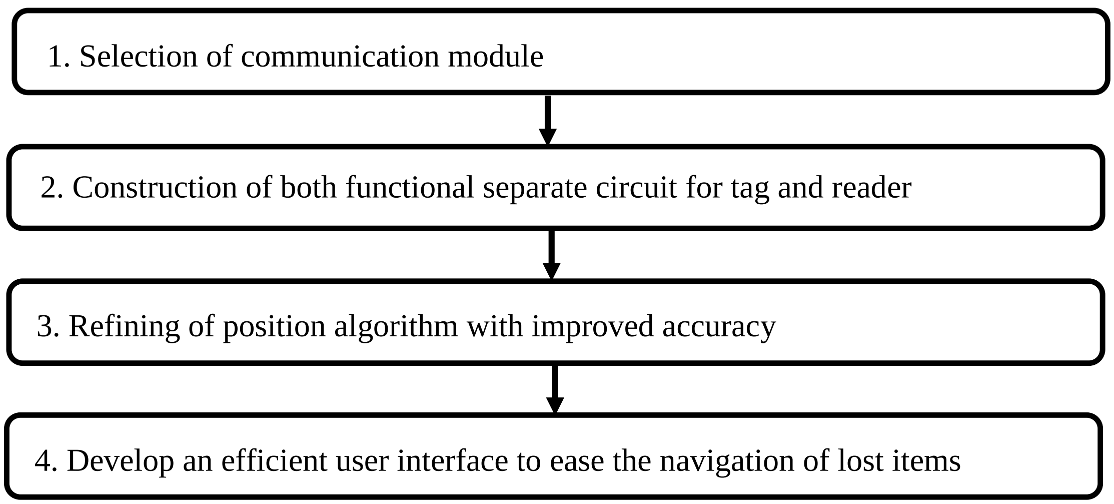
- 315 Mhz Transmitter and Receiver
- 433 Mhz Transmitter and Receiver
- Decoder (HT12D)
- Encoder (HT12E)
- 16 x 8 LCD display
- Keypad
- Arduino Mega 2560
- Bipolar Junction Transistor (2N4403)
- 50k Ω Potentiometer
- 10µF Capacitor
- 9V Battery

<u>Software</u>

- Arduino Software (IDE)

3.2 Description of Methodology

The development process of a fully operational prototype for indoor item tracing can be broken down into 4 stages as below:



3.2.1 <u>Selection of Communication Module</u>

The basic requisite of a fitting communication module is the ability for successful data transmission between transmitter and receiver within the indoor environment. Most of the time, the sight of the item are blocked which makes it impossible to locate. Therefore, the capability of communication module to penetrate considerate amount of obstacle within a room without the line of sight is equally important. Since RSS value will be utilized as the parameter for the following positioning algorithm for distance estimation, the module is required to have an accessible information of RSS value from receiver for monitoring purpose. Besides, cost effectiveness of the module is another considering factor during the module selection in order for mass adoption of tag attachment on indoor items.

Initially, the intended positioning system is by utilizing RFID due to the exceptionally low cost of tag, but the unusually expensive reader module marks the unfeasibility of this system for the prototype implementation. The module selection will mainly focus only radio frequency module. This is because most of the Bluetooth modules need to be configured by a microprocessor unit in order to function. Not only does it increases the cost, the complexity and the size of the circuit especially for the tag are significantly increased as well. As for Wifi modules, studies showed that Wifi positioning is impractical for indoor localization due to the low accuracy from drastic signal fluctuation except for hybrid system.

The ideal radio frequency module for this system implementation is receiver module with high signal sensitivity for better accuracy in location estimation. At present, the most suitable receiver module available on the market is the 433 MHz of RX-4MM5 from Aurel which is an Amplitude Shift Keying (ASK) radio frequency module. The reason of this module suitability is the high signal sensitivity of around -115dBm and the capability to pair with extreme low cost 433 MHz ASK transmitter namely FS1000A.

3.2.2 Construction of Functional Circuit (Tag and Reader)

The next stage of the development is the construction of both functional separate circuit for tag and reader. Generally, the tag circuit will mainly act as a transmitter while the role of reader circuit is as a receiver to infer the distance estimation based on the received signal strength.

For the circuitry of the tag, one major concern needed to be taken into consideration during the design stage is the frequency jamming issue. This problem is primarily due to the fact that when there are two or more wireless devices try to transmit a signal over the same frequency channel. Those wireless devices with weaker signal transmission will be completely obstructed by those with stronger signal. Similar to any communication modules available off the shelf, the transmitter module of FS1000A (which is intended to implement in all the tag circuits) are operating at the same frequency leading to the frequency jamming issue. When multiple tags are present within an area, the receiver is unable to estimate the desired target location but instead always estimate the nearest tag location because it is only able to pick up the strongest signal. This frequency jamming issue however is less susceptible by Bluetooth module due to its frequency hopping mechanism capability. Nevertheless, the issue can be resolved by stopping the signal transmission from all transmitters all at once and only enable the data packet transmission when it is being summoned one at a time. A pair of different channel (315Mhz) radio frequency module can be added which act as a transmitter at the reader circuit to summon the desired transmitter and as a receiver at the tag circuit to respond to the summon.

To be able to summon the desired transmitter, this actually leads to another critical prototype key features in the tag circuit which is the requirement of unique assigned address/identification number for each tag. It is extremely important for this application as the differentiation of items is crucial for item searching. With the inclusive of decoder (HT12D) into the tag circuit, address variance up to 8 bits can be assigned for each tag with difference combination. The following is the circuit connection for the tag:

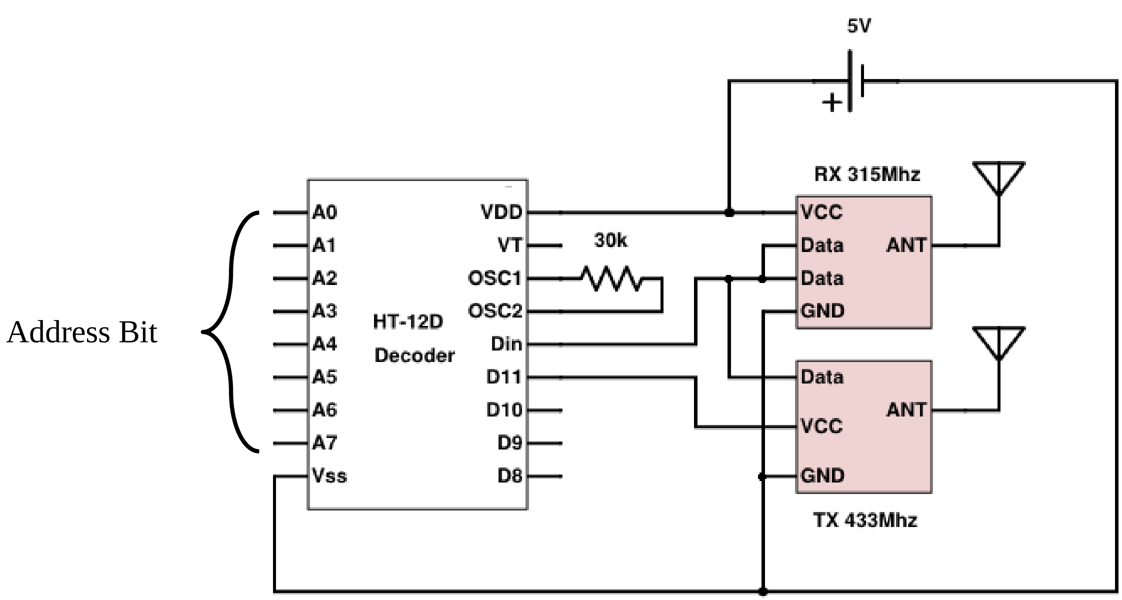


Figure 4: Circuit Diagram of Tag

As for the circuit design of reader module side, basically it is composed of 6 main components namely an encoder (HT-12E), a Arduino mega microcontroller, a LCD display, a keypad, a 315Mhz transmitter and 3 pieces of 433Mhz receivers (RX-4MM5). All address pins of the encoder are connected into separate digital pin of microcontroller for the address manipulation in order for the 315 MHz of transmitter to transmit signal to the specific desired tag. This is to activate the 433 MHz of transmitter (FS1000A) at the tag circuit for avoiding the frequency jamming issue as mentioned earlier. Since each of the tag circuit has difference combination of address, to reach/summon the desired tag the microcontroller need to match the exact same address pin set at the tag circuit by providing a series of high/low output into the address pin of encoder. The complete database of address with respective name of the tag are stored into the microcontroller and can be navigated through the list by user with the provided keypad and LCD display.

