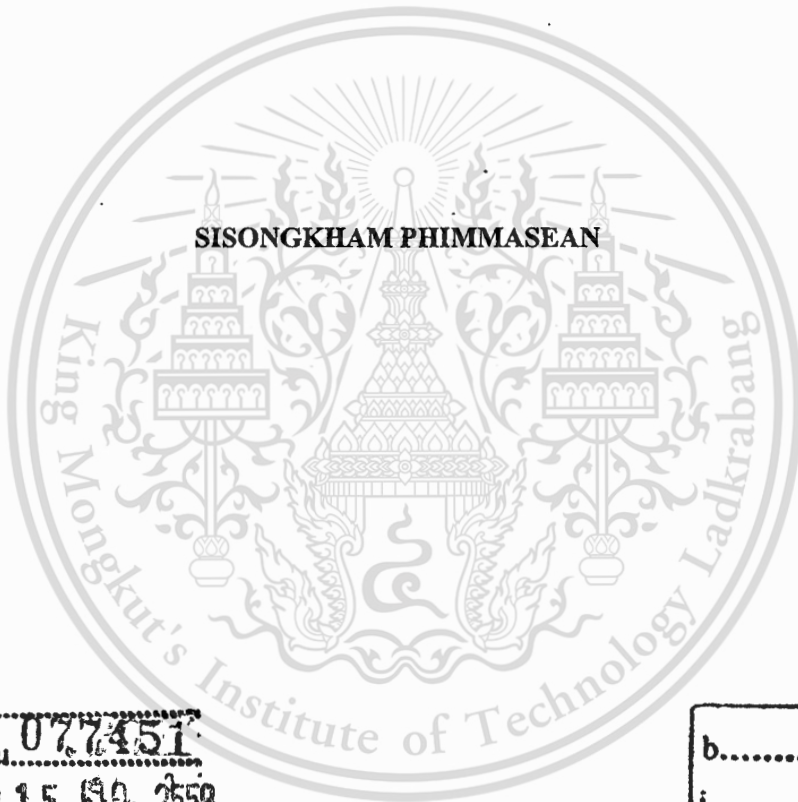


IMPLEMENTATION OF FINGERPRINT TECHNIQUE FOR INDOOR LOCALIZATION
USING RFID PASSIVE TAG



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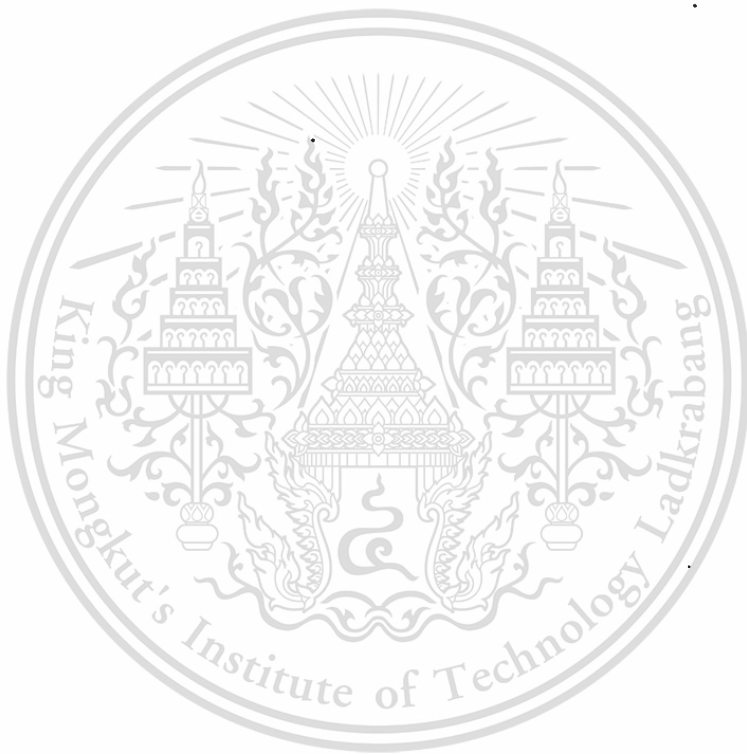
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Thesis Title	Implementation of Fingerprint Technique for Indoor Localization using RFID Passive Tag
Student	Mr. Sisongkham Phimmasean
Student ID.	54601103
Degree	Master of Engineering
Program	Computer Engineering
Year	2013
Thesis Advisor	Asst. Prof. Dr. Panarat Cherntanomwong
Co-advisor	Prof. Dr. Jun-ichi Takada

ABSTRACT

In recent day, RFID technology is very popular to use in a variety of applications because its capability of transmitting and receiving data. This technology leads the research in location finding or localization of objects. There are many papers of localization reviewed. However, indoor localization system for real applications is still limited. 2D indoor localization systems also have some but 3D indoor localization is very least. This thesis proposes 2D and 3D indoor localization system using fingerprint technique to solve the problem of difference target height and to show the target location on GUI in real-time.

Fingerprint technique is the technique allows us to have the database of information stored inside the system. The fingerprint information in database and the observed information are the main important points in this technique. To find the location of the target, the localization system must be comparing both of this information by using Dot Product. To support the Auto-ID information (from tags) the dot product is used as the pattern matching algorithm. In this work, the location of stationary and moving target can be estimated. Moreover, the graphic user interface (GUI) is developed to show the location of the target in real-time.

From the results, we can conclude that the fingerprint technique and the dot product algorithm can be applied in the real situation and application. The accuracy of the target and supporting the suitable information for the visitors are the main considering as the future work.

หัวข้อวิทยานิพนธ์	การใช้เทคนิคการพิมพ์ลายนิ้วมือสำหรับการหาตำแหน่งภายในอาคารโดยใช้ป้ายอาร์เอฟไอดีชนิดพาสซีฟ
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รหัสนักศึกษา	54601103
ระดับ	ปริญญาโท
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อาจารย์ร่วม	ศ.ดร.จุนอิจิ ทาคาคะ

บทคัดย่อ

ในยุคปัจจุบัน เทคโนโลยีอาร์เอฟไอดี (Radio Frequency Identification: RFID) ได้เข้ามามีบทบาทอย่างมากในการประยุกต์ใช้งานในส่วนต่างๆ ไม่ว่าจะเป็นในเรื่องอุตสาหกรรมในส่วนของการผลิตเพื่อการติดตาม และการตรวจสอบ (Track and Trace) การบริหารจัดการสินค้าคงคลัง และการกระจายสินค้า ระบบการขนส่ง การหาตำแหน่งของวัตถุ คน หรือสัตว์ เป็นต้น โดยเฉพาะในการหาตำแหน่งเป็นที่นิยมมากในยุคปัจจุบันเนื่องจากอาร์เอฟไอดีเป็นเทคโนโลยีที่มีต้นทุนต่ำ ใช้พลังงานน้อย ติดตั้งง่าย การสื่อสารข้อมูลเป็นไปอย่างมีประสิทธิภาพ และให้ผลที่มีความแม่นยำพอสมควร

การหาตำแหน่งถูกแบ่งออกเป็นสองประเภทหลัก คือการหาตำแหน่งภายในอาคาร และการหาตำแหน่งภายนอกอาคาร วิทยานิพนธ์ฉบับนี้ได้นำเสนอในส่วนของหาตำแหน่งของวัตถุในอาคารในแบบสองมิติ และแบบสามมิติ คือระบบที่ถูกพัฒนานี้สามารถระบุพิกัดของตำแหน่งเป้าหมาย และนอกจากนั้นยังสามารถจำแนกความสูงของวัตถุเป้าหมายได้อีกด้วย จากนั้นตำแหน่งเป้าหมายที่ได้ก็จะถูกจำลองขึ้น และแสดงบนกราฟฟิกอินเตอร์เฟซ (Graphic User Interface: GUI) เพื่อให้ผู้ควบคุมดูแลระบบ สามารถรู้พิกัดของตำแหน่งเป้าหมายได้ ในการระบุตำแหน่งเป้าหมายอาศัยเทคนิคการพิมพ์ลายนิ้วมือ (Fingerprint Technique) เป็นตัวเปรียบเทียบระหว่างข้อมูลที่มีอยู่ในฐานข้อมูลกับข้อมูลที่ได้จากตำแหน่งของวัตถุ (Observed Location) ในการเปรียบเทียบนี้ได้นำวิธีการดอทโปรดักต์ (Dot Product) มาประยุกต์ใช้งานเพื่อใช้ในการระบุตำแหน่งของเป้าหมาย

จากการวิเคราะห์ผลที่ได้ ทำให้ทราบว่าระบบการหาตำแหน่งโดยใช้เทคนิคการพิมพ์ลายนิ้วมือ (Fingerprint Technique) และ การเปรียบเทียบรูปแบบ (Pattern Matching) ที่ถูกพัฒนาขึ้นได้ สามารถนำไปประยุกต์ใช้กับการหาตำแหน่งภายในอาคารได้จริง โดยเฉพาะในส่วนงานของการติดตามหาตำแหน่งของนักท่องเที่ยวในพิพิธภัณฑ์ ในอนาคตนอกจากการหาตำแหน่งของเป้าหมายได้แล้ว ระบบดังกล่าวจะถูกพัฒนาให้มีความแม่นยำมากยิ่งขึ้น อีกทั้งยังสามารถตอบสนองข้อมูลที่ถูกต้อง และเหมาะสมกับนักท่องเที่ยวในแต่ละวัย

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Bangkok, Thailand

Sisongkham Phimmasean

20 May 2013

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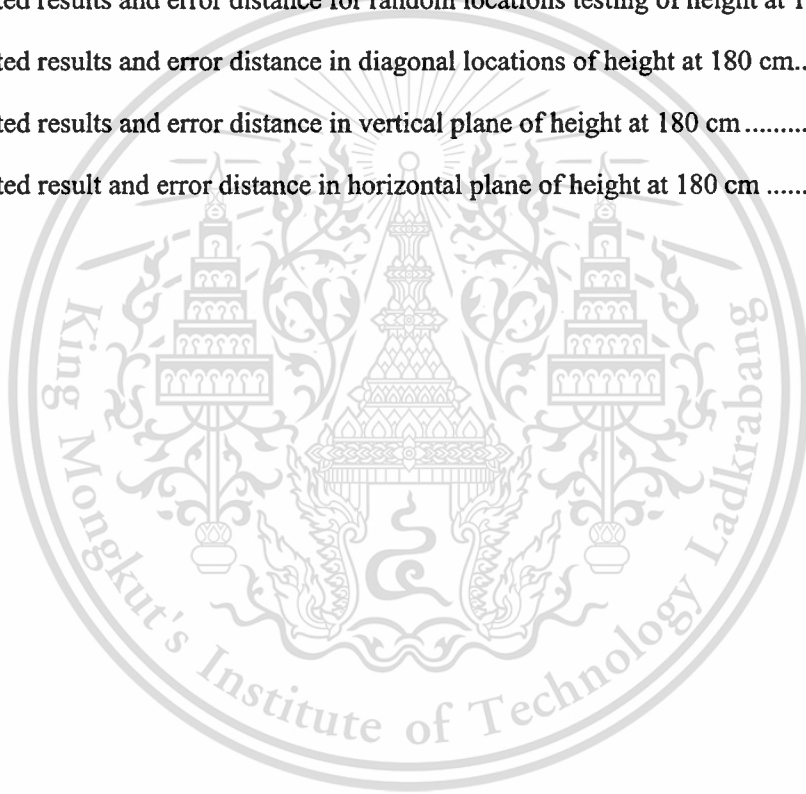
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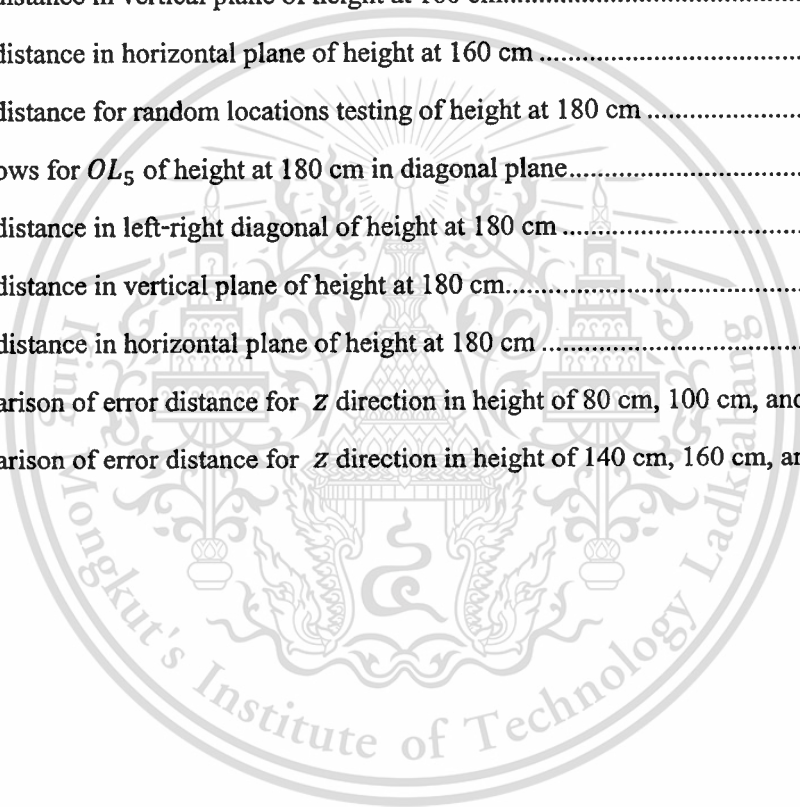
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CHAPTER 1

INTRODUCTION

1.1 Background

The indoor localization has been a vital research topic in applications of wireless networks. Examples of obvious applications are patient tracking in the hospital, children monitoring, location finding of the product, vehicle monitoring and tracking for the logistics, etc., [1]. The accuracy of the location estimation and the reliable localization system are the main factor required. In spite of that, the relatively simple and low cost system is preferable.

In recent days, wireless network technology-based localization and tracking system are used to locate the people or object. The well-known technology is global positioning system (GPS)-based, cellular-based, wireless local area network (WLAN standard such as IEEE802.11b), ultra wide band (UWB), Bluetooth (IEEE 802.15) and radio frequency identification (RFID) . These technologies have been developed for indoor localization system such as patient tracking in the hospital, location finding of the product, visitor tracking in the museum, etc., [2]. Most of these technologies are supported by RFID, because of its abilities to maintain data security, its cost-effective and its endurance. Furthermore, it can identify the difference of objects [3]. The RFID technology serves the same purpose as a barcode or a magnetic strip on the back of the credit card or ATM card, it provides a unique identifier for an object. Likewise, a barcode or magnetic strip must be scanned to get the information, so the RFID tag must be scanned or read to retrieve the identifying information. There are many types of RFID tags i.e., active tag, passive tag and semi-active tag. The various techniques are implemented during the development of localization system. Localization techniques can be classified into several categories, i.e., received signal strength (RSS), time of arrival (ToA) or time difference of arrival (TDoA), angle of arrival (AoA), location fingerprint based techniques, and their combinations [4]-[7]. However, the RSSI and time based techniques require at least three base stations (BSs) for the system. For AoA, the accuracy of the localization depends only from the accuracy of angle estimation. By considering the equipment used and the accuracy, the fingerprint technique is the localization technique that can make the localization system simple and accurate since only a single BS and comparatively simple equipment can be employed.

Location fingerprint technique as pattern matching-based localization is commonly used as non-real time localization technique. This technique allows us to have the signal information recorded as

database. This thesis proposes the indoor localization system using fingerprint-based technique and the pattern matching algorithm namely Dot Product [8]. The dot product algorithm is the single number result provided by an algebraic operation that takes two equal-length sequences of numbers. The result is provided by multiplying corresponding entries [9].

This chapter begins with some background issues in indoor localization system and the motivations of the work are presented in Section 1.2. The objectives of the thesis are well described in Section 1.3 and finally the outline of this thesis will be given in Section 1.4 as the last section in this chapter.

1.2 Motivations

Figure 1.1 depicts the four major problems in accurate and robust localization system. One of them is methodology/positioning algorithm which becomes our motivation to do this thesis work [10]. As we know, positioning algorithm especially in indoor environment has many factors affecting the accuracy of the system. In this work, indoor localization system based on fingerprint technique using RFID passive tag technology is proposed. Dot product algorithm is deployed as the pattern matching algorithm. This method is supported for matching between fingerprint information and observed information to find the estimated location of the target [9]. The localization system which provides the acceptable accuracy of position estimation, relatively cheap in cost, low power consumption, small in size, efficient, and simple in application is required. Regarding the accuracy of the system, many issues such as diffraction at edges, refraction by media with different propagation velocity and reflection in metallic objects is affected the localization system performance.