The crucial component in the reader circuit is the 3 pieces of 433 MHz receivers (RX-4MM5). All 3 RSS value from the receivers are connected into the analog pin of the microcontroller because the RSS value is an indication for measurement of received power from the signal. The analog data will then be converted into digital by the microcontroller to be processed for distance estimation through the positioning algorithm. Since the RSS value is not a continuous voltage but pulsed PWN signal, therefore a connection of low pass filter which consist of resistor and capacitor (10 pμ) is required. The RX-4MM5 receiver is also endowed with a pin of AGC which is designed to enable the automatic gain control. Setting the pin of AGC at low level will enable the automatic gain control to accept the largest dynamics of the received waveform which is up to 0 dBm. The receiver will be able to decode the RF signals received within the power range from -114 dBM to 0dBm. However if setting the AGC at high level will allow the receiver to work always with the maximum sensitivity. If the RF power is lower than a threshold, the receiver works with a linear behavior while if the input power is higher than that threshold, the receiver will works in the saturation zone. Since sensitivity is an essential factor for location accuracy, the AGC pin is set to high so that the receiver always works with maximum sensitivity.

For the antenna design, to take advantage of the performance described in technical specification, a wire of 50 ohm coaxial cable is the best fit antenna for RX-4MM5. Below is the circuit diagram of a complete reader circuit.

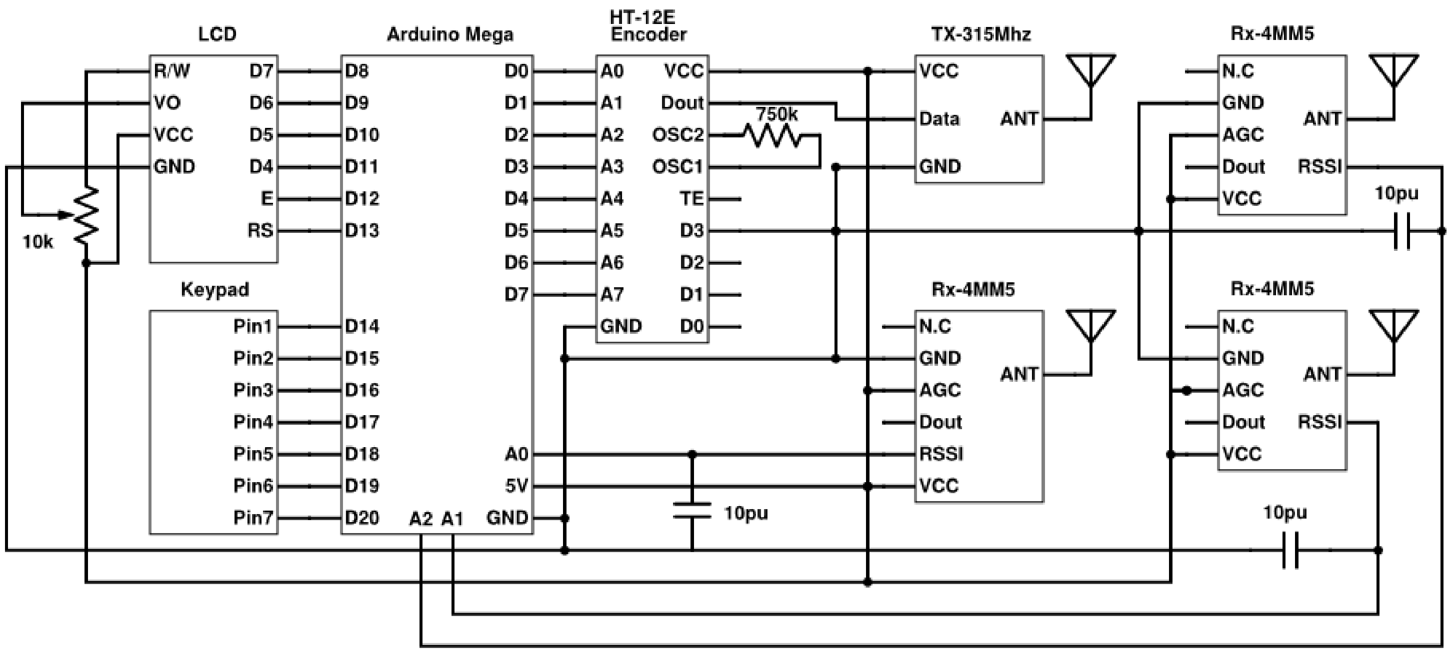
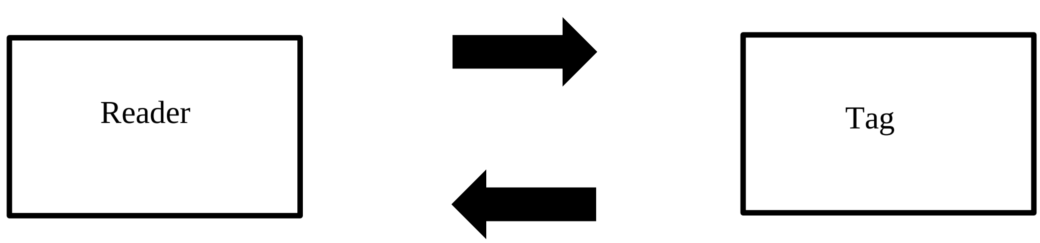


Figure 5: Circuit Diagram of Reader

Transmit at 315 MHz to activate tag



Transmit at 433 MHz for distance estimation

Figure 6: Working Principle of Prototype

3.2.3 Refining of Position Algorithm

The following stage is the refining of position algorithm with improved accuracy of 1m or less. A table of translation between RSS value and distance estimation will be developed based on actual measurement by experimenting on multiple location for different noise interference. To reduce the impact of noise interference on positioning accuracy, a reference point will be established by attaching a tag on a fix location such as wall or floor so that the respective RSS value can be recorded as a reference value. With the fix distance between the reference point and receiver, any variance of RSS value from the reference value will be mainly caused by noise interference and adjustment on RSS value can be made accordingly. The developed RSS based positioning algorithm will then be employed to pinpoint the tag location by referring to the developed table. Depending on the experimental result, further tuning and refining on the algorithm will be carried out. To reduce the influence of possible data outliner occasionally in distance estimation, a reading of 100 data will be tabulated before each computation and arranged in an ascending order based on the value. An average among 30 median value from the list will be calculated and taken as the final value for RSS to be processed by the positioning algorithm.

3.2.4 Development of an Efficient User Interface

The last stage of the process is developing an efficient user interface to ease the navigation of indoor lost item. The system is required to permit the registration of tag with respective name of item into a database and display location information of the desired tag for item searching. Unlike GPS with the standard assigned location coordinate for each places, an effective distance representation of the tag need to be formulated in order for user to understand the location information from computed result. Among several possible distance representations that could be utilized, the most effective way of presenting the information is to provide the direction and proximity of the tag with respect to the user position.

3.3 Key Milestones

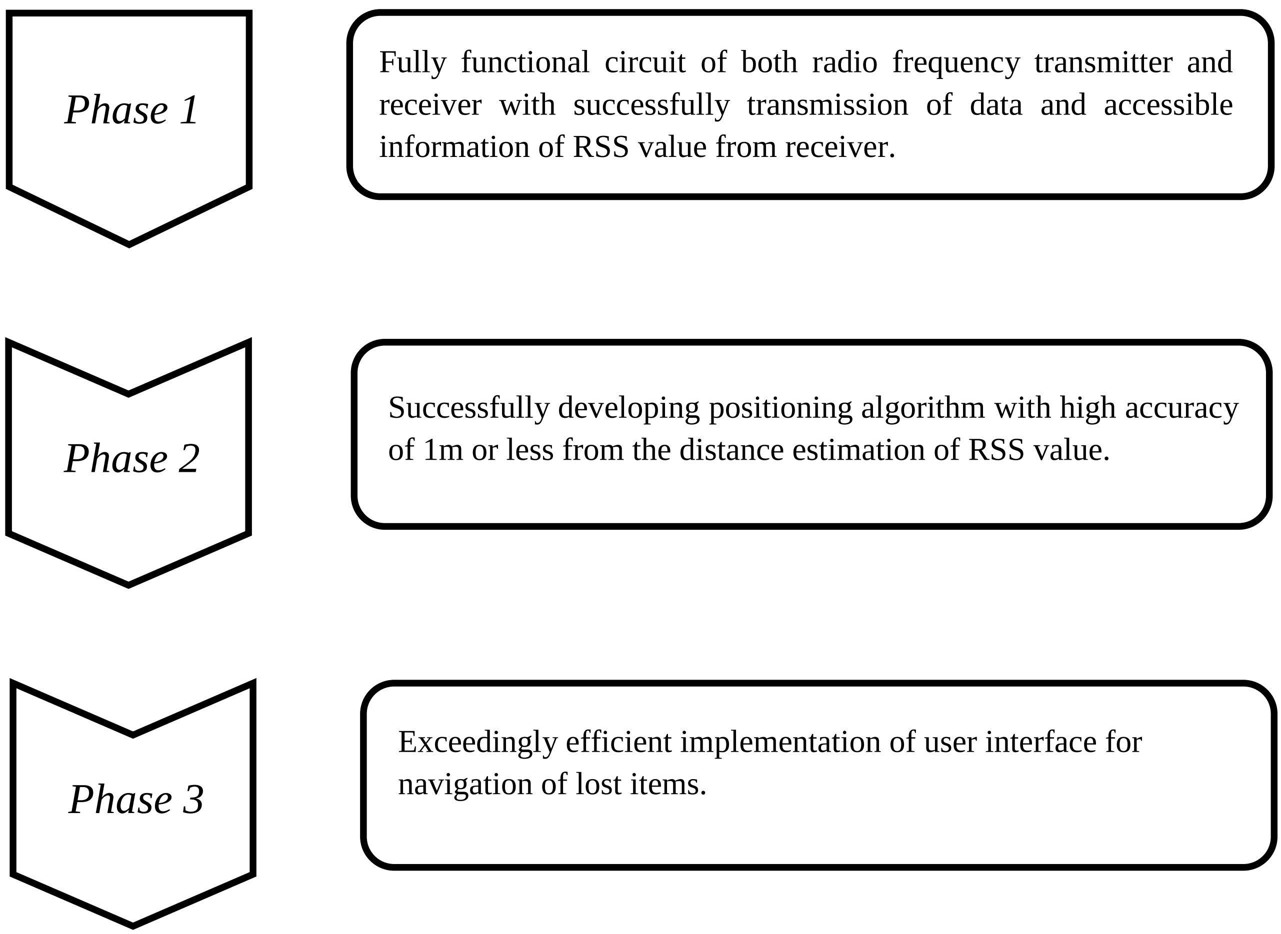


Figure 7: Key Milestones

3.4 Gantt Chart

3.4.1 Final Year Project I Gantt Chart

Task	Week													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Select a project title from the approved list of final year projects	■													
Discuss the selected project with respective lecturer for project allocation		■												
Experiment on the performance of RFID kit from communication lab			■											
Research on suitable radio frequency module for project implementation				■	■									
Purchase the required electronic components				■	■									
Prepare literature review based on current existing technology					■	■								
Submit the complete version of extended proposal with turnitin score						■								
Set up the working circuit from purchased radio frequency module							■							
Prepare for proposal defence by studying in depth the project theory								■	■					
Develop and experiment the performance of localization algorithms								■	■	■	■	■	■	■
Draft the layout of the final report												■	■	
Submit the complete version of final report with turnitin score														■

Figure 8: Gantt chart (FYP I)

3.4.2 Final Year Project II Gantt Chart

Task	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tabulate the finding of RSS value by varying difference parameters	■	■	■												
Utilize spectrum analyzer to examine the exact operating frequency of transmitter				■											
Modify factors which influence RSS value to obtain a finer reading					■	■	■	■	■						
Simulate the working of distance algorithm					■										
Experiment for verifying the working of distance algorithm in real life						■	■	■							
Improve the user interface for better representation of object location							■	■	■						
Submission of Progress Report								■							
Finalize all the minor details for the working prototype of the project								■	■						
Preparation for demonstration at ELECTREX/SEDEX										■	■				
Draft the layout of Final Report												■	■		
Submission of Final Report														■	
VIVA															■

Figure 9: Gantt chart (FYP II)

CHAPTER 4

RESULT AND DISCUSSION

4.1 Development of the algorithm

4.1.1 First Approach

To accurately estimate the approximate distance of the tag by cross referencing all RSS value based on trilateration technique, all three receivers are placed 1 meter apart in the respective axis of x, y and z. In the real world scenario, this is equivalent to any corner of the room which will serves as the starting coordinate of (0, 0, 0). The placement are as below:

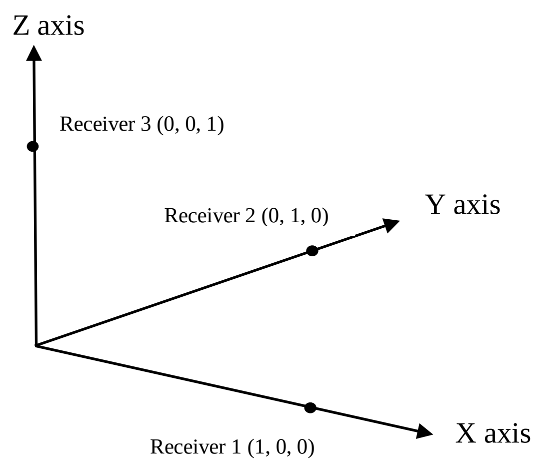


Figure 10: Placement of 3 Receivers

The distance formula is derived from Pythagorean Theorem which is $a^2 + b^2 = c^2$. With respect to the position arrangement of all 3 receivers as shown above, 3 distance formula is formulated in order to solve the 3 variables (x, y, z coordinate) of the tag simultaneously.

Note: D1 stands for the distance of tag from receiver 1, D2 stands for the distance of tag from receiver 2, D3 stands for the distance of tag from receiver 3

$$(x-1)^2 + y^2 + z^2 = D1^2$$
$$x^2 - 2x + 1 + y^2 + z^2 = D1^2$$
$$x^2 + y^2 + z^2 + 1 = D1^2 + 2x \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \; ①$$

$$x^2 + (y-1)^2 + z^2 = D2^2$$
$$x^2 + y^2 + 2y + 1 + z^2 = D2^2$$
$$x^2 + y^2 + z^2 + 1 = D2^2 + 2y \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \; ②$$

$$x^2 + y^2 + (z-1)^2 = D3^2$$
$$x^2 + y^2 + z^2 + 2z + 1 = D3^2$$
$$x^2 + y^2 + z^2 + 1 = D3^2 + 2z \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \; ③$$

By equating equation 1 and 3, the x coordinate of the tag can be computed in term of z. The same principal can be applied to obtain the y coordinate of the tag by equating equation 2 and 3.

$$D1^2 + 2x = D3^2 + 2z$$
$$x = \frac{D3^2 - D1^2 + 2z}{2} \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \; ④$$

$$D2^2 + 2y = D3^2 + 2z$$
$$y = \frac{D3^2 - D2^2 + 2z}{2} \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \; ⑤$$

For the z coordinate of the tag, by replacing both x and y variables from equation 1 with its substitute in equation 4 and 5, equation 1 can be solved like any quadratic equation for the value of z.

$$\left(\frac{D3^2 - D1^2 + 2z}{2}\right)^2 + \left(\frac{D3^2 - D2^2 + 2z}{2}\right)^2 + z^2 + 1 = D1^2 + 2\left(\frac{D3^2 - D1^2 + 2z}{2}\right)$$

$$3z^2 + z(-D1^2 + 2D3^2 - D2^2 - 2) - 0.5(D1)^2(D3)^2 + 0.25(D1)^4 + 0.25(D2)^4 + 0.5(D3)^4 - (D3)^2 + 1 - 0.5(D2)^2(D3)^2 = 0$$

$$A = 3$$

$$B = -D1^2 + 2D3^2 - D2^2 - 2$$

$$C = -0.5(D1)^2(D3)^2 + 0.25(D1)^4 + 0.25(D2)^4 + 0.5(D3)^4 - (D3)^2 + 1 - 0.5(D2)^2(D3)^2$$

$$z = \frac{-B \pm \sqrt{(B)^2 - 4AC}}{2A} \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \text{⑥}$$

The result obtained from simulation verified the accuracy of all three equations 4, 5 and 6 in computing the exact location of the tag. However, the different sign of either plus or minus within equation 6 leads to the potential of two different possible locations. This is primarily because trilateration method (3 receivers) is only capable of computing accurately in 2 dimension where the intersection of receivers are merely circles. For 3 dimension computation, the intersection between receivers are spheres instead of circles. This implies that when there is only one receiver, the possible location is anywhere on the surface of the sphere. When there is two receivers, the possible location is equal to the circumference of a circle between the intersections of two spheres. When there are three receivers, the possible location reduced to both the top and bottom point within the intersection of three sphere. It is only with the fourth receiver that the last inaccurate location can be eliminated and left behind with the actual location. Below is an illustration between 3 and 4 receivers in estimating the possible location.