The smart, small, relatively cheap, and low power consumption-sensor node is deployed in our localization system. The accuracy of the system is achieved by the improving the quality of database in the fingerprint technique. The fingerprint technique is applied to obtain the efficient and effective communication system. The estimated location accuracy is validated using the pattern matching algorithm. The position accuracy, simple and effective system are become our motivation conducting this research. Moreover, the other motivation for this research is to develop the indoor localization system to become the user-friendly graphic user interface (GUI). There are many kinds of visitors (kid, adult, as well as foreigner, etc.) are visited in the museum. Tracking the location of those visitors is considered. Moreover, classifying of those visitors by their different height is implemented to support the suitable information such as speech, text, video, etc., for them in the future as shown in fig. 1.2.

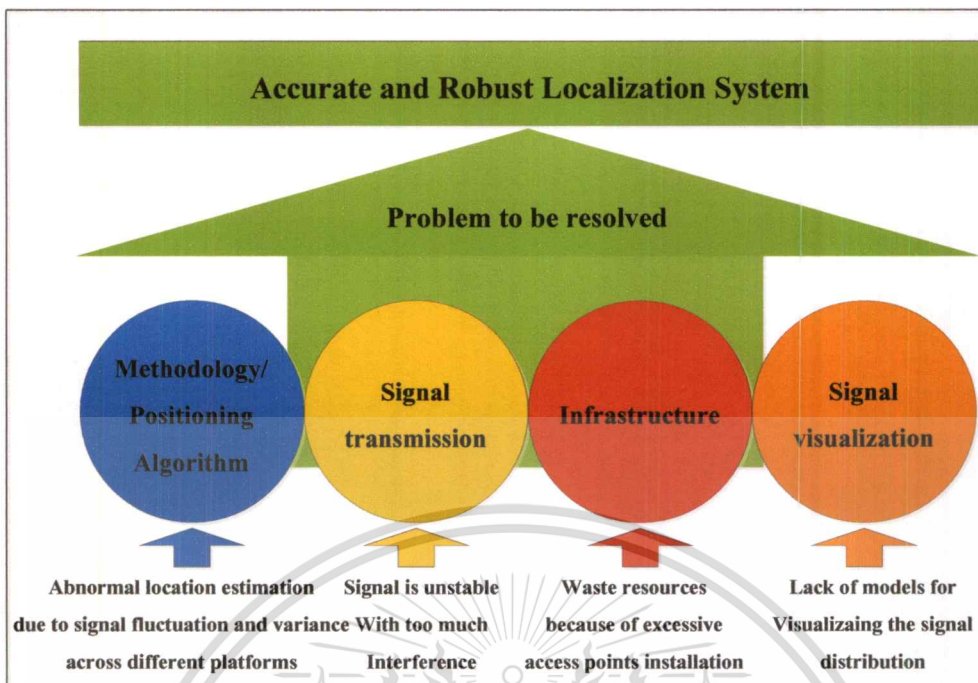


Figure 1.1 Four major problems of the localization system [10]

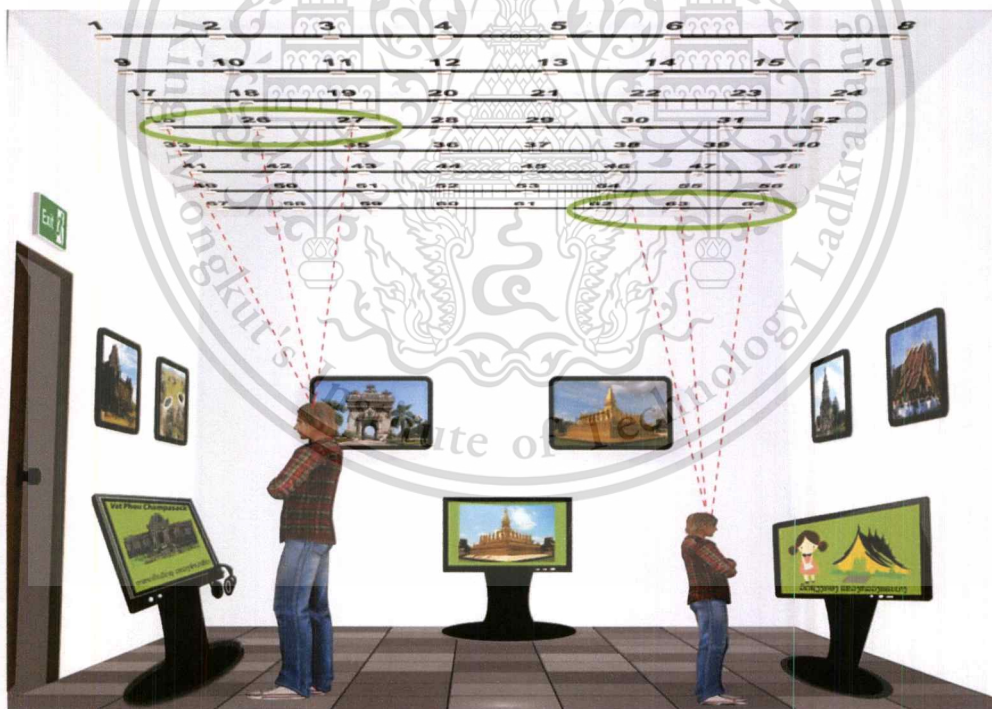


Figure 1.2 The graphic user interface for our motivation

1.3 Objectives

In this research, pattern matching is proposed to be implemented as the processing method for the fingerprint-based technique in indoor localization scenario to investigate the possibility of reducing the power and achieving effective communication in indoor localization system. Implementation of the fingerprint information in database and the target node in the area of interest is emphasized. The maximum value and 2nd maximum value of the dot product which explained in above are employed. So, the estimated location of the target is considered by matching between those information. Moreover, the GUI is developed based on the real situation of area of interest. This application can show the estimated location of the target on GUI in real-time. In addition to estimating the location of the visitor, this system can identify whether the visitors are adult or children by classifying the height of the visitors based on the fingerprint technique. The multimedia information can appropriately provide to different type of visitors which will be future works.

1.4 Thesis Outline

The thesis is organized in five chapters and is briefly summarized as follows.

Chapter 1 introduces some background information and previous works about the research in the localization technique and the application of localization system. The main idea in this chapter is to show the prospective benefit of implementing the indoor localization system that we have done.

Chapter 2 describes the literature reviews of wireless localization or positioning, a type of wireless localization, overview of radio localization, supported algorithm and RFID technology as final. The basic concept of RFID technology related with the communication, platform and parameters are discussed. Several localization techniques are described in this chapter such as the range-based and fingerprint-based localization techniques. In this thesis, the localization technique is employed so pattern matching algorithm and its implementation in our work are presented.

Chapter 3 presents methodology of the research including how to obtain database and to validate the performance of the fingerprint database. The simulation system parameter and hardware components for the research are also given.

Chapter 4 gives the simulation results and analysis of fingerprint based technique using pattern matching algorithm for indoor localization system. The discussions about the result are given more in this section.

Chapter 5 offers the conclusion of the thesis by reviewing and highlighting its contributions which have been presented in this thesis. The recommendations for future works related to this research are given as well.



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CHAPTER 2

LITERATURES REVIEW

The purpose of this thesis is the implementation and analysis of the dot product algorithm in the fingerprint-based localization technique as the indoor localization. The main point is to decrease the error distance of the target location and to create the user-friendly graphic user interface (GUI) system for support accuracy information for the controller. Some essential preliminaries are presented in this chapter, which will be described in the following chapter. Section 2.1 describes the overviews of wireless localization or positioning system. Section 2.2 types of wireless localization are explained. Section 2.3 describes the overviews of radio localization. While Section 2.4 reviews the algorithms supported. And finally section 2.5 the RFID technology is explained in more details, including RFID passive tag which is applied in this thesis.

2.1 Wireless Localization or Positioning

Wireless localization or positioning is one of applications for wireless network which is popular and emerging technology [11]. There are many commercial and government organizations as well as state enterprises have been deployed wireless localization such as in the park (to find the location of the lost children), in the museum (to find the location of the visitor), in the supermarket (to find the location of the customer including their product), in the hospital (to find the location of the patient), in the earthquake area (to find the location of the people who struck inside the building or soil), etc., [12]. Most of these technologies were supported by wireless module such as Global Positioning System (GPS), Wireless Local Area Network (WLAN IEEE 802.11b), Zigbee (XBee module), Ultra Wideband (UWB), Bluetooth (IEEE 802.15) and Radio Frequency Identification (RFID) [13]-[15].

2.2 Type of Wireless Localization

There are two main kinds of wireless localization such as outdoor and indoor localization. The explanation in details will be given more as below.

2.2.1 Outdoor Localization

Outdoor localization is use for locate the location of people, animal, and objects in outdoor environment. In case of finding location for disaster victim, police tracking, thief monitoring, children localization in the park or school, dog positioning, truck or car tracking, and the most popular in recent

day is smart phone tracking (when the mobile was lost the operator can know its location), etc.,. Most of these technologies were supported by Global Positioning System (GPS). GPS is the most well-known among wireless network because of its endurance and accuracy. However, it still have limited for using such as the price, and restricted signal for outdoor localization. The main problem for outdoor localization is signal fluctuating propagation. To solve the problem of localization in outdoor environments GPS was deployed. Unfortunately, the signal from the GPS satellites is too weak to penetrate most buildings, making GPS useless for indoor localization [15].

2.2.2 Indoor Localization

There are many technologies that support indoor localization such as Wireless Local Area Network (WLAN), Ultra Wideband (UWB), Bluetooth (IEEE 802.15) and Radio Frequency Identification (RFID). Some well-reviewed localization papers can be found in [1]-[2]. These technologies have been developed for indoor localization system such as patient tracking in the hospital, location finding of the product, visitor tracking in the museum, etc. Most of these technologies are supported by Radio frequency identification (RFID), because of its abilities to maintain data security, its cost-effective and its endurance. Furthermore, it can identify the difference of objects. This thesis will be given more in details about the indoor localization system based on fingerprint technique and pattern matching algorithm.

2.3 Overview of Radio Localization

Radio localization can be defined as a process to measure the radio signal parameters or information which is consequently used to estimate the location of mobile terminal. In this subsection, the radio localization techniques and its classification will be concisely given. Moreover, the examples of the existing algorithm are explained.

2.3.1 Radio Localization Technique

The two main categories of radio localization technique are mobile-based and network-based localization technology [16].

1) Mobile based Localization Technique

For example, in the global positioning system (GPS), the system has base station (BS) and mobile station (MS) or mobile terminal. The MS estimates its own position based on signals received from BSs.

This form is usually defines as a self-location system. For this localization technique, the MS needs to be modified, so that it is able to obtain highly accurate location estimation. This matter causes to increase cost, size and battery (power) consumption. Furthermore, network synchronization is required.

2) Network based Localization Technique

In the network based localization technique, the BSs measure the MS signal information and relay them to a central site for further estimation of MS position. Unlike the previous category, this form of localization technique is defined as a form of remote location system. One of the advantages of this system is the MS is not involved in the location-estimation process, so this technology does not need the modifications to the existing mobile handsets. The location estimation using the network-based localization technology requires two operations as the BSs: (1) the BSs measure signal parameters such as RSS, AOA, TOA, TDOA, etc., from MS, and (2) the measured signal parameters are combined in a data fusion stage to give the final location estimation.

2.3.2 Taxonomy of Indoor Localization Technique

Indoor localization technique can be classified into three general types: (1) scene analysis, (2) triangulation, and (3) proximity as shown in fig. 2.1 [17].

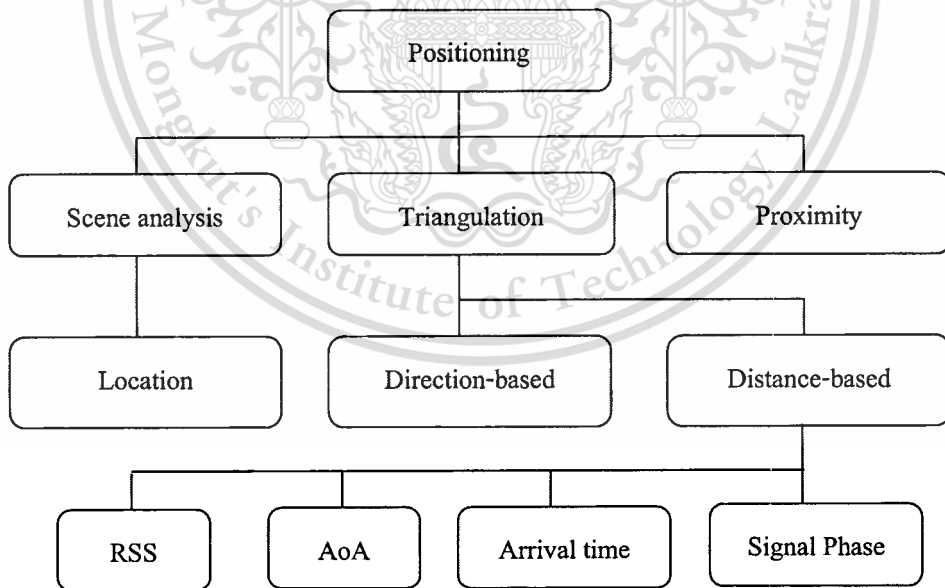


Figure 2.1 Three types of indoor localization techniques

1) Scene Analysis

Scene analysis positioning techniques collect and extract features from observed scene. The scene could be the radio frequency waves, acoustic sound, visual images or measurable physical phenomena which usually exist near the object. The typical technique of radio frequency based scene analysis is location fingerprinting (LF). The observed features (fingerprints) are usually specific and unique. The fingerprints are used to estimate the location of observer or of observed objects in the scene. The distance can be estimated by matching the similarity of features.

2) Triangulation

Triangulation uses the geometric properties of triangles to estimate the target location. It can be divided into subcategories of literation, using distance measurement, and angulations, using primarily angle or bearing measurement. Literation calculates the target position by measuring its distance from multiple reference points. Since it uses the distance for estimating position, this technique is called range measurement technique. The distance can be measured by many parameters such as received signal strength (RSS), time of arrival (TOA), or time difference of arrival (TDOA), and the distance is derived by computing the attenuation of the emitted signal strength or by multiplying the radio signal velocity and the travel time. Roundtrip time of flight (RTOF) is also called received signal phase applied for range estimation in some system.

Angulation locates an object by calculates the angle relative to multiple reference points such as in angle of arrival (AOA).

3) Proximity

The proximity technique usually provides symbolic relative location information. This technique identifies an object with a tag and a dense grid antenna in a known location detects the tag. If the tag is detected by a single antenna, the location of an object refers to 'near' with that antenna. For more than one antenna detect the mobile object, it is considered to be estimated as those the one receives the strongest signal. The example of using proximity technique such as radio frequency identification (RFID), infrared radiation (IR), pressure and touch sensors, and capacitive field detectors.

2.4 Algorithms Supported

Wireless communication system has been used to monitor and measure the environment change. This technology is also appropriate for application of location finding in indoor and outdoor, respectively. For locating and tracking the object or target, there are system and algorithms that have been extensively researched to achieve the reliable and effective system.

2.4.1 Received Signal Strength

The most commonly used parameter to find the location of the target is received signal strength (RSS). The RSS based localization method uses a mathematical model which describes the path loss attenuation with distance. To find the target, the intensity of received signal from the reference points is used to measure the distance between the mobile station (MS) and those base stations (BSs). This is also usually called as beacon node localization technique [16]. Since the distance between the MS and each BS is known using the signal strength measurement, the location of MS can be estimated on a circle which the BS is at the center. In this method, at least three BSs have to be installed. Figure 2.2 shows the geometry of RSS based localization technique.

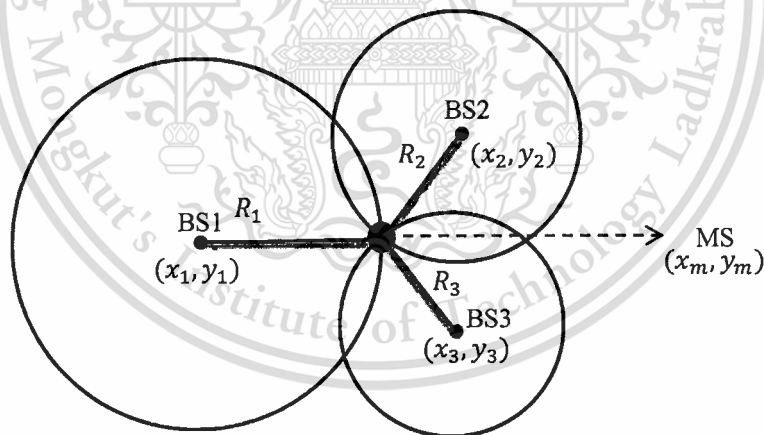


Figure 2.2 Location estimation using the RSS measurement

To measure the distance, the signal strength is converted to the voltage. Due to the variance of the signal environments, this algorithm is not used for the application which needs high accuracy in the result. This is because RSS often gives the error its estimation. An error that occurred may be caused by following factors:

1. Non Line of Sight (NLOS)

The communication is not in a straight line of the measured angle. So, the distance will increase.

2. Multiple access interference is a problem that occurs in any of the Code Division Multiple Access (CDMA) system.
3. Fluctuation in signal propagation: Speed of sound wave propagation is disturbed by external factors such as wind or temperature, and the moisture in the air. These factors can cause high error rates at the greater distances.

To measure the received signal strength indicator (RSSI) in the hardware, especially for ZigBee as IEEE wireless communication standard 802.15.4, the equation of RSSI linearly with the distance is shown in (2.1). The radio signal strength is measured in decibel mill watts (dBm).

$$RSSI = -10n \log_{10}(d) + A, \quad (2.1)$$

where, n is the path loss exponent or the signal propagation constant, d is the distance from transmitter in meter, and A is the received signal strength at 1 meter distance, in dBm. From (2.1), if the distance (d) increases, it will result in a decrease in the signal strength. This result can be used to determine the distance and position of the object [18].

2.4.2 Angle of Arrival (AOA)

AOA is a technique to find the location using the angle of the signal sent from the object (MS) to BSs. It can be defined as AOA based localization technique determines the location of the MS by first calculating the AOAs of a signal received from the MS at several BSs using the array antenna. By considering a two dimensional geometry, the AOAs at only two BSs is enough to estimate the location as shown in fig. 2.3.

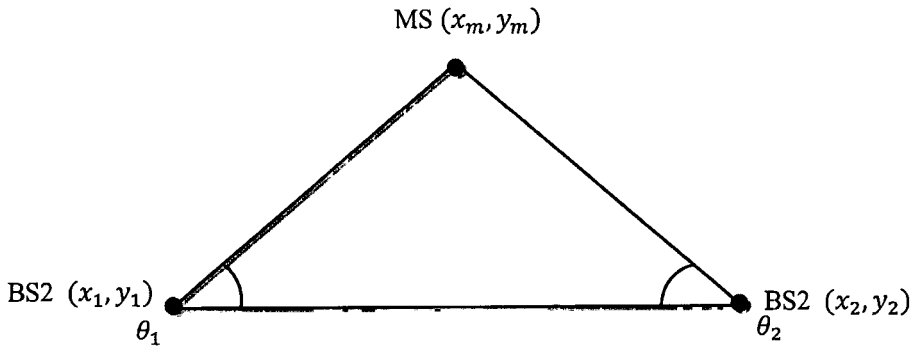


Figure 2.3 Location estimation using the AOA estimation method

Given that, θ_1 and θ_2 are AOAs of the signal from mobile terminal arriving at BS1 and BS2, respectively, the position of MS can be calculated by following equation:

$$y_m - y_1 = \tan(\theta_1) (x_m - x_1) \quad (2.2)$$

$$y_m - y_2 = \tan(\theta_2) (x_m - x_2) \quad (2.3)$$

From (2.2) and (2.3), we can obtain:

$$\theta_1 = \tan^{-1} \left(\frac{|y_m - y_1|}{|x_m - x_1|} \right) \quad (2.4)$$

$$\theta_2 = \tan^{-1} \left(\frac{|y_m - y_2|}{|x_m - x_2|} \right) \quad (2.5)$$

By substituting (2.4) and (2.5), the position of MS (x_m, y_m) will be determined. In this technique, the similar issue in RSS based localization technique is also happened. It is the absence of a LOS signal component between the MS and BSs. It results the estimated angles do not correspond to the actual direction from MS to BSs. Moreover, the multipath still affects the AOA estimation even the system is in LOS between MS and BSs. The error in AOA estimation results in the error in the location estimation of the MS. Because of it, the high accuracy of the AOA estimation is needed to achieve a high accuracy of location estimation [18], [19].

2.4.3 Time of Arrival (TOA)

The TOA based localization method is the method that position of MS can be estimated based on TOAs of the signal of MS arriving at least in three different BSs [19]. If t_i is the TOA of the signal of MS at BS_i , the distance between the MS and BS_i can be calculated by this following equation

$$R_i = (t_i - t_0)c, \quad (2.6)$$

where t_0 is the time instant at which the mobile terminal begins transmitting the signal, and c is the signal propagation speed (speed of light: $c = 3 \times 10^8$ m/s).

2.4.4 Time Difference of Arrival (TDOA)

There are two types of method to calculate the time difference. First, the simplest way to calculate the time difference is to directly subtract the signal arrival times from two receivers. After that the time difference will be converted into range (distance) difference. The second way is to use the cross-correlation technique of two signals to find the range difference.

TDOA is used to solve the problems of consistency and accuracy of the clock signal between the nodes (synchronize). As the signal moving at the speed of light so that the time measurement error of only 1 micro-second, the error in measuring distances up to 300 meters is used in order to solve the problem of the consistency of the clock causes. The TDOA based localization technique estimates the position of MS by finding the intersection of hyperboloids which are the set of range difference measurement between three or more BSs as shown in fig. 2.4.

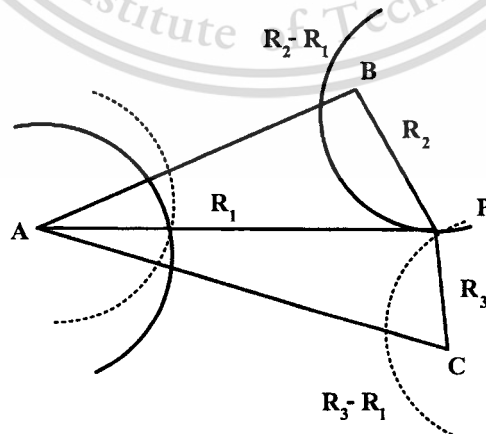


Figure 2.4 Location estimation using the TDOA estimation method

TDOA offers solution in order to find the location of the object by looking up the location of a BS by using the principle of the time. The difference is the quality of the signal from the object to the BS position i and position j to the value of hyper anabolic considered the relationship of the difference of the distance between the BS position i and position j as shown in (2.7).

$$R_{i,j} = ct_{i,j} = R_i - R_j \quad (2.7)$$

$R_{i,j}$ is the difference of the distance between BS_i and BS_j , and $t_{i,j}$ is the difference between the times of the signal from the object to BS_i and BS_j , and c is the speed of light. R_i is TDOA between object and BS position i cross to speed of light and R_j is TDOA between the object and BS position j cross to speed of light. The equation (2.7) will become

$$\begin{aligned} R_{i,j} &= (t_i - t_0)c - (t_j - t_0)c, \\ &= (t_i - t_j)c, \end{aligned} \quad (2.8)$$

where $t_i - t_j$ is the TDOA between BS_i and BS_j . The hyperboloids that explain the range difference $R_{i,j}$ between BSs are given by

$$R_{i,j} = \sqrt{(x_i - x_m)^2 - (y_i - y_m)^2 - (z_i - z_m)^2} - \sqrt{(x_j - x_m)^2 - (y_j - y_m)^2 - (z_{ij} - z_m)^2}, \quad (2.9)$$

where (x_m, y_m, z_m) is the unknown coordinates of the object (mobile terminal), (x_i, y_i, z_i) and (x_j, y_j, z_j) are the locations of BS_i and BS_j , respectively. Similar case in the TOA based localization method, if the number of unknowns or coordinates of the object is equal to the number of equations, or measurements of range differences, the system is consistent and gives a unique solution. On the contrary, the system may be inconsistent and a unique solution may or may not exist. The advantage of TDOA based localization method is that TDOA does not need to know the instant time beginning to transmit the source signal as TOA method does [17], [18], [19].

2.4.5 Location Fingerprinting

The location fingerprinting is one of the localization methods that based on the RSS measurement or other signal information to form a database of known signal-location information. In this fingerprint method, a two-phase process is involved. First, during the off-line calibration phase the received signals

at selected locations are recorded in a database. This database is also referred to as the radio map. Then, the second phase, called the on-line, pattern matching algorithms are used to infer a target's location by comparing the current observed signal features to the pre-recorded values in the database. The key points of this technique are the selection of the spatial signature and the method in constructing database. The location fingerprint is also referred in the literature as pattern matching, pattern recognition, and database correlation.

As mentioned before, to estimate the location of MS, firstly, the system needs to measure the signal information at particular locations and uses some localization algorithms to determine the MS location. The location of MS can be estimated by comparing the current received signal information with the previously recorded as database through pattern matching algorithms. The location in the database that gives the best match or the minimum error between the fingerprint and the current observed signal information is represented as the estimated location of MS. Figure 2.5 shows the block diagram of the fingerprint based localization system.

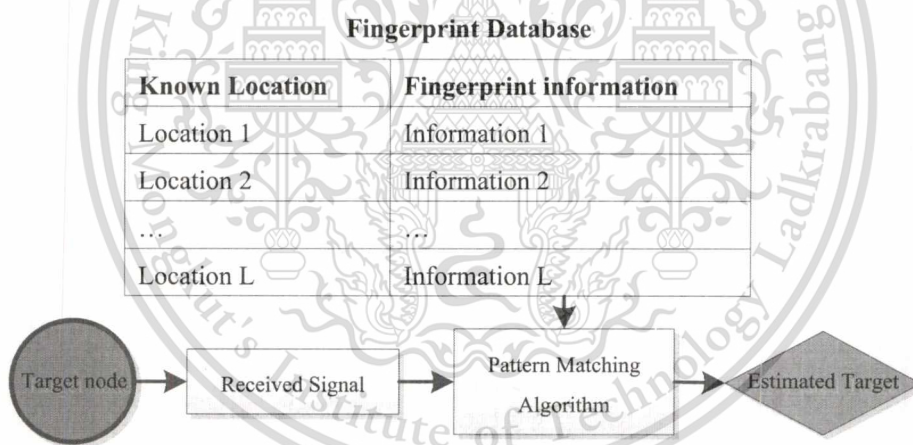


Figure 2.5 Location estimation using the location of fingerprint technique [16]

The advantage of the fingerprint based localization technique is that it requires only 1 BS and does not need the additional or modified hardware or software within MS. Furthermore, it is more appropriate to estimate the location of MS in the multipath environment where the geological method such as AOA, TOA, TDOA, and RSS often fail for locating the location estimation. However, the disadvantages of this technique are time consuming and requiring a lot of effort during the process of constructing database [14]. There are one technique which is included in pattern matching algorithm

namely dot product. In this thesis the maximum value and the 2nd maximum value of the dot product are considered to be main key for estimated location of the target [9].

The dot product is the single number result provided by an algebraic operation that takes 2 equal-length sequences of numbers. In this paper, the dot product is used as the pattern matching algorithm to find the location of the target by multiplying row vector of fingerprint location with the row vector of the observed location [20]. The (scalar-valued) dot product of two n-tuple vectors $\mathbf{u} = (u_1, \dots, u_n)$ and $\mathbf{v} = (v_1, \dots, v_n)$ is defined as

$$\mathbf{u} \cdot \mathbf{v} = u_1 v_1 + u_2 v_2 + u_3 v_3 + \dots + u_n v_n = \sum_{j=1}^n \mathbf{u}_j \mathbf{v}_j \quad (2.10)$$

The properties of the dot product are defined by (2.10) possesses the following important properties:

$$\text{Commutative: } \mathbf{u} \cdot \mathbf{v} = \mathbf{v} \cdot \mathbf{u} \quad (2.11a)$$

$$\begin{aligned} \text{Nonnegative: } \mathbf{u} \cdot \mathbf{u} &> 0 \text{ for all } \mathbf{u} \neq \mathbf{0} \\ &= 0 \text{ for } \mathbf{u} = \mathbf{0} \end{aligned} \quad (2.11b)$$

$$\text{Linear: } (\alpha \mathbf{u} + \beta \mathbf{v}) \cdot \mathbf{w} = \alpha(\mathbf{u} \cdot \mathbf{w}) + \beta(\mathbf{v} \cdot \mathbf{w}), \quad (2.11c)$$

For any scalars α, β and any vectors $\mathbf{u}, \mathbf{v}, \mathbf{w}$. The linearity condition (2.11c) is equivalent to the two conditions $(\mathbf{u} + \mathbf{v}) \cdot \mathbf{w} = (\mathbf{u} \cdot \mathbf{w}) + (\mathbf{v} \cdot \mathbf{w})$ and $(\alpha \mathbf{u}) \cdot \mathbf{v} = \alpha(\mathbf{u} \cdot \mathbf{v})$. For example, the explanation of the dot product $(\alpha \mathbf{p} + \beta \mathbf{q}) \cdot (\gamma \mathbf{r} + \delta \mathbf{s})$. Using (2.11), we obtain

$$(\alpha \mathbf{p} + \beta \mathbf{q}) \cdot (\gamma \mathbf{r} + \delta \mathbf{s}) = \alpha[\mathbf{p} \cdot (\gamma \mathbf{r} + \delta \mathbf{s})] + \beta[\mathbf{q} \cdot (\gamma \mathbf{r} + \delta \mathbf{s})] \quad \text{by (2.11c)} \quad (2.12)$$

$$= \alpha[(\gamma \mathbf{r} + \delta \mathbf{s}) \cdot \mathbf{p}] + \beta[(\gamma \mathbf{r} + \delta \mathbf{s}) \cdot \mathbf{q}] \quad \text{by (2.11a)} \quad (2.13)$$

$$= \alpha[\gamma(\mathbf{r} \cdot \mathbf{p}) + \delta(\mathbf{s} \cdot \mathbf{p})] + \beta[\gamma(\mathbf{r} \cdot \mathbf{q}) + \delta(\mathbf{s} \cdot \mathbf{q})] \quad \text{by (2.11c)} \quad (2.14)$$

$$= \alpha\gamma(\mathbf{r} \cdot \mathbf{p}) + \alpha\delta(\mathbf{s} \cdot \mathbf{p}) + \beta\gamma(\mathbf{r} \cdot \mathbf{q}) + \beta\delta(\mathbf{s} \cdot \mathbf{q}) \quad (2.15)$$

$$= \alpha\gamma(\mathbf{p} \cdot \mathbf{r}) + \alpha\delta(\mathbf{p} \cdot \mathbf{s}) + \beta\gamma(\mathbf{q} \cdot \mathbf{r}) + \beta\delta(\mathbf{q} \cdot \mathbf{s}) \quad \text{by (2.11a)} \quad (2.16)$$

This is the same way that we will get $(a + b)(c + d) = ac + ad + bc + bd$ in scalar arithmetic.

2.5 RFID Technology

2.5.1 Basic of RFID

RFID is a wireless Auto-ID system which has increasingly gained popularity until recent day. It is used to identify any object or person by applying radio wave. RFID is the process and physical infrastructure by which a unique identifier, within a predefined protocol definition, is transferred from a device to a reader via radio frequency waves [21]-[23]. It differs from other technologies such as barcode, finger-print scanning etc., as known it uses the radio frequency to identify difference from barcode that should be scanned by laser to get the information. RFID has been called a replacement technology for bar code. RFID offers many capabilities that barcode system cannot, however, such as ability to both read and write to tags, the abilities to operate without a direct line of sight between tag and reader, and the ability to communicate with hundreds of tags simultaneously rather than one at a time. These capabilities can produce cost-saving benefits that will offset the high price of implementing RFID in many cases. RFID technology has been known since 1945. At that time it uses to intercept signal from an airplane to identify between the allied and the enemies. Nowadays, the application of RFID are developed and used in many kinds of work such as smart home system, car parking system, location finding for customer in the supermarket, patient tracking in the hospital, location finding of the product, visitor tracking in the museum, etc.

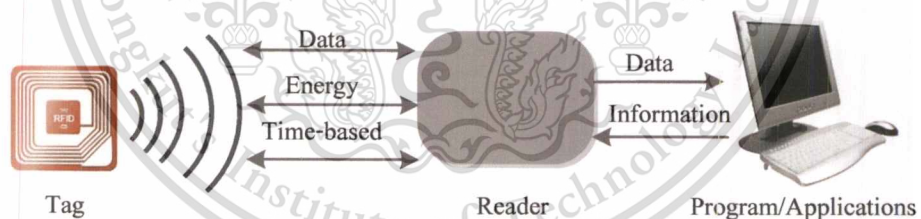


Figure 2.6 Extended RFID Infrastructures [19].

Figure 2.6 shows the interaction of the component of RFID that consists of RFID tag or transponder, RFID reader and computer program (applications). The communication between the RFID reader and RFID tag is based on data, energy, and time. The applications deployed the data (signal) received from the reader and the information (signal/ID) transferred back or it was keep in the database.

For the frequency of radio wave can be classified into standard categories as shown in Table 2.1. In this thesis the UHF-300 MHz to 2999 MHz is deployed as the frequency of RFID reader. 902 MHz- 928 MHz is the actually frequency which is applied.