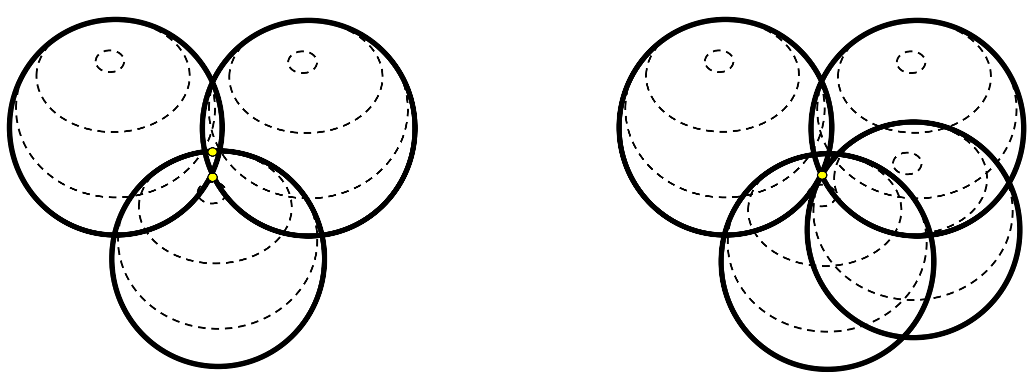


Figure 11: Comparison between trilateration and multilateration method

Therefore, multilateration (at least 4 receivers) is required to narrow down all the possible locations into one. An addition receivers is included into the earlier position arrangement of receivers by placing at the starting coordinate of (0, 0, 0) as the following:

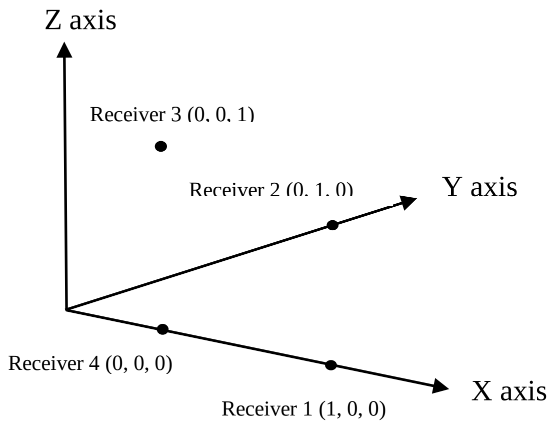


Figure 12: Placement of 4 Receivers

This results in a fourth distance formula being formulated in prior to the first three equation:

$$x^2 + y^2 + z^2 = D4^2 \quad \sim\sim\sim\sim\sim\sim\sim\sim\sim \text{⑦}$$

It serves as the verification of actual tag location between the last two possible results after being computed with equation 4, 5 and 6.

Though the derivation of distance algorithm from this approach indicates its feasibility for implementation theoretically, the real time execution reveals the opposite. The reason for its failure can be broken down into two main factors.

1. Although the presence of noise interferences do affect the reading of RSS value, the utilization of reference point does minimize its impact upon the developed algorithm. Depending on the different level of noise interference each day, all the translated distance from RSS value are shifted into higher or lower. However, the unforeseen occurrence originates from the assumption made that all four receivers are always exposed to the same level of noise interference within the

room. The finding obtained after the experiment concludes the results otherwise. Certain receivers are exposed to more significant level of noise interferences compare to other receivers due to location proximity toward the object of disturbance. This introduces the error of uncoordinated reading from one receiver to the others. Partial of this error also coming from the lack of product standard consistency across all constructed receivers from manufacturer. The value of RSS changes after interchanging any of the receivers with an identical receiver. The absence of coordinated reading among receivers is one of the core elements which affects the calculation of algorithm into all sort of unacceptable results.

2. The distance algorithm was developed according to the principle that signal strength should decreases across distance. While it was also taken into the consideration that the decrease might not be linear, the occasional increase of signal strength after certain distance was unexpected. This affects the operational of the algorithm as there are multiple location possibilities for a particular value of signal strength. Below is the general graph tabulation of signal strength across distance.

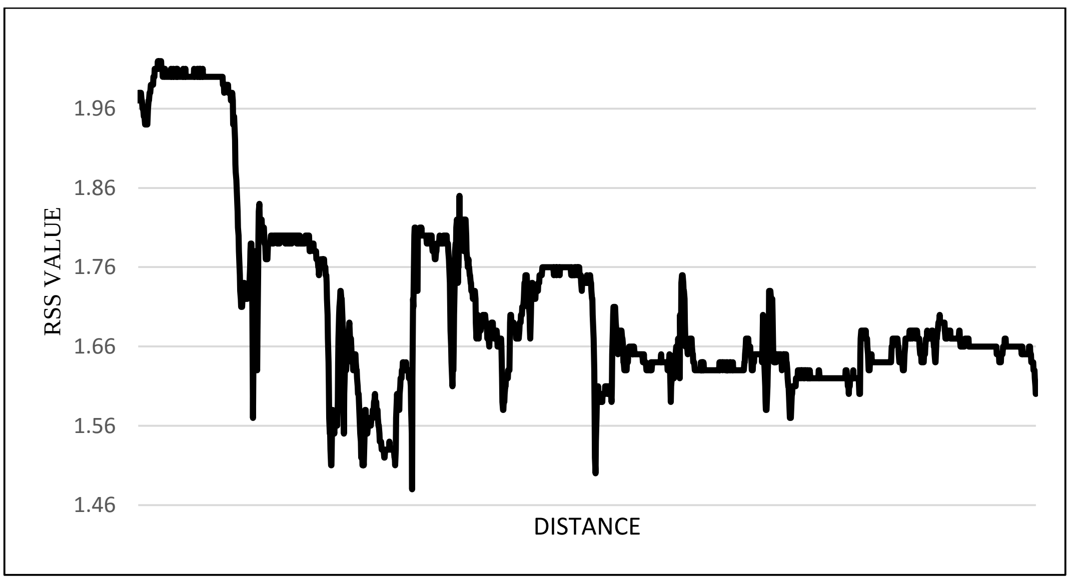


Figure 13: General Variation of Signal Strength across Distance

The finding from this approach concludes the poor direct translation of signal strength for distance estimation.

4.1.2 Second Approach

The previous issue of uncoordinated relation between receivers can be resolved by using only one receiver to compute the RSS value at different locations. This however necessitates the mobility of the reader from being placed at a fix location into a hand-held device. The recorded reading of RSS results from multiple locations are then being weighed against each other to infer the necessary distance information. This procedure also removes the variation of different standard of receivers which further promote the distance accuracy. As for the occasional spiking of signal strength at certain distance, by reutilizing 3 receivers with each receiver still relating the RSS reading against itself but not each other, the level of accuracy regarding the extracted distance information can be increased considerably. As a result, the second approach is modified into accommodating the limitation of signal strength which is to first calculate the probability of direction then estimate the proximity of item.