Table 2.1 Frequency Classifications

Designation	Frequency	Wavelength
ELF = Extremely low frequency	3 Hz to 29 Hz	100,000 km to 10,000 km
SLF = Super low frequency	30 Hz to 299 Hz	10,000 km to 1,000 km
ULF = Ultralow frequency	300 Hz to 2999 Hz	1,000 km to 100 km
VLF = Very low frequency	3 kHz to 29 kHz	100 km to 10 km
LF = low frequency	30 kHz to 299 kHz	10 km to 1 km
MF = Medium frequency	300 kHz to 2999 kHz	1 km to 100 m
HF = High frequency	3 MHz to 29 MHz	100 m to 10 m
VHF = Very high frequency	30 MHz to 299 MHz	10 m to 1 m
UHF = Ultrahigh frequency	300 MHz to 2999 MHz	1 m to 10 cm
SHF = Super high frequency	3 GHz to 29 GHz	10 cm to 1 cm
EHF = Extremely high frequency	30 GHz to 299 GHz	1 cm to 1 mm
VHF = Very high frequency	30 MHz to 299 MHz	10 m to 1 m
UHF = Ultrahigh frequency	300 MHz to 2999 MHz	1 m to 10 cm

2.5.2 Past, Present, and Future of RFID [21]-[23]

2.5.2.1 The Past

In 1888, the German physicist Heinrich Rudolf Hertz (1857 to 1894) was the first to prove the existence of electromagnetic radiation and Maxwell's Theories. Hertz accomplished this by building a device that produced radio waves. Soon thereafter, in 1901, Guglielmo Marconi (1874 to 1937) transmitted a transatlantic radiotelegraph (WGBH, 1998). Marconi has sent the first wireless long distance transmission making the start of a new era in human history. Twenty-three years later, the British Broadcasting Corporation (BBC) was already transmitting across England and Europe.

Moreover, the researching during 1920s to 1930s eventually led to the development of radar (radio detection and ranging) (Landt and Catlin, 2001). Radar was the first developed as an anti-collision system. Radar can determine the location of an object using three basic steps. First, a directed radio wave is transmitted. Next, the radio wave propagates from the source and is reflected by any object with which it comes in contact. Lastly, when the source services the reflected radio wave, a simple calculation is performed to determine the distance of the object from the source. The distance of the object from the source is given by the equation:

$$\text{Distance} = ct/2 \quad (2.17)$$

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In this equation, c is the speed of light and the variable t is the amount of time it takes for the wave to travel from the source to the object and back. The multiplication of these two variables results in the total distance traveled by the radio signal. The total distance must then be divided by two to account for the fact that the signal traveled to the object and returned.

Radio broadcasting and radar are the technologies fundamental to radio frequency identification. The first known implementation of RFID is believed to be the “identification friend or foe,” or IFF, system developed during World War II. The IFF system allowed the British military to determine if incoming aircraft were friendly or hostile. Using radar technology a signal was transmitted from a British military base to an incoming airplane. This signal would excite the airplane’s radio transponder. If the airplane was friendly, the transponder was expected to transmit a reply to the military base encoded with a secret code that identified the incoming airplane as being friendly. If the airplane responded with the wrong code or the airplane failed to respond, the British military would consider the incoming airplane to be a possible threat (Wikipedia, 2005c). The IFF system was later enhanced to reduce friendly fire between airplane and between Allied forces. An enhanced IFF system is still in use today by most military forces around the world. Today, much more data is transmitted than a single code, but the concept is much the same as it was in 1940s as shown in fig 2.7.

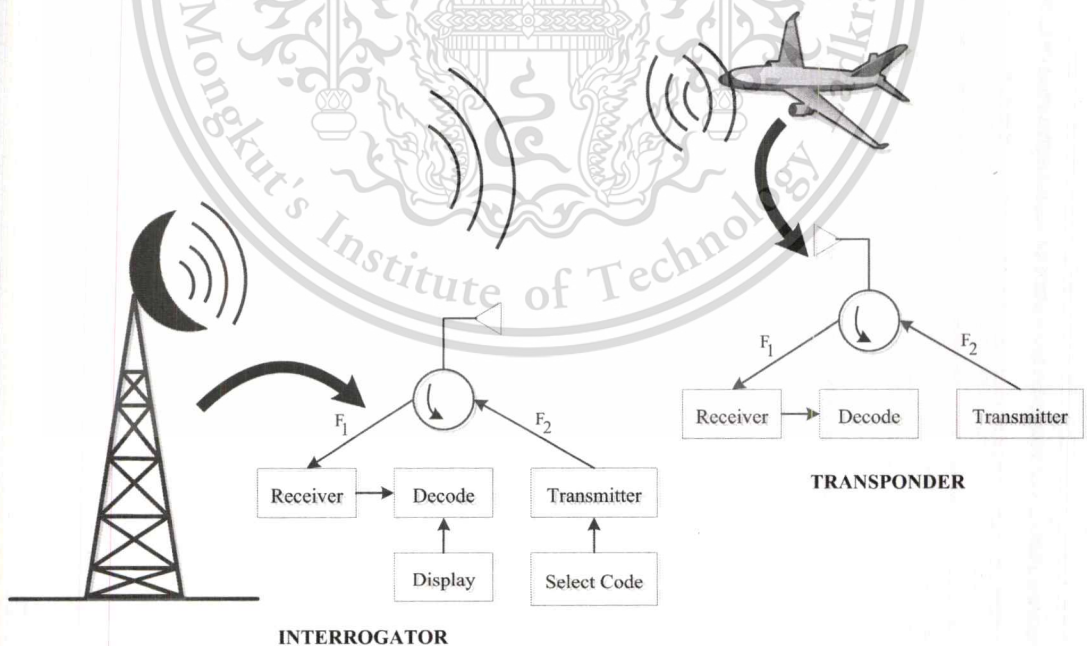


Figure 2.7 The identification friend or foe (IFF) system

2.5.2.2 The Present

Radio Frequency Identification (RFID) technology are very popular in recent days. This technology leads the research in commercial and industrial sectors, agriculture sectors, food-beverage and healthcare sectors, and education sectors. Especially, the commercial and industrial sectors include the transportation and distribution, retail and consumer packaging, industrial and manufacturing, as the final is security and access control. As note, most of the recent growth in RFID technology has been in various commercial sectors of the global economy. However, as potential users of RFID technology gain understanding of the technology and assess the impact it will have on their business environment, user demand will increase and further opportunities for development will emerge. However, with additional strategic thinking and innovative application development, RFID usage will develop, expand and become a commonplace technology that is used throughout the world.

As table 2.1 is the list of specific RFID applications prominently in use today. While not necessarily a comprehensive list, it dose provided some insight into the scope and breadth of the technology's applicability and usage in today's society.

Table 2.2 Current RFID Commercial Applications

Sectors	Applications
Transportation and distribution	<ul style="list-style-type: none"> - Aircraft, Vehicles, Rail Cars - Containers Equipment - Fixed Asset Tracking - Real-Time Location System
Retail and Consumer Packaging	<ul style="list-style-type: none"> - Supply Chain Management - Carton Tracking - Crate/Pallet Tracking - Item Tracking - Inventory and Tracking
Industrial and Manufacturing	<ul style="list-style-type: none"> - Manufacturing - Tooling - Work-in-Progress

Table 2.2 Current RFID Commercial Applications (cont.)

Sectors	Applications
Security and Access Control	<ul style="list-style-type: none"> - Airport and Bus Baggage - Anti-Counterfeiting - Computer Access - Employee Identification - Forgery Prevention - Branded Replication - Parking Lot Access - Room, Laboratory, and Facility access

2.5.2.3 The Future

Interest in RFID technology is growing rapidly. In 10 to 15 years RFID technology will be ubiquitous. The quickly falling cost of implementation, the emergence of an RFID standard, and a potentially high return on investment are all contributing factors to this phenomenon. The RFID systems are consisted of RFID tags, RFID reader and RFID hosts. In the coming future, the RFID tag's prices will be quickly fall than in the past. The power consumption will be decreased, it means can use for longer time than before (for active tag). The communication between tag and reader will be extended to longer distance. The size of RFID readers will smaller than before, the responsible for communicating with RFID tags and relaying information to and from RFID host computers are more fast and accurate, it also implement the security and anti-collision measures. Finally, RFID hosts are used to network multiple RFID reader together to form coherent RFID networks. As soon as, it possible to use the same frequency standard in the world, it means the products of RFID which buy from Europe can be used in Asia as the opposite ways the RFID products from Asia must be can used in Europe as well.

In coming future, RFID will be widely understood. Its applications will not only supported for commercial sectors, industrial sectors, agriculture sectors, education-sport-culture sectors, and food-beverage and healthcare sectors but it will cover all in every sectors such as government working, management natural resource and environment, foreign affairs, secure between country, religion studying, etc.

2.5.3 RFID Architecture

The fundamental components of RFID are including RFID reader, RFID tag, middle ware, RFID database and enabled applications some are referred as fig. 2.6. The most atomic element of RFID is the tag. The communication protocol between the antennas on the tag and on the reader allows the two entities to pass data back and forth as shown in fig. 2.8.

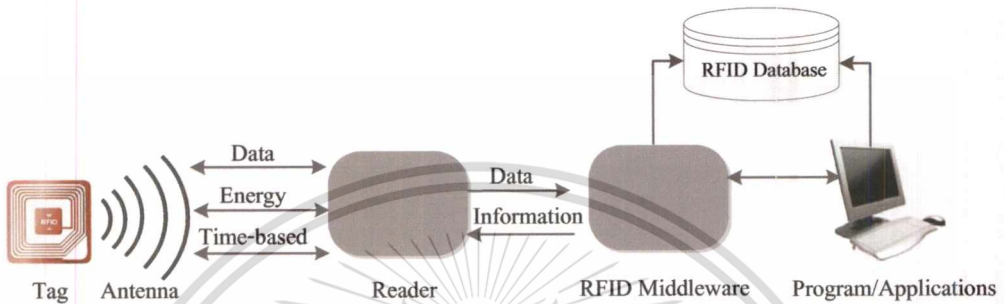


Figure 2.8 Fundamental components of RFID [21]-[23]

The passive tags will gain the power from the reader. For the active tags, it will gain the energy from the internal battery. The data/information will transferred to/from RFID middle ware. The RFID middleware is the link between RFID devices and existing system software. Features and functions of middleware will vary from deployment to deployment, but many of concepts are common to most to most successful RFID implementations. Three majors functional segments are addressed in middleware capabilities: device controls, event management, and tagged object tracking refers to fig. 2.9 which shows the RFID components application stack.

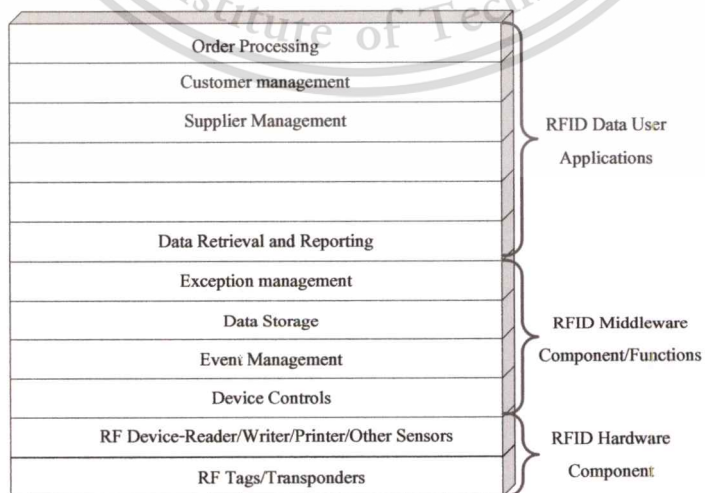


Figure 2.9 RFID Component application stack

2.5.4 The RFID Reader

Another important part in an RFID system is the reader subsystem. It is impossible to divide an RFID reader system into differentiated groups, namely, the high frequency interface and the control system. These groups interact among each other and with an external host system. The main functions performed by a reader are demodulating the data received from the tag. For more details about diagram of the reader is shown in fig. 2.10.

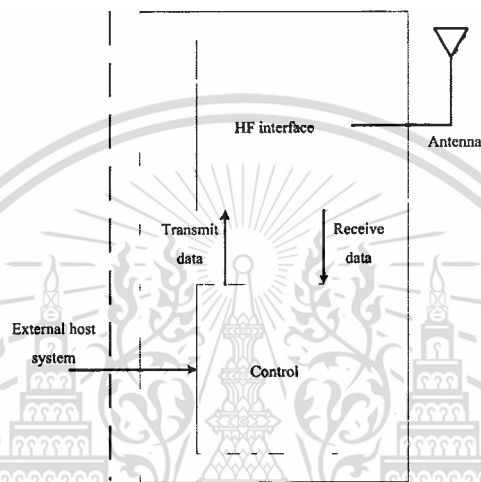


Figure 2.10 General RFID reader diagram

2.5.4.1 The HF Interface

The HF interface performs the following basic functions:

- Demodulating and decoding the data retrieved from the tag
- Energizing, in the case

Elements include the following:

- Transmitter: The capability of the transmitter is to transmit power and the clock cycle to the tags. It is part of the transceiver module.
- Receiver: This component is responsible for receiving signals from the tag via the antenna. Afterward, it sends these signals to a microprocessor, where the digital information is extracted.
- Power: This module supplies adequate power to all components in the reader.

2.5.4.2 The Control Group

To allow the function of decoding, error checking, and communication with an external system, the control unit makes use of a microprocessor, a controller, a communication interface, memory, and input/output channels:

- Microprocessor. In the microprocessor the reader protocol is implemented. The microprocessor interprets the receive command, and depending on the protocol required by the specific standard (i.e., ALOHA for HF frequencies, Tree walking for UHF frequencies), the microprocessor searches the memory for the corresponding program code and executes it. It is here where error checking is performed.

- Controller. In order to allow joint operation with an external system, a system called the controller, responsible for converting external orders to understandable microprocessor binary code, is needed to enable communication. It is possible to have a controller in either a software or hardware form.

- Communication interface. By using the controller, the communication interface is able to interact with an external host system by transferring data, passing or responding to instructions. The communication interface can be a part of the controller or an independent entity depending on the integration level and speed requirements.

- Memory. The memory is responsible for storing the data receive from the tags. The data will be transmitted to the host system when demanded.

- Input/output channel for external sensors. When a reader is in operation, the tag might not be in its read range, making continuous operation a waste of energy. By using external sensors able to detect the presence of an nearby-for instance, in a conveyor belt crossing in front of the reader-it is possible to efficiently operate the reader by activating it at the required times.

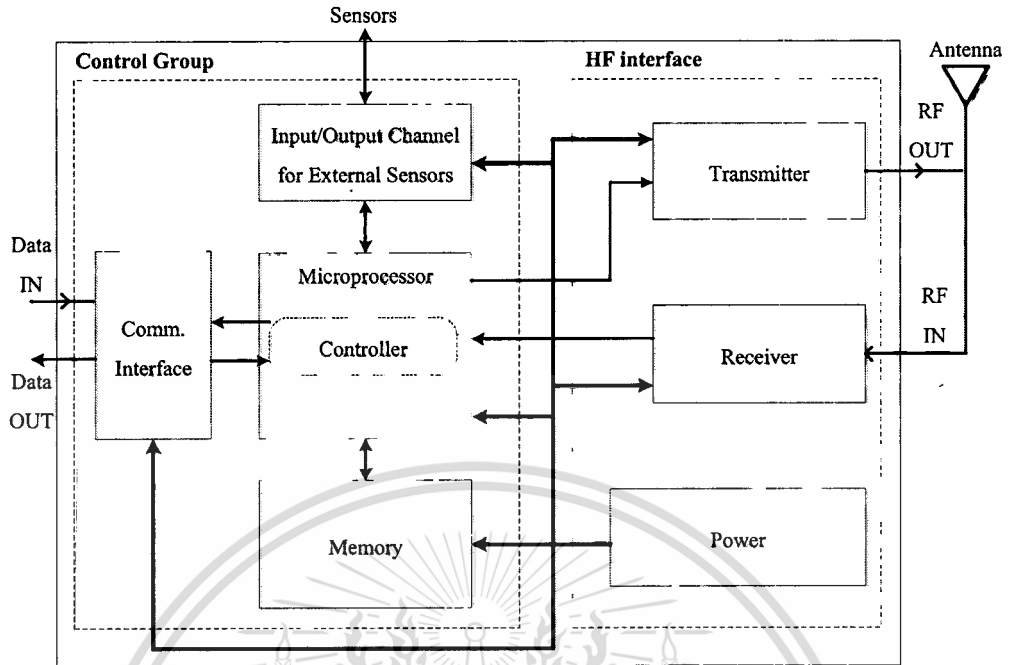


Figure 2.11 Sub-block RFID reader diagram

Additionally, it is possible to classify the readers by the communication interface in use or by its mobility. A brief description of each category follows.

Communication interface:

+ *Serial RFID reader*. This reader uses a RS-232 (Recommended standard 232) serial port to communicate with the host system and transfer data or commands executed by the user or application. These readers have a lower data transfer rate compared with others, such as a wired network reader, and have a cable length limitation. Moreover, serial port connections are more reliable.