In order to ensure a more accurate estimation of direction, the 3 receivers are mounted on 3 different directions of the reader which are at the center, left and right. The user is then requested to turn the reader at 3 continuous directions while staying at the fix location to record the reading of RSS at each direction as follow:

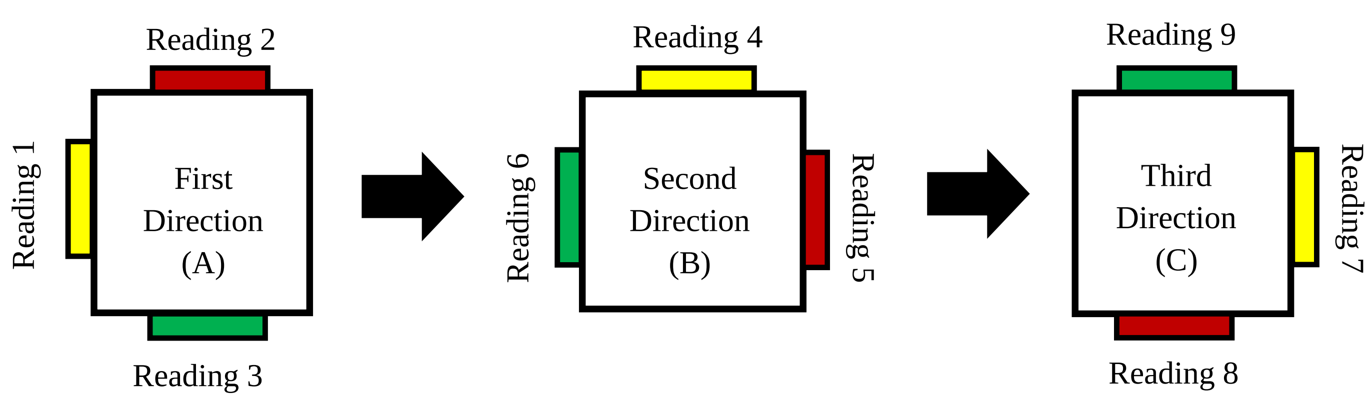


Figure 14: Computing Procedure of Reader at 3 Continuous Direction

Note: The first receiver is represented by the color of yellow, the second receiver is represented by the color of red, and the third receiver is represented by the color of green.

A total of 9 reading is recorded for comparison to deduce the direction of the item. The possible directions are categorized into center, left, right and behind with respect to the position of third direction, which is the final position of the user after the computing procedure. This provides an even better distance representation for the user regarding the location of item compare with the coordinate representation during the first approach. The probability of direction are calculated as below:

1. Each receiver contributes 33.33% of probabilities toward one direction by assessing the highest value of RSS reading among all three positions it is exposed to. The following are the 3 possible directions with respect to the position at third direction for all 3 receivers:

   a. First Receiver (Yellow) : Behind (A) / Left (B) / Center (C)
   b. Second Receiver (Red) : Left (A) / Center (B) / Right (C)
   c. Third Receiver (Green) : Right (A) / Behind (B) / Left (C)

   The ideal outcome after the computation from this assessment would be all 3 receivers are indicating the same direction. However there are always the possibilities of 3 receivers are either indicating 3 different directions or 2 of the receivers indicate one direction while the other receiver indicates a different direction. Therefore, the second level of assessment is required.

2. To narrow down the probabilities of direction into only 2 if 3 receivers are indicating 3 different directions, further computation is being carried out. Among the remaining 3 directions after first assessment, the middle direction is definitely one of the accurate directions. Therefore it is not being compared in this stage of assessment. For example, left is the middle direction among the three directions of center, left and behind. The remaining 2 directions are being weighed against each other with the following calculation depending on the direction. The direction with a higher value in RSS reading will be the accurate direction along with the middle direction. This means approximately

90 degree of the area in between the two directions are the possible location of the item. This level of assessment is however exempted from being executed if the result returned from the first assessment is in one final direction or 2 final directions.

a. Left Comparison : Reading 2 + Reading 9
b. Right Comparison : Reading 3 + Reading 8
c. Center Comparison : Reading 7 + Reading 5
d. Behind Comparison : Reading 1 + Reading 6

3. In order to finalize the tendency of object orientation into only one particular direction, the third level of assessment is being carried out with the same calculation used in the second assessment. The reason for not combining the execution of this level assessment with second assessment is to avoid the case where the middle direction might be eliminated during the combined calculation. Therefore it is important for this algorithm to perform the computation accordingly for minimizing the impacts of variation in receiver's standards.

The experiment conducted with this algorithm shows promising result in accuracy. The first level of assessment for narrowing the directions from 4 into 3 is performing flawlessly 90% of the time. This is primarily because the absence of different receiver standard within the calculation. The computation is done entirely on the result recorded from each receiver against itself. As for the second and third level of assessment, a slight calculation error is introduced as the evaluation are being done against two different receivers instead of one.

The subsequent step after the direction estimation is the calculation of distance proximity for the item. A RSS to distance translation table is being utilized for this proximity calculation. The average RSS reading computed from the third assessment is compared against the table to find the closest value for its distance translation. The following is the tabulation of RSS value to distance:

RSS Value	Distance (m)
>2.20	0.1
2.10 - 2.20	0.2
2.00 - 2.10	0.3
1.85 - 2.00	0.6
1.68 - 1.85	1.2
1.60 - 1.68	1.8
1.55 - 1.60	2.4
1.50 - 1.55	3.0
1.45 - 1.50	3.5
1.30 - 1.45	>3.5
1.20 - 1.30	No signal

Table 1: RSS value to distance translation

All the 50 results obtained during the verification of this algorithm is recorded as below:

Experiment	Result		Accurate	Mostly accurate	Inaccurate	Distance Deviation
	Between	Toward				
1	Behind and Left	Behind	✓			0.2 m
2	Behind and Right	Behind		Toward Right		0.7 m
3	Center and Right	Right		Toward Center		0.9 m
4	Center and Left	Left	✓			0.3 m
5	Behind and Right	Right		Toward Behind		0.6 m
6	Behind and Right	Right	✓			0.2 m
7	Center and Left	Left		Toward Center		1.1 m
8	Behind and Left	Behind	✓			0.4 m

9	Behind and Right	Behind			Behind and Left	1.8 m
10	Behind and Right	Right	✓			0.3 m
11	Center and Left	Left			Center and Right	2.1 m
12	Center and Right	Right			Center and Left	1.4 m
13	Behind and Right	Behind	✓			0.3 m
14	Center and Left	Left			Center and Right	1.9 m
15	Center and Left	Left		Toward Center		0.8 m
16	Behind and Left	Behind	✓			0.2 m
17	Behind and Right	Behind			Behind and Left	1.7 m
18	Behind and Right	Behind	✓			0.5 m
19	Center and Left	Left			Center and Right	1.6 m
20	Behind and Left	Behind			Center and Left	2.0 m
21	Center and Right	Center	✓			0.4 m
22	Center and Left	Left	✓			0.3 m
23	Center and Left	Center		Toward Left		0.8 m
24	Behind and Left	Behind		Toward Left		1.1 m
25	Behind and Right	Behind	✓			0.5 m
26	Center and Right	Right			Behind and Right	1.5 m
27	Behind and Left	Left	✓			0.3 m
28	Center and Left	Center	✓			0.2 m
29	Behind and Right	Right			Center and Right	1.6 m
30	Center and Right	Right	✓			0.4 m
31	Behind and Left	Left		Toward Behind		0.8 m
32	Behind and Left	Behind			Behind and Right	1.3 m
33	Behind and Right	Right			Behind and Left	1.9 m
34	Center and Left	Left	✓			0.3 m
35	Center and Right	Center		Toward Right		1.2 m
36	Behind and Left	Behind		Toward Left		0.9 m
37	Behind and Right	Behind	✓			0.5 m