+ *Network RFID reader*. This reader can be connected wired or wirelessly to a computer; therefore, it appears as a network device. In this case, the cable length is not a limitation, but the connection is not as reliable as a serial readers.

Mobility of readers:

+ *Stationary reader*. These readers are mounted on a wall, portal or suitable structure in the read zone. They can be mounted on moving objects such as trucks. These readers usually are connected to external antennas. Agile readers are able to operate in different frequencies and use different communications protocols. An RFID printer is a type of stationary reader able to print a barcode and write on its RFID tag.

+ Handheld reader. This type of reader has an integrated antenna on it and can operate as a handheld unit.

2.5.5 The RFID Tags [21]-[23]

On more important part of RFID system is RFID tag or sometimes called transponder. It is different shapes, size, and capabilities. When an RFID solution is designed, the solution's architect must take into account both business and technology requirements before choosing the type of RFID tag to use. This section examines the different types of tags available and discusses how and when a certain type of tag should be used. Matching the best frequency to be an application for the tags is shown on Table 2.3.

Table 2.3 Common Frequency and Their Uses

Frequency Range	Common Frequency	Common Uses
LF-Low frequency	<ul style="list-style-type: none"> • 30 kHz • 125 kHz • 134.2 kHz • 300 kHz 	<ul style="list-style-type: none"> • Access control • Animal identification • Lot identification • Chemical process use • Distribution
HF-High frequency	<ul style="list-style-type: none"> • 3 MHz • 13.56 MHz (ISO 15693) • 30 MHz 	<ul style="list-style-type: none"> • Logistic warehouse management • Automotive manufacturing and tracking • Retail • Hospitals • Baggage check • Library management • Parcel tracking • Security • Smart card

Table 2.3 Common Frequency and Their Uses (cont.)

Frequency Range	Common Frequency	Common Uses
UHF-Ultrahigh frequency	<ul style="list-style-type: none"> • 300 MHz • 433 MHz • 866 MHz (Europe) • 915 MHz (United States) 	<ul style="list-style-type: none"> • Retail • Toll roads • Logistics-inside a factory and through the supply chain • Long-range applications • Item tracking
Microwave frequency	<ul style="list-style-type: none"> • 2.54 Gigahertz • 3.0 Gigahertz 	<ul style="list-style-type: none"> • Long-range applications • Item tracking • Freight tracking

All RFID tags have the following essential components in common:

Antenna

1. Integrated circuit
2. Printed circuit board/substrate

2.5.5.1 Antenna

A task of an RFID tag's antenna is to transmit and receive radio waves for the purpose of communication. The antenna is also known as the coupling mechanism. The electronics, coupling refers to the transfer to energy from one medium to another. In the case of RFID, the transfer of energy is in the form of electromagnetic radiation, which is the way the tag and reader communicate. Some antennas are also designed to collect energy from radio waves. In the correct environment and proximity to an RFID tag reader, these antenna can collect enough energy to power the tag's other components without a battery. Based on the type and intended use of the tag, the antenna may have many different shapes and sizes.

2.5.5.2 Integrated Circuit

The integrated circuit (IC) is a packaged collection of discrete components that provide the brains for the tag. The IC in an RFID tag is much like a microprocessor found in any cellular phone or

computer, but it is usually not very sophisticated, and for many RFID tag, the IC component has a single purpose. Its purpose is to transmit the tag's unique identifier. If the tag has any peripheral components, the IC is also the master controller that is responsible for gathering any extra information and transmitting it long with the tag's unique identifier.

To ensure that all tags do not transmit their information at one time, the IC is responsible for implementing the correct transmission algorithm. These algorithms either ensures that the tag transmits at the proper time slot or cause the tag transmit at random intervals.

2.5.5.3 Printed Circuit Board/Substrate

The printed circuit board (PCB) is the material that holds the tag together. The circuit board may be rigid or flexible and is composed of many different types of materials, depending on the type and purpose of the tag. For example, tags that are used for tracking components on an assembly line where extremely high temperatures may be encountered would tend to be much more rigid and are usually placed inside a protective enclosure. Flexible tags must be durable enough to withstand the stress of any normal barcode tag but also protect the internal IC. RFID tags used in document tracking solutions may be very flexible, so that they bend with the paper. Flexible tags use thin plastic films in which the tag's components and circuit PCBs are also known as inlays. Tags that may be applied to a part or subsystem in a manufacturing process may use in flexible tags that encase the tags components and circuitry in a type of epoxy resin. Most rigid tags are also housed in some time of enclosure to further protect the PCB and components.

There are three main types of RFID tag. They include active tag, semi-active tag and passive tag. In this thesis the explanation about passive tag will give more details than the other types because the passive tags are deployed as the reference nodes.

2.5.5.4 RFID Active Tags

The onboard power source allows active tags to be extremely flexible in terms of the functionality they can offer. The battery affords the tag a greater read range and allows the tag to be read through materials that are usually impenetrable to magnetic radiation broadcast by other types of tags; however, active tags do not get as much publicity today as the other types of tags found on the market. This is mainly because active tags are larger in size and cost more than passive tags. The size of tag grows as the number of extra components and as the size of the battery increases. Figure 2.12 shows an example

of an active tag manufactured by RFCode Corporation. The metallic clip pictured on the front of the tag holds the tag's battery.



Figure 2.12 RFCode Corporation, active tag and enclosure [www.realtimeid.com]

Active tags that use battery as a power source have a limited life span. The tag's life span is usually measured in years of operation. Most active tags offer a replaceable battery for when the tag has depleted the energy stored in the battery. Active tags are commonly used in real-time location system (RTLSS). RTLSSs allow organizations to instantly know the location of a tag because the tag is constantly monitored by a network of antennas and readers. Tags are associated with assets such as laptops and other types of expensive or vital equipment. In most RTLSSs, the tagged assets must be visible to the systems. If an asset disappears, the system will notify the proper users that an asset has disappear in addition to the asset's last known location. Process analysis is also a common use for active tags. Tags are placed on the various actors in a process such as people, tools, and products. The active RFID system collects data as the process is performed.

2.5.5.5 RFID Semi-Active Tags

Semi-active tags are a cross between a passive and an active tag. They do contain onboard battery like the active tag, but the battery is not used unless the tag is interrogated by a reader. A semi-active tag still has a short interrogation range when compared to an active tag because, as with a purely passive tag, it must travel fairly close to an antenna in order to activate the battery. Once the battery is activated, the tag can behave exactly like an active tag. If the tag has temperature or chemical sensors, the battery can power those peripheral exactly the same way that a pure active tag can. Also the battery allows the tag to transmit at the same power level as an active tag, which gives the tag greater transmission distance. Semi-active tags may contain peripheral functionality on the same scale as an active tag. It is

important to keep in mind that both active and semi-active tags are bounded by the maximum lifespan of the onboard battery.

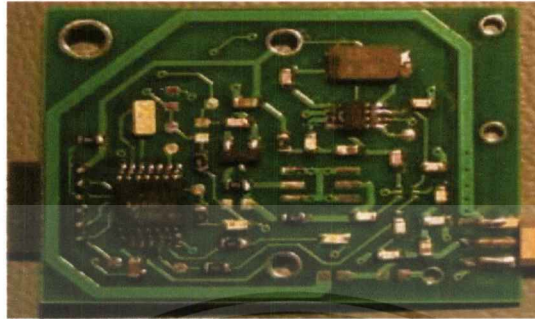


Figure 2.13 The RFID semi-active tag [http://home.ku.edu.tr/ctasdemir/public_html/]

2.5.5.6 RFID Passive Tags

The passive tags are significantly cheaper; thus they are the tag of choice for high-volume, supply chain solutions where thousands to millions of objects will be tagged. Passive tags do not contain an onboard power source. This equates to lower-cost and typically smaller tags when compare to most active tags. Passive tags derive their energy from an electromagnetic field supplied by a close-proximity antenna attached to a tag reader. The lack of an onboard power source limits the range at which passive tag can be powered and read. The distance at which the tag can be read is directly proportional to the amount of an energy it can absorb from the electromagnetic field generate by an antenna connected to the reader. In addition, the amount of energy that can be absorbed is directly proportional to the length of the tag's antenna.

Passive tags are usually much smaller than active tags. Some passive tags, such as Hitachi's μ -Chip[®], depicted in fig. 2.14, can be smaller than a grain of rice. The μ -Chip's read range is extremely limited because of the length of the tag's antenna, but it can achieve a read range up to 25 cm when an external antenna is used. This range will be reduce even farther if the tag was separated from the reader by a type of material that impaired the propagation of electromagnetic radiation between the tag and reader.

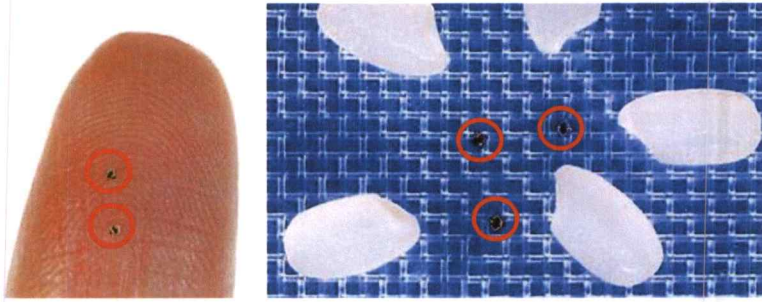


Figure 2.14 Hitachi's μ - Chip passive tag on fingertip (www.hitachi.com)

The red circle in fig. 2.14 refers to the Hitachi's μ - Chip which has the size 0.4×0.4 mm and the radio frequency 2.45 GHz. The information of the passive tags is transmitted by an RF technique called "backscatter." A tag uses the backscattering technique when interrogated by the reader by transmitting the response data back along the reader's original interrogation carrier wave. Most passive tag antennas are engineered for energy collection and efficient backscattering, which creates an antenna that is not very good for transmitting.

The organization which is set up to achieve worldwide adoption and standardization of Electronic Product Code (EPC) technology or "EPCglobal, Inc" has defined six classifications for RFID tags (0 to 5). Table 2.2 is an overview of the classifications of tags based on their power characteristic, read range, memory capabilities, communication protocol and peripheral systems. For passive tags are usually classified into class 0 to 3. The RFID passive tags that deployed in this thesis are based on class 1 Gen 2. Class 4 describes active tags, and class 5 is reserved for tag readers and active tags that can be read data from other tags.

Table 2.4 EPC Tag Classification

Class	Power	Range	Memory	Peripheral	Cost
0	None	< 3m	1 to 96 bits Read Only	None	Low
1	None	< 3m	1 to 96 bits Read/Write Once	None	Low
2	None	< 3m	1 to 96 bits Read/Write	Security	Medium
3	Battery Assisted	< 100 m	< 100 Kilobytes Read/Write	Security, Sensors	High
4	Battery Assisted	< 300m	< 100 Kilobytes Read/Write	Security, Sensors	High
5	Battery Assisted /AC/DC connection	Unlimited	Unlimited Read/Write	Security, sensors, can communicate with other tags	Very High

CHAPTER 3

IMPLEMENTATION AND RESEARCH METHODOLOGY

In this chapter, the research methodology is presented. The fingerprint-based localization technique is used as the technique to find the estimated target location. The previous researches of fingerprint-based localization technique in indoor localization have been presented in [16], [17]. The implementation of dot product using the fingerprint technique can be referred as simplifying method in pattern matching algorithm. In this research, the performance of localization technique in indoor environment is analyzed by comparing the true location information (IDs information) and the object/target information (IDs information). The estimated location of the target is provided after, the accuracy of the estimate location of the target is considered. The 2D scenario and 3D scenario are considered for implementation to find the location of the target and also its error distance which compare by true observed location and the estimated location. In 3D localization the user friendly system (GUI) is provided the estimated location of the target in real-time.

3.1 The equipment of experiment

In this thesis, the indoor localization using fingerprint technique to find the location of an object (wireless device) is utilized. The implementation of fingerprint technique using dot product as the pre-processing before pattern matching algorithm of fingerprint technique is proposed. In this subsection, the explanation of the experiment setup and fingerprint database will be described.

For indoor localization system, both 2D and 3D indoor localization system, the RFID passive tags are scattered in the area of interest (fingerprint locations) and the RFID reader is placed as the target location. From fig 3.1, the 64 passive tags are separated and attached to the ceiling in the area of interest and all of them have the unique ID to refer itself. The reader will be held on the robot, it is stable or moving to the observed locations as the same manner between 2D and 3D scenario. The difference for 3D scenario is the fingerprint information (database) was combined between the ID information from 100 cm height and 160 cm height. For more detail about 2D and 3D scenario setup is will be given in the next section.

In thesis, the experiment was conducted at the hall of 6th floor, 12th building, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL). The equipment for doing experiment are included:

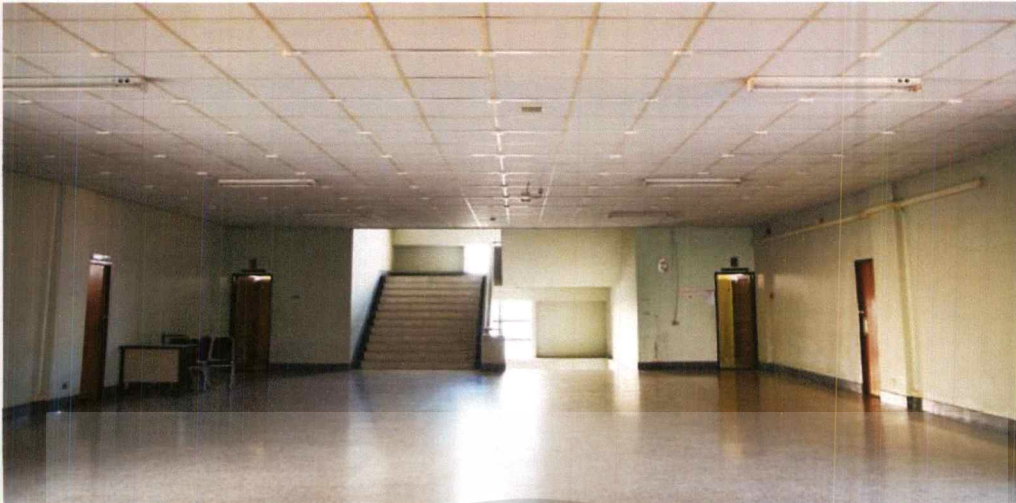


Figure 3.1 Illustration of the real experiment setup in 840 cm × 840 cm

- Notebook Computer: The UHF801 Integrated Reader program was installed in the computer to communicate with RFID reader. This program was developed by Microsoft Visual Basic 6.0 as shown in fig. 3.2 (We were developed our GUI by editing this program). The serial port RS232 is deployed as the connector between the computer and the RFID reader. Since computer which is applied has only USB port so it needs to have the accessories to convert from serial port to USB port as illustrated in fig. 3.3 and fig. 3.4. The explanations about setting program that used for experiment are shown as Table 3.1.

Table 3.1 UHF Integrated Reader program setting

Settings	Setup Properties	Notice
Computer Port	COM8	Supported port for notebook computer
BaudRate	9600bps	-
Addr Code	Generic	-
Power	30 dBm	1 W or 1000 mW
FreqUse	902 MHz-928MHz	920 MHz to 925 MHz (ISO Thailand UHF used)
FreqType	China	The third frequency range of China is 915 MHz to 928 MHz UHF
Time	continuous	After finished one time then continuous to read until pause stop button in program.
Interval	10 ms	10 millisecond per 1 time for reading

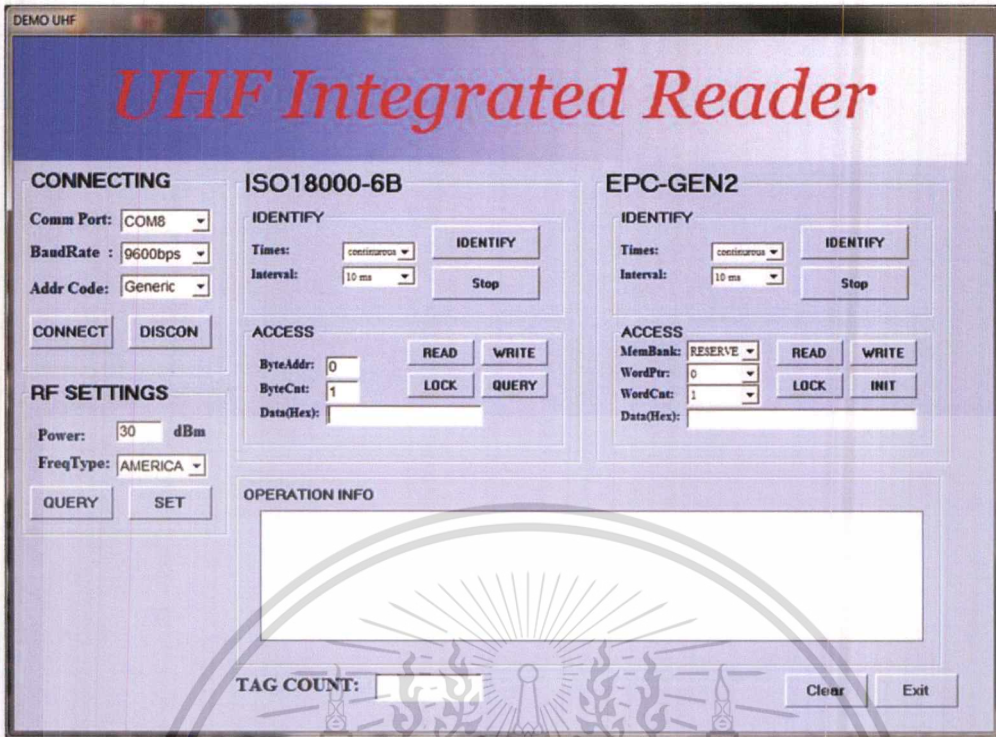


Figure 3.2 UHF integrated reader program

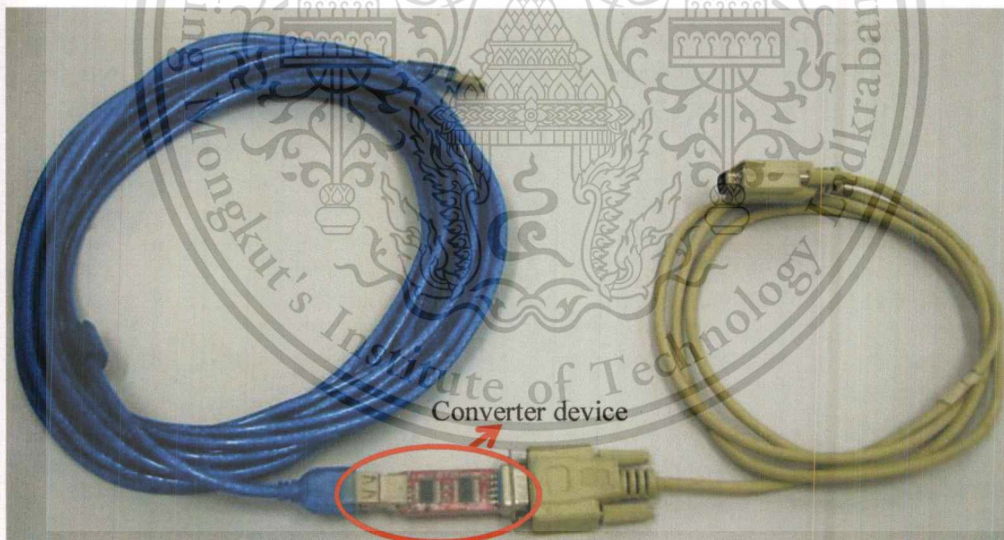


Figure 3.3 Converter devices from serial port RS232 to USB port

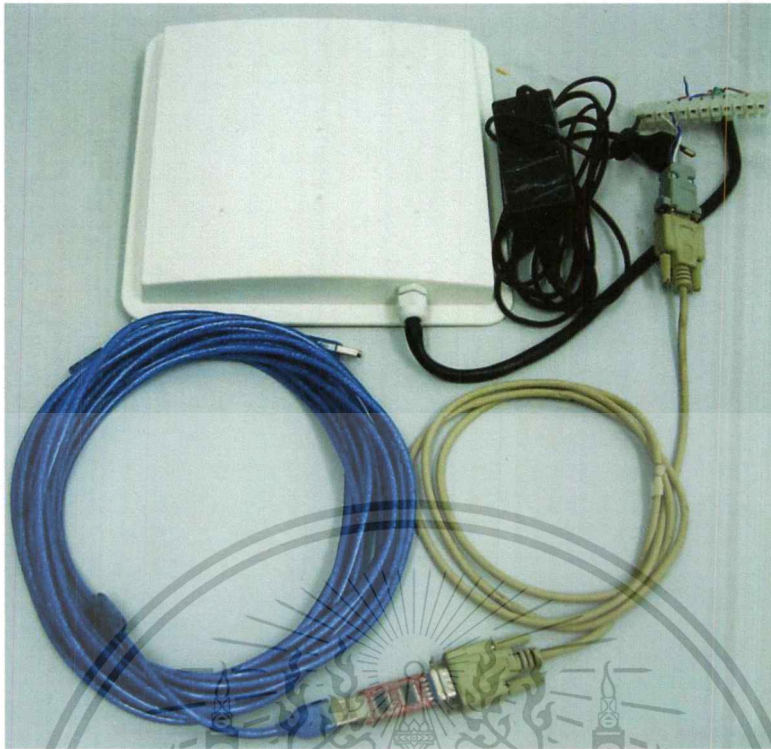


Figure 3.4 Connecting between RFID reader, USB port and RS232 serial port

- Passive tag

The factors of cost-effective and power consumption are the reason deploying this RFID passive tag. The other reason is the distance for reading ID information is suitable with this experiment. RFID passive tags which applied in this work are Rafsec brand, ISO EPC Class1 Gen 2, internal memory 240 bit, supported frequency between 860 MHz to 960 MHz. It used polarization antenna, this antenna is made from aluminum. As known, RFID passive tags have no build-in power source. Power is provided by the radio wave created by the reader that induces in the antenna a tiny but sufficient electrical current to active the tag.

Table 3.2 Comparison the abilities of passive tag and active tag

Active tag	Passive tag
Internal power source	External power source (gains energy from the reader)
Shorter battery life	Longer battery life
Detecting away from the reader	Cannot be detected away from the reader (only 3 m-5 m)
High cost	Low cost
Bigger size	Smaller size

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The information from Table 3.2 gives the easier decision about choosing the devices for support indoor localization in this thesis. Since RFID passive tag has long life battery, more cheap, small size, and endurance. In this experiment, 64 RFID passive tags are deployed as the fingerprint locations (reference nodes).

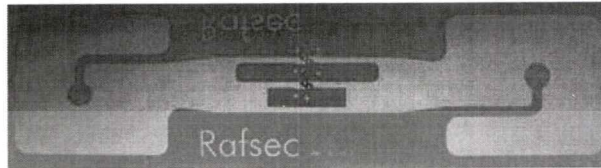


Figure 3.5 RFID passive tag with polarization antenna

- RFID reader

In this project, RFID reader which is deployed work in Ultra High Frequency (UHF) version URW801/811. This RFID reader is quite cheap and suitable with this experiment. It was sale by Acentech* Company (Thailand). For more details, it will be shown in Table 3.3.

Table 3.3 Specification of RFID Reader

Specification of RFID Reader	
Version	URW 801
Read range	3m – 5 m
Protocols	ISO 18000-6B, 6C and EPC Gen 2
RF Output Power	20-30 dBm
Modulation Method	ASK or FSK
Dimension	Length 215 × Width 215 × Height 75 mm
Weight	Approximately 1 kg
Frequency	902-928 MHz, 920-925MHz
Power consumption	<6W
Connector	RS232 serial port
Antennas Connectors	1 antenna build-in
Read rate	<30 tags per second
Carrier	Frequency Hopping Spread Spectrum
Hopping Channel	63 Channels
Channel Spacing	400 KHz
Protection Level	IP54

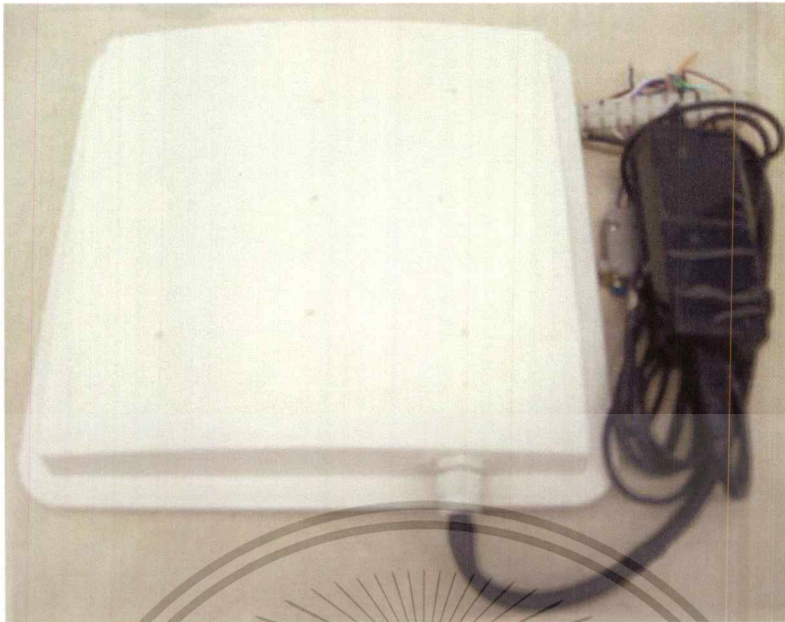


Figure 3.6 UHF RFID reader (Ultra High Frequency 902 MHz to 928 MHz)

- Manual Robot

For the hardware design of the robot are consisted of H-Bridge circuit, microcontroller AVR ATmega1280, Bluetooth EGBT-046S, and sensor ELB140D30 which connected to the wheel. Since H-Bridge circuit is the standard circuit which can control the motor and gives more effectiveness, so in this work the H-bridge circuit is deployed.

The module Bluetooth device in our board receives the Bluetooth signal from Bluetooth device as computer. Then the received signal will transfer to micro controller via line using converter device UART, then microcontroller will process the revived signal/data for controlling the motor of robot using H-Bridge. The direction moving of manual robot can be controlled by mouse. The controller program was developed by Visual Basic program. Moreover, it can adjust the high and also can control via keyboard as shown in fig 3.7 and fig 3.8.

- Accessories

Stair, future board, foam, double-sided adhesive, and scissor are the equipment which applied in this project. Before the passive tags stuck to the ceiling, it was stuck on this thick foam first. Then, this foam with RFID passive tag was stuck by double-sided adhesive to the long future board again. The reason for using long future board is to decrease the noise that will be given by metal, aluminum, and electromagnetic signal nearby.

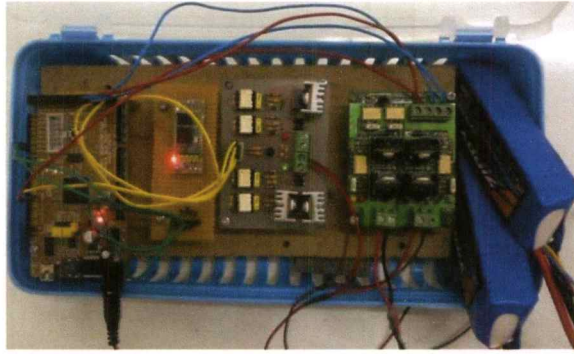


Figure 3.7 Overview of manual robot circuit



Figure 3.8 The shape of manual robot

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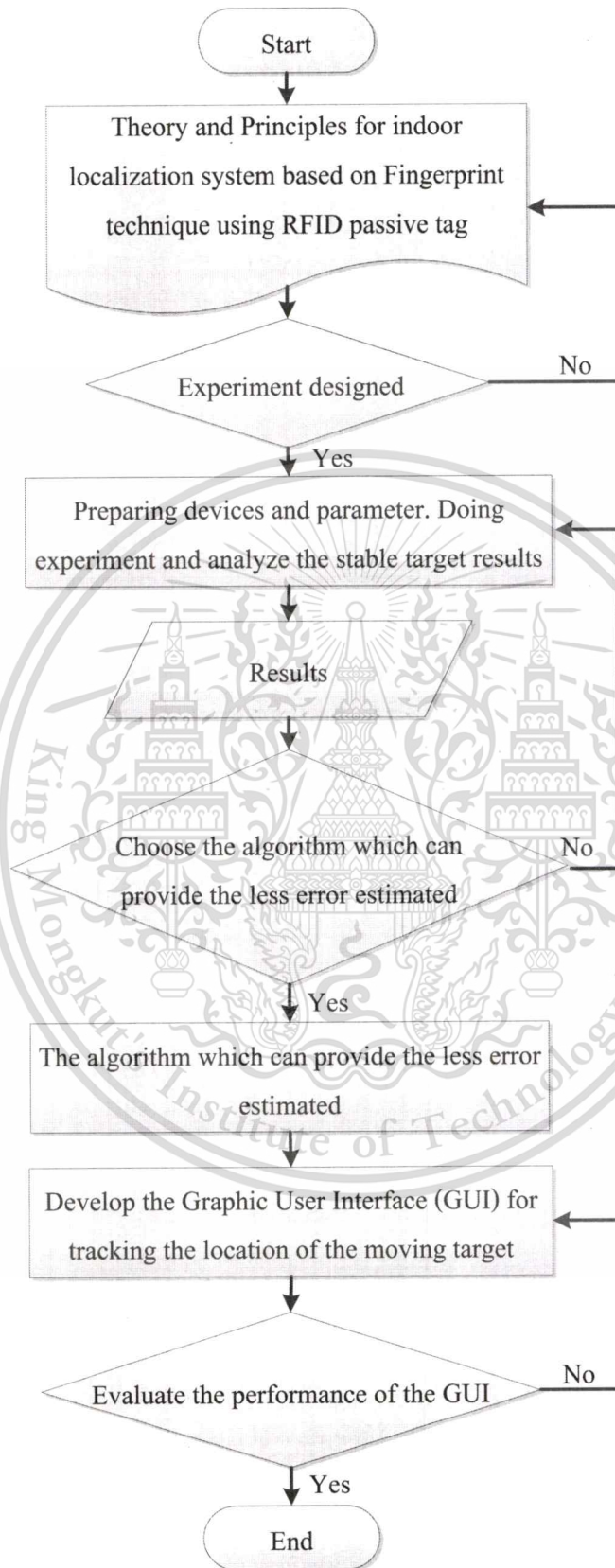


Figure 3.9 Flowchart for doing experiment and development the graphic user interface

3.2 Experiment System and Setup

3.2.1 Preparation the Environment

The first step for doing experiment is using the RFID reader to write the number (unique ID) to the tags, start from number 1 to number 64. Before those tags are stuck to the ceiling, they were stuck by foam first. To make it easy for doing experiment setup, those tags will be stuck to the long future board again to protect some propagation which will come from the ceiling itself, lamp, light, wall and others that we could not know. The gap between two tags is set to 120 cm (the distance between 2 grids of the ceiling). The reason is get easier of measuring and correcting data. The area of interest is set to 840 cm \times 840 cm, the reason that we prefer to observed in this area are: since the limited of our passive tags and the indoor experiment area that we have. Note, the area of interest which is large or small is not the important thing. The important is, if the gap between tags (fingerprint locations) is smaller, it can provide the less error distant.

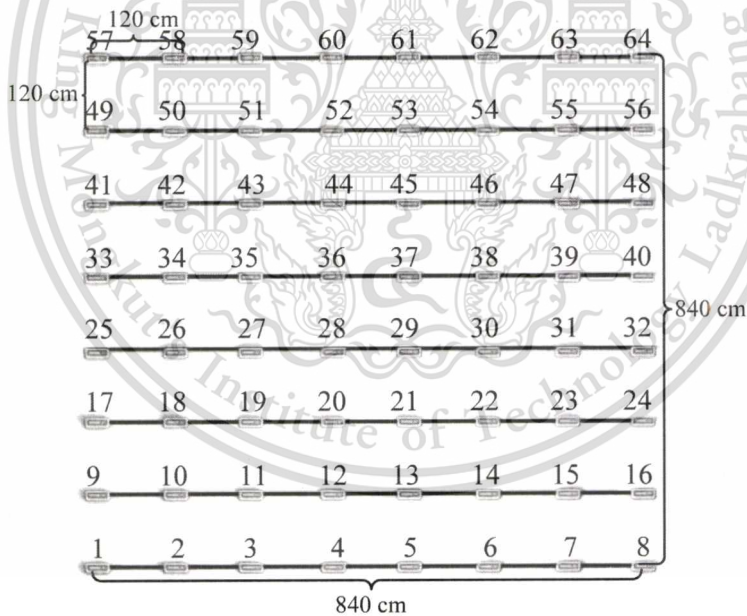


Figure 3.10 The arrangement of 64 tags in the area of interest (840 cm \times 840 cm)

Figure 3.10 and Figure 3.11 show the position of the tags in the area of interest which are having the coordinate and unique ID number. The unique IDs which are written on the foam are referred to as the unique ID inside the tags also. The reasons are making it easy for measurement or to

implement the experiment. It will be more comfortable and faster, if they have the reference number on the ceiling and on the floor.