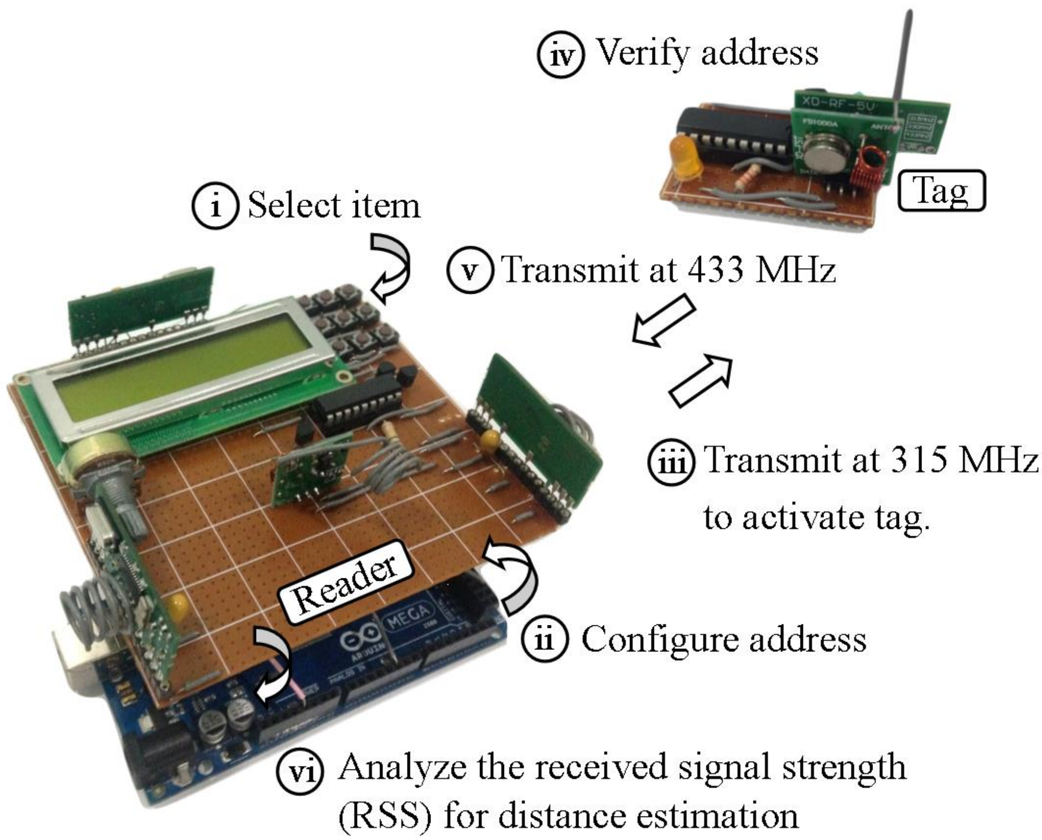
38	Center and Right	Right			Center and Left	1.1 m
39	Center and Left	Center		Toward Left		1.1 m
40	Center and Right	Center	✓			0.2 m
41	Behind and Left	Left			Center and Right	1.2 m
42	Center and Left	Center		Toward Left		0.8 m
43	Behind and Left	Left			Behind and Right	1.9 m
44	Behind and Right	Behind	✓			0.5 m
45	Center and Left	Left	✓			0.3 m
46	Center and Right	Center			Center and Left	1.6 m
47	Behind and Left	Behind		Toward Left		0.8 m
48	Behind and Right	Right		Toward Behind		0.6 m
49	Center and Right	Center			Behind and Right	1.7 m
50	Center and Left	Left	✓			0.2 m
Total			20	14	16	45 m

Table 2: 50 Results Collected for the Verification of Algorithm

Percentage of error for direction probability: $\frac{16}{50}\ x\ 100\% = 32\ \%$

Accuracy of distance: $\frac{45\text{m}}{50}\ = 0.9\ m$

Figure 15: Prototype of both the Reader and Tag



4.2 Tabulation of RSS value

Since RSS value defines the accuracy of distance estimation, factors that influence RSS reading are carefully examined throughout the experimental session in order to search for a better approach in reducing the percentage of error. All potential causes are narrowed down into four basic elements as below:

4.2.1 Voltage Reference for Analog Digital Converter (ADC)

In order to compute and analyze the analog reading of RSS value from the receiver, the conversion into digital value is mandatory. With built-in 10 bits resolution of ADC within Arduino, output ranges from 0 up to 1023 is used as the representation of analog input. The process of conversion is a matter of proportion which relates to the proportion of input voltage against reference voltage. This reference voltage is normally regarded as 5v due to the standard voltage output of USB port. However, after several measurement with multimeter for verification, it is concluded that the 5v supply from USB port is not always consistent and intermittently it drops as low as 4.8v. This is critical as the accuracy of analog reading will be affected by not having an absolutely 5v supply. At the moment of low voltage, the input value will be relate to 4.8v instead of 5v. This differences introduce a substantial error toward the calculation of distance estimation and affect the result immensely. Therefore, an external power supply of 9v is adopted as the USB port replacement for eliminating voltage supply variation. An additional precaution could be incorporated to further ensure the consistency of reference voltage which is the utilization of AREF pin on Arduino with 3v external power supply. This implementation is especially valuable when supplying power draining components to evade drastic voltage drop.

Another prominent issue discovered during the construction process, is the inaccurate reading of all analog input except for one, when attempting to read from multiple analog pin simultaneously. It is then realized the issue originates from the inadequate time allocated for the multiplexer of ADC to switch between pins and for the voltage to stabilize after the switching. Hence for each analog input, two reading will be taken with a small delay after the first reading. This is basically to initiate the switching of ADC multiplexer during the first reading and to designate time for the voltage to stabilize with the small delay. The first reading will then be discarded and replaced with the more accurate reading of second.

4.2.2 Transmission of Transmitter

In the attempt to obtain a finer reading of RSS value, aside from enhancing all the receiving parameters of a receiver, the transmission of transmitter serves as equally significant portion. The specification of transmitter specify the operating voltage begins with a minimum of 2.5v up until 12v, with the indication that higher transmitting power can be harvest with higher voltage supply. Nevertheless after a thoroughly examination, 8v of power supply is certified as the ideal voltage for transmitter as any additional increment on voltage poses a little influence on the RSS value. Below is the RSS value gathered at the fix distance of 0.3m while varying the voltage supply from 2.5v until 12v with 0.5v increment.

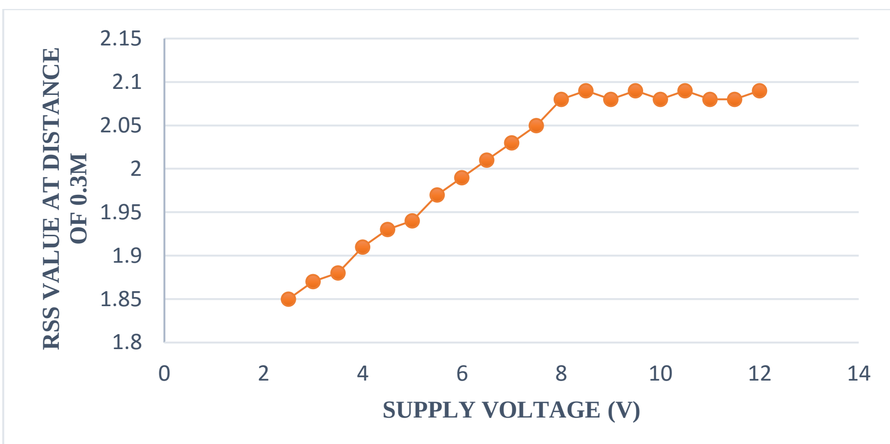


Figure 16: RSS Value against Supply Voltage

4.2.3 Electromagnetic Shielding

One of the greatest drawback from the application of electromagnetic (EM) wave is the susceptible toward surrounding environment especially water and metal. Water is a decent medium for the absorption of EM radiation while metal is an excellent reflector. At the encounter of both materials, RSS value is dramatically reduced and deviate the estimated location from its true position. Since 70% of human body is made up of water, the presence and movement of human does affect the reading of RSS value if it is in between the transmitter and receiver. Consequently to reduce the impact of human presence, throughout the entire experimental session, one person (user) is taken into consideration by staying in front of the receiver while tabulating the result. To ensure the uniformity of antenna reading, the reflective properties of metal is adopted by placing a cylinder shaped of aluminum foil around the receiver to limit the wide space of signal entry from multiple direction into only the upper part of cylinder opening.

4.2.4 Antenna Design (Receiver)

The presence of antenna mounted on top of both transmitter and receiver greatly affects the RSS reading and contributes to the value fluctuation. As the intent of antenna inclusion in receiver is to increase the capability for signal power received, it too escalates the potential in picking up stray electrostatic discharge in the air and surrounding noises occasionally. Though grounding the connection of antenna does improve the reading marginally, the overall issue still remained. The absence of antenna however, does helps in reducing the value fluctuation, but significantly weaken the sensitivity of receiver toward distance variation. Below is the RSS value tabulated between the presence and absence of antenna at the distance apart of 0.6m starting from 0m until 3m.

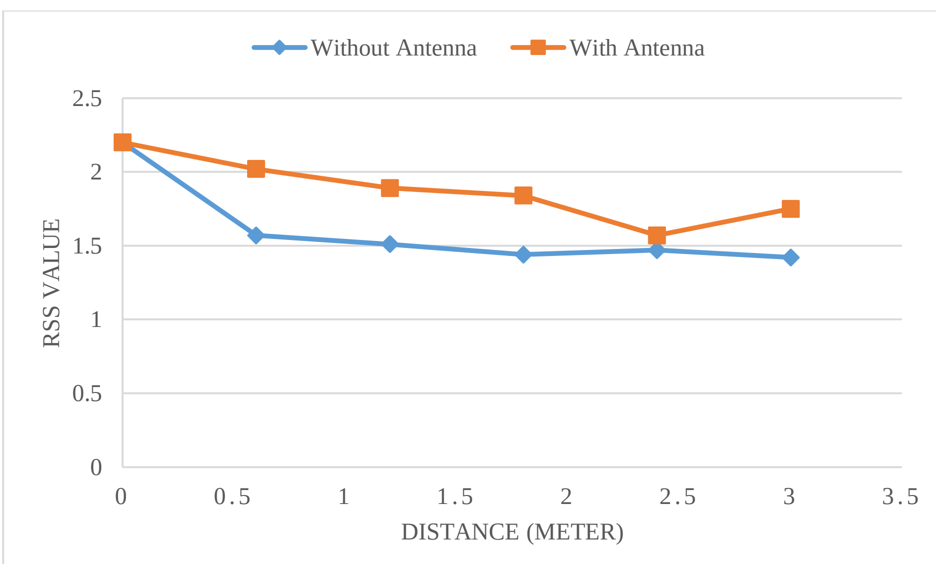


Figure 17: RSS Value against the Absence and Presence of Antenna

In the effort to further improve the reading from antenna for optimal performance, the length of antenna is essential. By constructing the antenna roughly the half or quarter wavelength of its operating frequency, the signal reflection and reactive components can be reduced considerably and thus promote maximum power transfer. Realizing that wavelength is equal to the division of speed of light over frequency, the length of antenna for half and quarter wavelength can be calculated respectively as below:

$$\frac{1}{2}\lambda = \left(\frac{3\ x\ 10^8 m/s}{433.25\ x\ 10^6\ Hz}\right)\left(\frac{1}{2}\right)$$
$$= 0.34\ m$$

$$\frac{1}{4} = \left(\frac{3\ x\ 10^8 m/s}{433.25\ x\ 10^6\ Hz}\right)\left(\frac{1}{4}\right)$$
$$= 0.17\ m$$

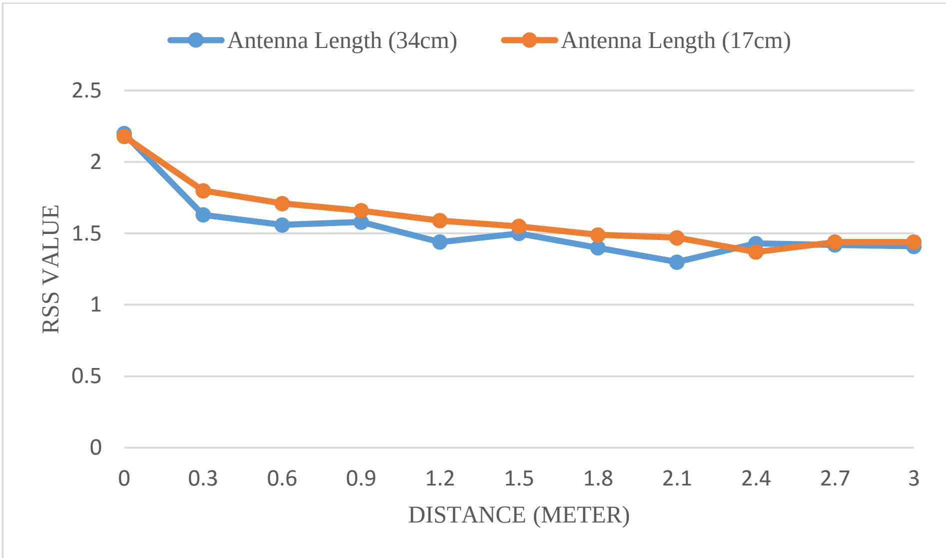


Figure 18: RSS Value against the Length of Antenna

From the comparison above between half and quarter wavelength for the antenna length, it is clearly illustrated that quarter wavelength demonstrates a more linear performance over half wavelength and thus serves as a better selection length in antenna design. The necessity to verify between these two is generally due to the fact the quarter wavelength relies on the size of ground plane being large enough to cause the physical reflection of the ¼ wave conductor. Since there is no obvious indication within the specification of components which highlight on the details, validation between half and quarter wavelength for antenna design is required.

The subsequent modification on obtaining a more precise and error reduction RSS value is on the construction of band pass filter for removing surrounding noise interference. A band pass filter can be formulated by cascading a single low pass filter circuit with high pass filter circuit. However, information such as frequency bandwidth, maximum and minimum frequency are exceptionally crucial to be determined before the process of band pass filter design. Therefore, after an assessment with spectrum analyzer on the frequency transmitted from transmitter, the operating frequency is identified to be at exactly 433.25 Mhz, while the maximum and minimum frequency side band are 430.5 Mhz and 438 Mhz respectively. The following is the calculation on passive RC filter for both low and high pass:

$$Low\ Pass\text{:}\ \ 430.5\ Mhz = \frac{1}{2\pi RC} \qquad\qquad High\ Pass\text{:}\ \ 438\ Mhz = \frac{1}{2\pi RC}$$

$$RC = (100\Omega)(3.7pF) \qquad\qquad RC = (100\Omega)(3.6pF)$$

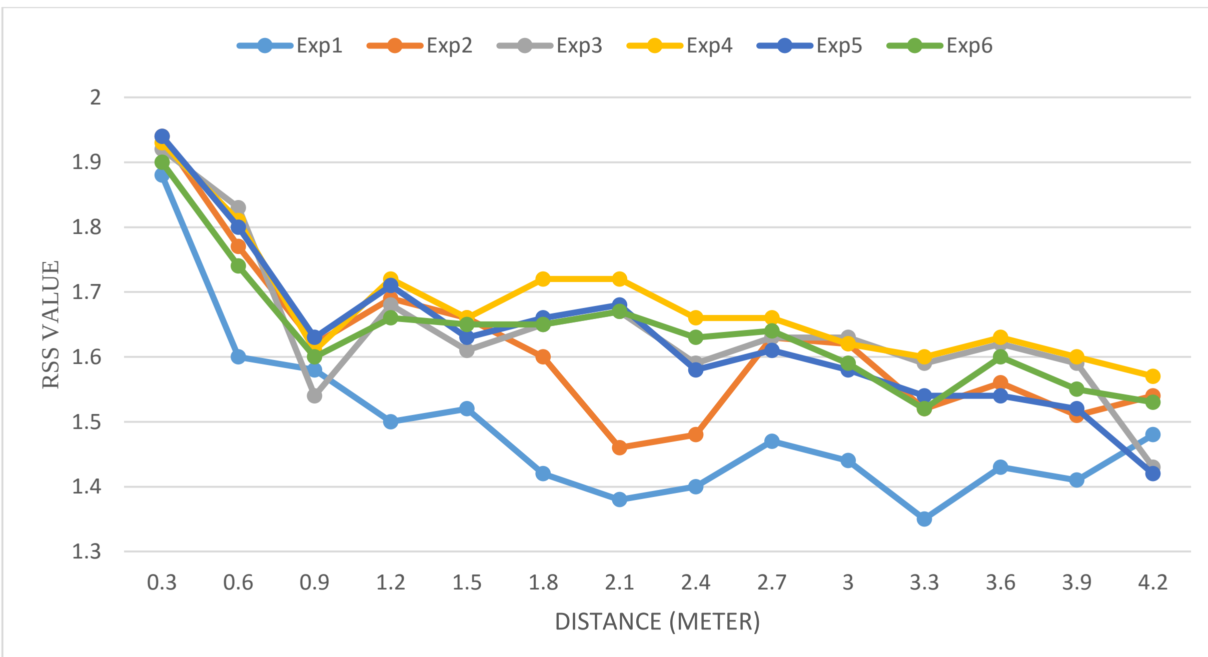


Figure 19: Behavior of RSS Value with Varied Combination of Parameters

Exp1: With Supply Filter

Exp2: With Calculated Band Pass Filter

Exp3: With Antenna

Exp4: Without Antenna

Exp5: With Aluminum Foil

Exp6: Without Aluminum Foil

The 6 experimental results above each with varied combination of parameters illustrate the generic pattern of RSS value over the distance of 4.2m. The first experiment is conducted with the implementation of a supply filter utilizing 100 Ω and 3300μF to balance out the power supply noise from USB powered Arduino. This power supply noise could be further minimized with an external DC power source which will be verified in the following weeks of experiment. Nevertheless experiment 1 demonstrate the most consistent RSS value reduction across distance. The experiment 2 is carried out with the application of band pass filter from previous calculation. However, the result indicates the additional of band pass filter has little influence on RSS value improvement. Experiment 3 and 4 is the repetition experiment from previous discussion which is included for the purpose of comparison. While this result is different in contrast to previous reading, it is largely caused by varying noise level at separate day of experiment. As for experiment 5 and 6, the utilization of aluminum foil as electromagnetic shield does improve the reading of RSS slightly especially toward the completion of distance. This experiment will continuously be carried out to smoothen the reduction of RSS value over distance.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objective of this project is to resolve the prominent issue that has becoming one of our daily tedious tasks which is searching for any item or object. With the attenuation properties of signal over distance, the aim to locate a desired object by distance estimation is feasible. However experimental result showed that utilizing signal strength is a poor indication for indoor localization due to the significant amount of indoor interferences and other limitation in external factors. For example the limited resolution of ADC and the inconsistency of product standard.