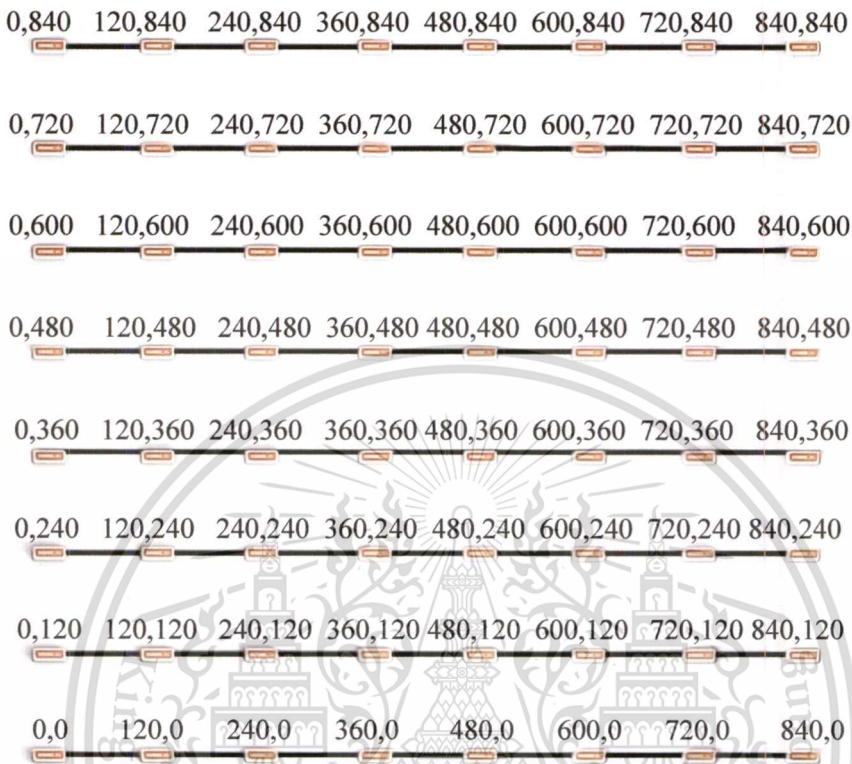


Figure 3.11 The true coordinated of 64 tags in the area of interest

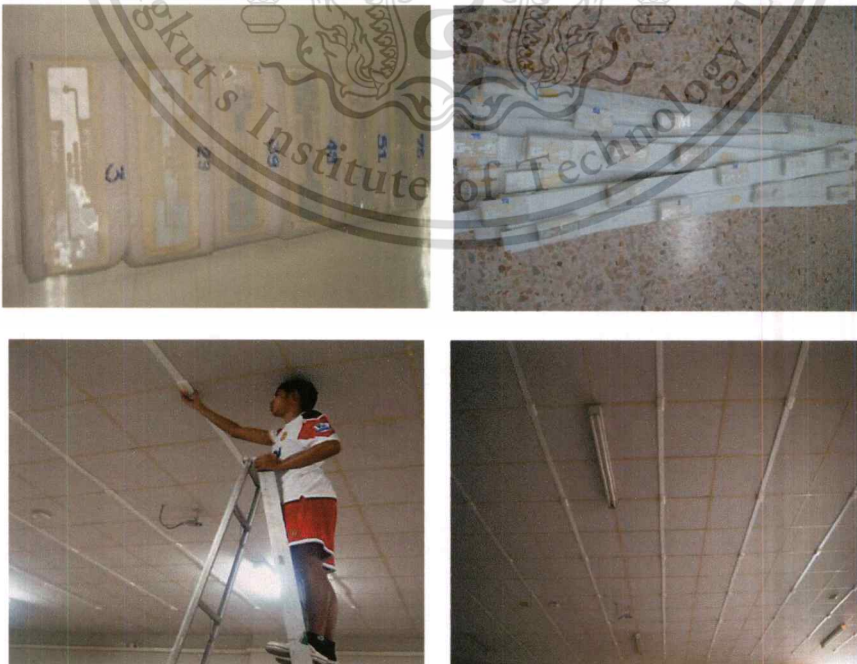


Figure 3.12 Overview of setting tags in the area of interest

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Figure 3.13 The 64 tags on the ceiling and facing the reader in the area of interest

Figure 3.13 shows the 64 passive tags on the ceiling in the area of interest (840 cm × 840 cm) which are ready for doing experiment. After setting up the tags, next step is “setting up the reader” or the target in our case. The RFID reader was held by the manual robot, for adjusting the height of the reader in detail will be explained in experiment models. In this work, the experiment system and specification are shown in Table 3.4.

Table 3.4 Measurement System and Setup

Measurement System	
Number of passive tag	64 tags
Area of interest	840 cm × 840 cm
Height of the ceiling	300 cm
Height of the target	100 cm and 160 cm for the high of fingerprint information. 80 cm, 120 cm, 140 cm and 180 cm are the addition high for observed locations
Observed location	128 locations per high (128 × 6 = 768 locations for all observed locations in this work)
Gap between tags	120 cm

Table 3.4 Measurement System and Setup (cont.)

RFID reader specification	<ul style="list-style-type: none"> - Version URW 801 - Read range (3m – 5 m) - Protocols ISO 18000-6B, 6C and EPC Gen 2 - RF Output Power (20-30 dBm) - Dimension length 215 × width 215 × height 75 mm - Weight: Approximately 1 kg - Frequency 902-928 MHz, 920- 925MHz - Power consumption <6W - Connector (RS232 Serial port) - Antenna (1 antenna build in)
RFID Passive tag specification	<ul style="list-style-type: none"> Brand: Rafsec - Standard: EPC class 1 Gen 2 - Internal memory: 240 bit - Frequency: 860-960 MHz - No battery inside (gain power from reader) - Antenna: Polarization (aluminum) - Dimension: 85.6 x 54x 0.8mm (± 0.5mm)

3.2.2 Experiment Models

In this work, the experiment was conducted by 2 dimension (2D) scenario and 3 dimensions (D) scenario. For 2D scenario, it was conducted for proving our proposed technique and algorithm. This scenario used only one level of fingerprint information height (height of the target or RFID reader height). For 3D scenario, it was deployed two levels of fingerprint information height (100 cm and 160 cm of the target or reader height) which recorded in the database. The explanation in details will be given more as below.

3.2.2.1 2D Environment for Indoor Localization

To prove our fingerprint technique and pattern matching algorithm, the 2D scenario was evaluated and implemented. In this scenario, we simply record the database (in the same process and situation but different time) in 5 times. Then, those data was union to become one set of fingerprint information in each location. After that, all of FI were mapped to the row vector $M_{1 \times n}$ and the observed information was mapped to the row vector $N_{1 \times n}$. For more details about mapping, it was

explained in the previous section. Figure 3.14 shows the layout of experiment setup using 64 passive tags in the area of interest.

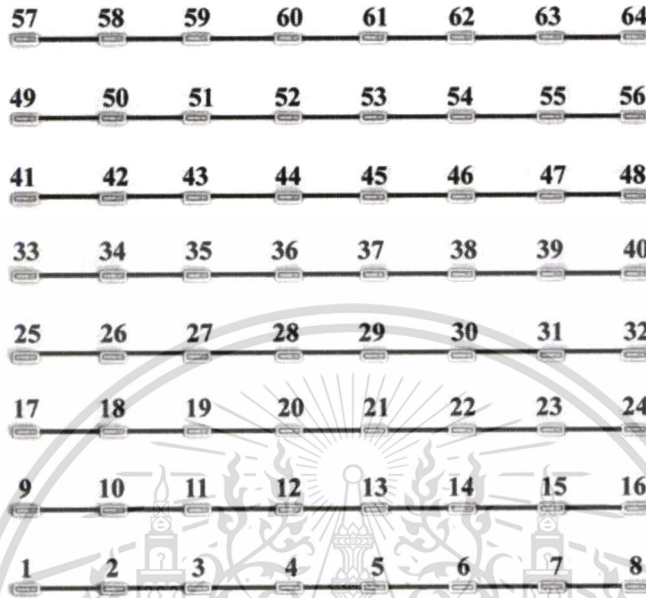


Figure 3.14 Experiment setup for 2D scenario

In this work, the RFID reader is used as observed location or target and 64 passive tags are the reference node. The height of the reader is 160 cm which is estimated value of the average height of Asian people. To get easier of measuring and correcting data, the gap between two tags is set to 120 cm (distance between 2 grids of the ceiling). The RFID passive tags will be attached to the ceiling. The reader will be held on the manual robot and moving around the area of interest.

In 2D scenario, the random testing 80 locations (40 locations in backward direction and 40 locations in forward direction) are applied in order to validate the performance of fingerprint database. These locations are included; firstly, the ten green diamonds are referred to as the observed locations as the same with fingerprint location. Secondly, the ten purple stars are the observed locations which are placed in between two fingerprint locations in horizontal plane. Third, the ten red circles are the observed locations placed in between two fingerprint locations in vertical plane. The last one are the observed locations placed in between four fingerprint locations or in the middle as shown in fig. 3.15.

These 80 observed locations are tested in two times and different directions. Firstly, the reader antenna is faced in forward direction. Secondly, the reader antenna is turned back to backward direction as shown in fig. 3.16. The main reason for placing the 80 observed locations in different place and

different antenna directions are to observe our technique and algorithm, it works with other locations except fingerprint location or not, and also to support in the case of the real situation that the target or visitors will walk around in different locations in the room, not only follow the fingerprint locations.

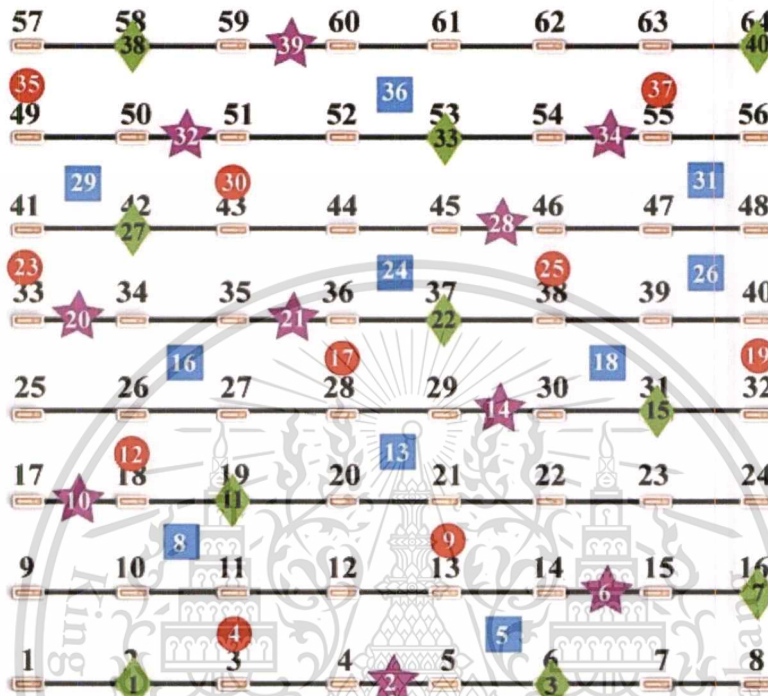


Figure 3.15 The illustrate for the observed locations in 2D scenario

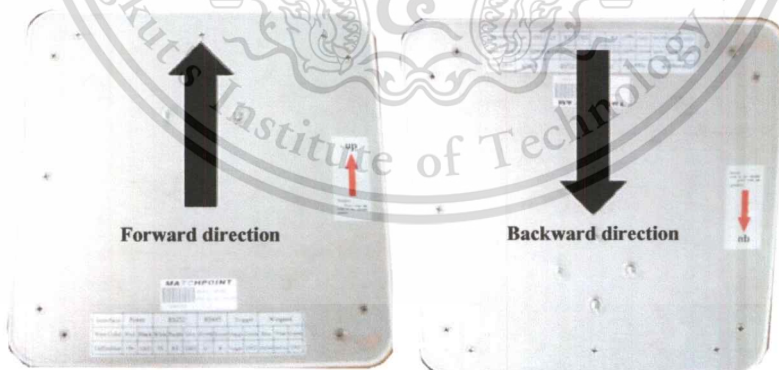


Figure 3.16 The illustrate for reader antenna in two directions

3.2.2.2 3D Environment for Indoor Localization

The RFID reader is employed as the target in each level (100 cm and 160 cm of the reader or target height), for recording the fingerprint information. The RFID reader as fingerprint locations (128 locations) is scattered in the area of interest. The area of interest consists of (840 cm × 840 cm × 100

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cm) and (840 cm × 840 cm × 160 cm). The observed locations are placed on four levels (same with two levels of the recorded fingerprint information and four additional levels: height at 80 cm, height at 120 cm, height at 140 cm and height at 180 cm). The 80 observed locations for random, the 16 observed locations for left and right diagonal testing and 32 observed locations for horizontal plane and vertical plane testing locations.

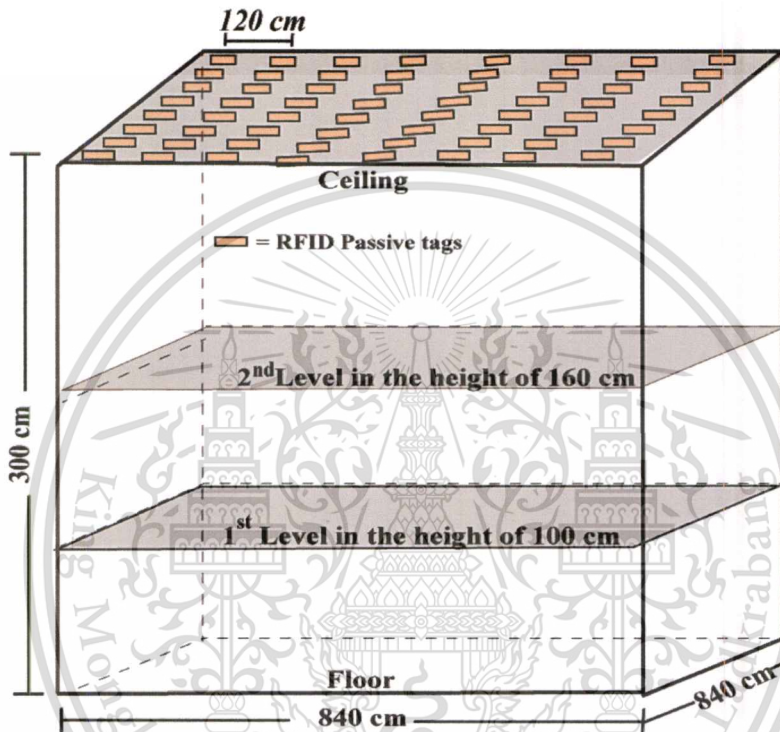


Figure 3.17 Illustration of the experiment setup for 3D scenario

Therefore, 128 observed locations are located in each level. In each height, 80 observed locations are placed in random locations and different directions same as 2D scenario. For other 48 observed locations are placed in diagonal, horizontal, and vertical, respectively which it will explained in the next section. Our objective of placing the observed locations in different level is to validate the performance of our proposed algorithm as mentioned before. We expect to get the good results to support 3D indoor localization.

3.2.2.2.1 Diagonal Position Testing

The first experiment to obtain the validation of our proposed method, the diagonal position testing is applied. Figure 3.18 shows the 64 fingerprint locations and the observed locations at diagonal

positions on the area of interest $840 \text{ cm} \times 840 \text{ cm} \times 300 \text{ cm}$. For the left diagonal testing, the observed location is first placed at $(0 \text{ cm}, 0 \text{ cm}, z \text{ cm})$; $z = 80 \text{ cm}, 100 \text{ cm}, 120 \text{ cm}, 140 \text{ cm}, 160 \text{ cm},$ and 180 cm) and increase continuously by 120 cm . For instance, the target node location for the diagonal left is moved from $(0 \text{ cm}, 0 \text{ cm}, z \text{ cm})$ and continued until reaching the observed location at $(840 \text{ cm}, 840 \text{ cm}, z \text{ cm})$. For the right diagonal position, the target node location is moved from coordinates $(840 \text{ cm}, 0 \text{ cm}, z \text{ cm})$ to $(0 \text{ cm}, 840 \text{ cm}, z \text{ cm})$ as shown in fig. 3.18.