Nevertheless, a positioning algorithm was developed to minimize the impact of those influential factors during the location estimation of item. The obtained results indicate a promising improvement in enhancing the accuracy up until 0.9 m of positioning error and 32 % of direction error. A better distance representation was successfully developed which is to provide the user direction and the proximity of the item with respect to the location of the user.

All the activities were executed accordingly to the planned schedule in Gantt chart for completion. Each intended objectives for this project are achieved within the allocated time frame of two semesters.

5.2 Recommendation

With the time and resource constraint placed on this project, there is only a limited amount of outcome this project can delivered. Thus for future further advancement, some of the recommended work include utilizing a passive tag (without battery source) instead of active tag for object attachment. The lifespan of a passive tag can last indefinitely without the constant need of replacing the power supply as it comes from electromagnetic induction of an active source. This feature is extremely useful in this project application as there is always the possibility of active tag lost its power when attempting to be located. However, one of the major setback from the existing electromagnetic induction technology is the limited distance coverage and costly implementation.

Besides, by exploiting the capability of mobile phone to detect and analyze radio frequency, the development of a mobile application as reader is highly recommended to remove the redundancy of having an extra reader tool for locating item. Multiple functionality can also be included into the application to ease the item searching process for example the ability to retrieve the last location of the desired item from database in the scenario where the signal of the tag could not be detected, incorporate visual aids in better displaying the location of lost item and so on.

To further reduce the computing procedure, a combination of single receiver with gyroscope can be implemented to remove the variation in receiver standard from multiple receivers. For each slight movement, the RSS value from the receiver will be monitored and observed the microscopic changes to infer the necessary distance information.

References

[1] W. Fan, H. Zhengyong, Y. Hui, T. Xiaohua, W. Xinbing, and H. Jinwei, "EESM-based fingerprint algorithm for Wi-Fi indoor positioning system," in *Communications in China (ICCC), 2013 IEEE/CIC International Conference on*, 2013, pp. 674-679.

[2] Z. Farid, R. Nordin, and M. Ismail, "Recent Advances in Wireless Indoor Localization Techniques and System," *Journal of Computer Networks and Communications,* vol. 2013, p. 12, 2013.

[3] D. Dodge. (2013). *Indoor Location startups innovating Indoor Positioning*. Available: http://dondodge.typepad.com/the_next_big_thing/2013/06/indoor-location-startups-innovating-indoor-positioning.html

[4] M. A. Al-Ammar, S. Alhadhrami, A. Al-Salman, A. Alarifi, H. S. Al-Khalifa, A. Alnafessah, *et al.*, "Comparative Survey of Indoor Positioning Technologies, Techniques, and Algorithms," in *Cyberworlds (CW), 2014 International Conference on*, 2014, pp. 245-252.

[5] (2012). *Lost something already today? Misplaced items cost us ten minutes a day*. Available: http://www.dailymail.co.uk/news/article-2117987/Lost-today-Misplaced-items-cost-minutes-day.html

[6] A. Baniukevic, D. Sabonis, C. S. Jensen, and L. Hua, "Improving Wi-Fi Based Indoor Positioning Using Bluetooth Add-Ons," in *Mobile Data Management (MDM), 2011 12th IEEE International Conference on*, 2011, pp. 246-255.

[7] A. Farshad, L. Jiwei, M. K. Marina, and F. J. Garcia, "A microscopic look at WiFi fingerprinting for indoor mobile phone localization in diverse environments," in *Indoor Positioning and Indoor Navigation (IPIN), 2013 International Conference on*, 2013, pp. 1-10.

[8] X. Zhao, Z. Xiao, A. Markham, N. Trigoni, and Y. Ren, "Does BTLE measure up against WiFi? A comparison of indoor location performance," in *European Wireless 2014; 20th European Wireless Conference; Proceedings of*, 2014, pp. 1-6.

[9] F. Karlsson, M. Karlsson, B. Bernhardsson, F. Tufvesson, and M. Persson, "Sensor fused indoor positioning using dual band WiFi signal measurements," in *Control Conference (ECC), 2015 European*, 2015, pp. 1669-1672.

[10] F. Subhan, H. Hasbullah, A. Rozyyev, and S. T. Bakhsh, "Analysis of Bluetooth signal parameters for indoor positioning systems," in *Computer & Information Science (ICCIS), 2012 International Conference on*, 2012, pp. 784-789.

[11] A. Baniukevic, C. S. Jensen, and L. Hua, "Hybrid Indoor Positioning with Wi-Fi and Bluetooth: Architecture and Performance," in *Mobile Data Management (MDM), 2013 IEEE 14th International Conference on*, 2013, pp. 207-216.

[12] P. Vorst, J. Sommer, C. Hoene, P. Schneider, C. Weiss, T. Schairer, *et al.*, "Indoor Positioning via Three Different RF Technologies," in *RFID Systems and Technologies (RFID SysTech), 2008 4th European Workshop on*, 2008, pp. 1-10.

[13] C. Xi, X. Lei, W. Chuyu, and L. Sanglu, "Adaptive Accurate Indoor-Localization Using Passive RFID," in *Parallel and Distributed Systems (ICPADS), 2013 International Conference on*, 2013, pp. 249-256.

[14] Z. Deng, Y. Yu, X. Yuan, N. Wan, and L. Yang, "Situation and development tendency of indoor positioning," *Communications, China,* vol. 10, pp. 42-55, 2013.

[15] M. Hasani, J. Talvitie, L. Sydanheimo, E. S. Lohan, and L. Ukkonen, "Hybrid WLAN-RFID Indoor Localization Solution Utilizing Textile Tag," *Antennas and Wireless Propagation Letters, IEEE,* vol. 14, pp. 1358-1361, 2015.

[16] L. Hui, H. Darabi, P. Banerjee, and L. Jing, "Survey of Wireless Indoor Positioning Techniques and Systems," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on,* vol. 37, pp. 1067-1080, 2007.

[17] X. Jinhong, L. Zhi, Y. Yang, L. Dan, and H. Xu, "Comparison and analysis of indoor wireless positioning techniques," in *Computer Science and Service System (CSSS), 2011 International Conference on*, 2011, pp. 293-296.

[18] G. Yanying, A. Lo, and I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," *Communications Surveys & Tutorials, IEEE,* vol. 11, pp. 13-32, 2009.

[19] M. Pourhomayoun, J. Zhanpeng, and M. Fowler, "Spatial sparsity based indoor localization in wireless sensor network for assistive healthcare," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, 2012, pp. 3696-3699.

[20] S. Dong-Ho and S. Tae-Kyung, "Comparisons of error characteristics between TOA and TDOA positioning," *Aerospace and Electronic Systems, IEEE Transactions on,* vol. 38, pp. 307-311, 2002.

[21] S. Zickler and M. Veloso, "RSS-based relative localization and tethering for moving robots in unknown environments," in *Robotics and Automation (ICRA), 2010 IEEE International Conference on*, 2010, pp. 5466-5471.

[22] D. Niculescu and B. Nath, "Ad hoc positioning system (APS) using AOA," in *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, 2003, pp. 1734-1743 vol.3.

[23] D. Genming, Z. Jinbao, Z. Lingwen, and T. Zhenhui, "Overview of received signal strength based fingerprinting localization in indoor wireless LAN environments," in *Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE), 2013 IEEE 5th International Symposium on*, 2013, pp. 160-164.