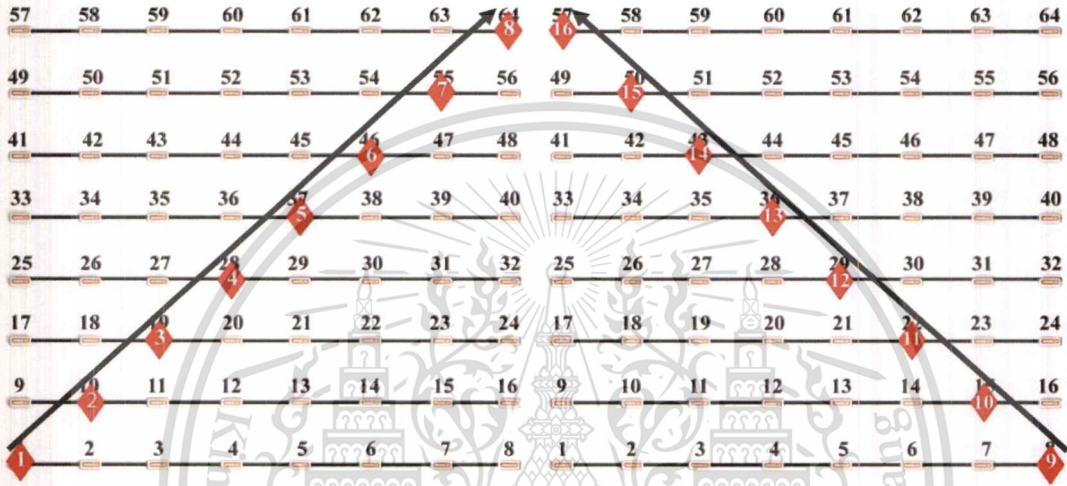


Figure 3.18 Left and right diagonal testing

3.2.2.2.2 Horizontal and Vertical Testing

The other types of observed locations are horizontal and vertical position. Figure 3.25 shows the measurement setup for horizontal and vertical plane of observed locations. For the horizontal plane, the observed location is started to be placed from $(0 \text{ cm}, 360 \text{ cm}, z \text{ cm})$ with the increasing distance are 120 cm for x axes. For example, observed location number 1 is $(0 \text{ cm}, 360 \text{ cm}, z \text{ cm})$, number 2 $(120 \text{ cm}, 360 \text{ cm}, z \text{ cm})$, number 3 $(240 \text{ cm}, 360 \text{ cm}, z \text{ cm})$, etc., the location is continued until $(840 \text{ cm}, 360 \text{ cm}, z \text{ cm})$. Then, it will start again from number 1 at $(840 \text{ cm}, 480 \text{ cm}, z \text{ cm})$ with the decreasing distance are 120 cm for x axes, the location is continued until $(0 \text{ cm}, 480 \text{ cm}, z \text{ cm})$. For the vertical plane, the observed location is started to be placed from $(360 \text{ cm}, 0 \text{ cm}, z \text{ cm})$ with the increasing distance are 120 cm for x axes. For example, observed location number 1 is $(360 \text{ cm}, 0 \text{ cm}, z \text{ cm})$, number 2 $(360 \text{ cm}, 120 \text{ cm}, z \text{ cm})$, number 3 $(360 \text{ cm}, 240 \text{ cm}, z \text{ cm})$, etc., the location is continued until $(360 \text{ cm}, 840 \text{ cm}, z \text{ cm})$. Then, it will start again from number 1 at $(480 \text{ cm}, 840 \text{ cm}, z \text{ cm})$ with the decreasing distance are 120 cm for x axes, the location is continued until $(480 \text{ cm}, 0 \text{ cm}, z \text{ cm})$. As

shown in fig. 3.19, the observed locations in horizontal plane are 16 locations and the observed locations in vertical plane are 16 locations also.

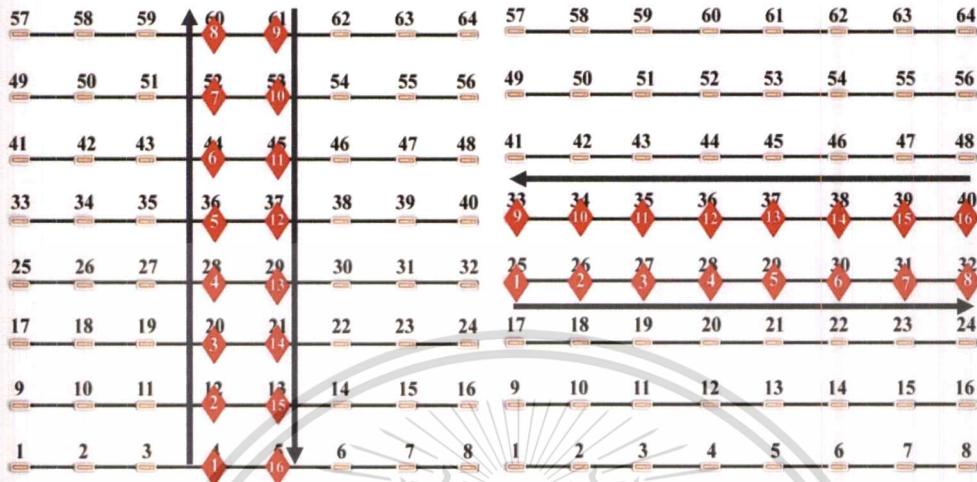


Figure 3.19 Horizontal and vertical diagonal testing

3.3 Fingerprint Technique

This technique gains an idea from the human fingerprint. As the human fingerprint, it uses the unique pattern to identify people. This method has been developed in applications of image processing. The difference in our research is using radio frequency pattern for identification. This pattern could be Receive Strength Signal Information (RSSI), tag ID or ID information, etc. Fingerprint technique consists of two phase processes. Firstly, it is called the off-line or training phase process and secondly, it is called the online phase process. For more detail, it will be given as below [16]-[19].

3.3.1 Offline Phase or Training Phase

In this phase, the ID information detected at each fingerprint locations are recorded into the database. For this thesis, 64 fingerprint locations are deployed in the area of interest in 2D scenario, for 3D scenario are deployed 128 fingerprint locations. Given FL is the number of the fingerprint locations, for 2D, $L(FL_1, FL_2, \dots, FL_{64})$ and 3D, $FL(FL_1, FL_2, \dots, FL_{128})$. Given FI is the group of IDs information of detected tags of the 64 fingerprint locations, 2D, $FI(FI_1, FI_2, \dots, FI_{64})$ and $FI(FI_1, \dots, FI_{128})$ for 3D.

3.3.2 Online Phase or Localization Phase

The online or real-time phase process is the second phase. In this phase, the estimated location evaluated by comparing the current ID information with those of fingerprint information in the database

by using the dot product algorithm which will be explained in the next section. Figure 3.20 shows the two-phase process of the fingerprint technique including off-line and online-phase processes. L is the number of known location and the number of fingerprint information.

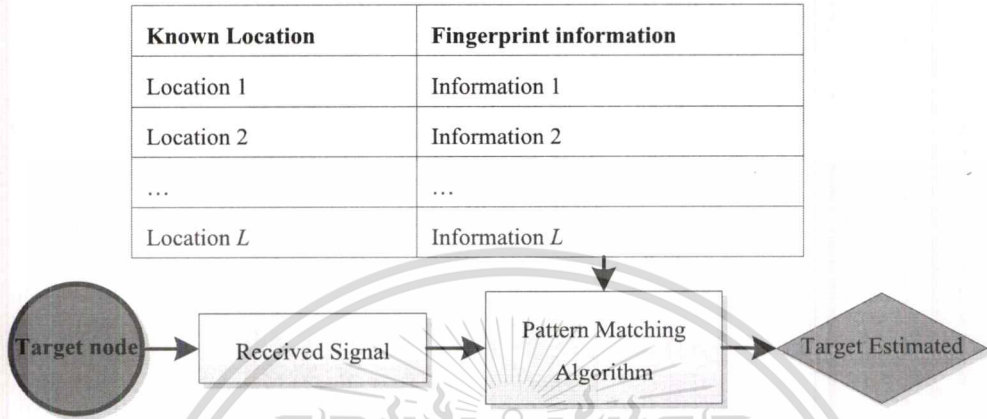


Figure 3.20 Location estimation using fingerprint technique

Table 3.5 Fingerprint Database Model

Fingerprint Location	Fingerprint Information
FL_1	$FI_1 = \{\text{ID tags that detected at } FL_1\}$
FL_2	$FI_2 = \{\text{ID tags that detected at } FL_2\}$
...	...
FL_{L-1}	$FI_{L-1} = \{\text{ID tags tag that detected at } FL_{L-1}\}$
FL_L	$FI_L = \{\text{ID tags tag that detected at } FL_L\}$

3.4 Pattern Matching Algorithm: Dot Product Algorithm

The dot product is sometimes called scalar product or inner product (in the context of Euclidean space) [9]. The result of the dot product is provided by multiplying corresponding entries. It means that before getting the single number of the result, it must be multiplied by two row vectors that have the same member's length. In this research, the pattern matching algorithm is used the dot product to find the estimate location of the target. Defined OL be the observed locations $OL(OL_1, OL_2, OL_3 \dots, OL_{80})$ for 2D and $OL(OL_1, OL_2, OL_3 \dots, OL_{128})$ in 3D. While DO_i be the group of detected tags at the

i observed location, where $i = 1, 2, \dots, 80$ (2D) and $i = 1, 2, \dots, 128$ (3D). Given FI_j be the group of detected tags at the FL ($j = 1, 2, \dots, 64$ in 2D) and FL ($j = 1, 2, \dots, 128$ for 3D).

The FI is mapped to the row vectors $M_{1 \times n}$, ($n = 1, 2, 3, \dots, 64$ for 2D and $n = 1, 2, 3, \dots, 128$ for 3D), which considers in two cases; for the first case, the detected tags (IDs information) in the group which are the same as fingerprint location will become "1". For the second case, except the first case, the other locations will become "0". In the same manner, DO is mapped to row vector $N_{1 \times n}$ as the same like vector M for becoming 1 and 0.

$$DOT = M \cdot N = \sum_{i=1}^n M_i N_i = M_1 N_1 + M_2 N_2 + \dots + M_n N_n, \quad (3.1)$$

Finally, after the dot product between M and N , it will provide the single result. Then the maximum value and 2nd maximum value of the dot product will refer as the fingerprint location that can be used to estimate the target location, so the location of the target can be calculated by the center of gravity (CG) of these fingerprint locations. CG is a geometric property of any object and it is the average of two or more locations. So, for the coordinate of the target location can be estimated as

$$(x, y, z) = \left(\frac{LF_{1x} + LF_{2x} + \dots + LF_{nx}}{n}, \frac{LF_{1y} + LF_{2y} + \dots + LF_{ny}}{n} \right), \quad (3.2)$$

and

$$(x, y, z) = \left(\frac{LF_{1x} + LF_{2x} + \dots + LF_{nx}}{n}, \frac{LF_{1y} + LF_{2y} + \dots + LF_{ny}}{n}, \frac{LF_{1z} + LF_{2z} + \dots + LF_{nz}}{n} \right), \quad (3.3)$$

where $LF_{1x}, LF_{2x}, \dots, LF_{nx}$ is the locations of the fingerprint in x axis, $LF_{1y}, LF_{2y}, \dots, LF_{ny}$ is the locations of the fingerprint in y axis, and $LF_{1z}, LF_{2z}, \dots, LF_{nz}$ is the locations of the fingerprint in z axis n is the number of FLs which is provided the maximum value and 2nd maximum value of the dot product. Figure 3.21 shows the summarized flowchart of proposed location estimation method.

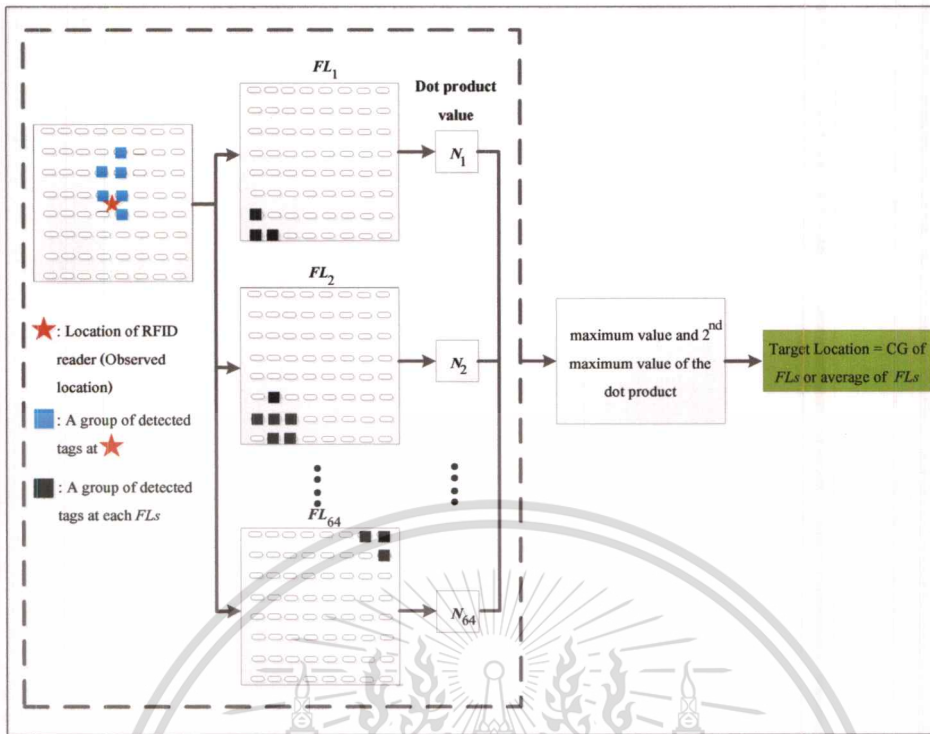


Figure 3.21 Summarized flowchart of proposed location estimation method

3.5 Error Distance

The error distance is analyzed to validate the accuracy of our proposed method. This distance is between the true location (exact location) of the target node and the estimated location of the target node from our proposed localization system. In our work, the Norm equation is used to find the error distance of the target location estimation. These equations for 2D and 3D environment are

$$\text{Error distance} = \sqrt{(x - x')^2 + (y - y')^2}, \quad (3.4)$$

and

$$\text{Error distance} = \sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2}, \quad (3.5)$$

Where (x, y) and (x, y, z) are the true location of the target (true testing position). While (x', y') and (x', y', z') are the estimated location of the target (the actual position). From these equations, the accuracy of the system will be obtained by observing the error distance between the true location and the estimated location of the target.

3.6 Graphic User Interface: GUI

The user-friendly GUI is developed based on the real situation and the real environment of the experiment area as shown in fig. 3.22.

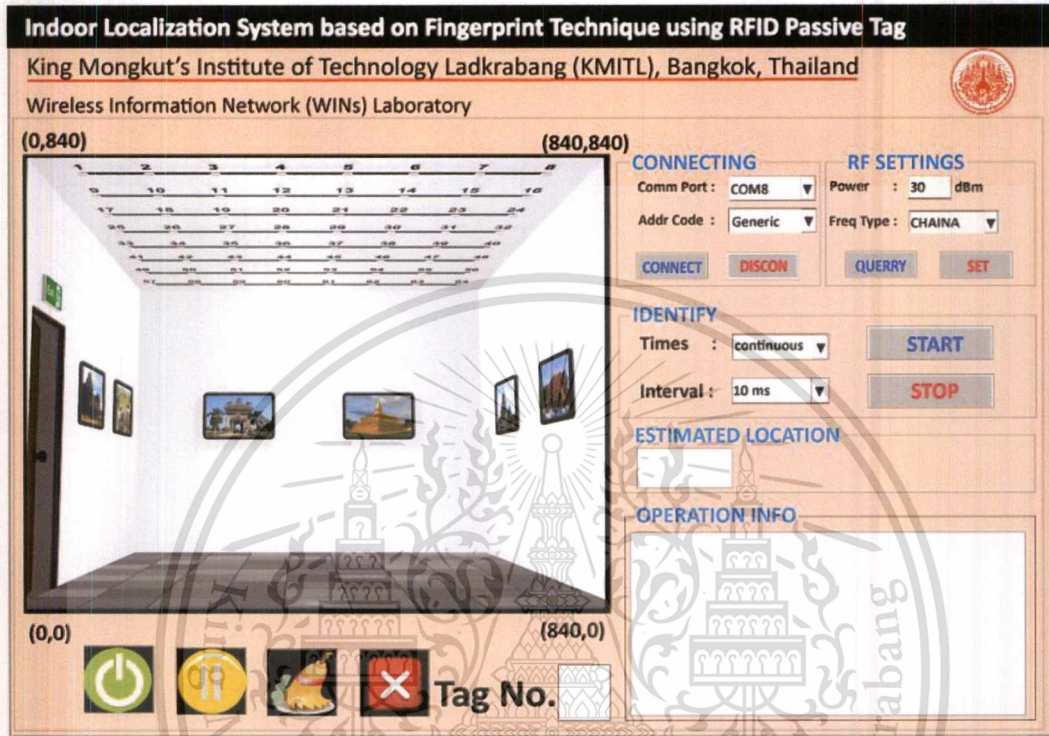


Figure 3.22 The reality model of GUI windows

This application is developed by Microsoft Visual Basic 6.0 based on fingerprint technique and pattern matching algorithm. To respond our expectation, this GUI is able for tracking the target in indoor environment in real time and shows the information of the target (Tag number, group of detected tags, and the estimated location of the target) on it.

CHAPTER 4

RESULTS AND ANALYSIS

This section describes the methodology used in this research. The fingerprint technique using dot product algorithm for 2D and 3D scenes is evaluated. The performance evaluation is the matching between fingerprint information (IDs) in the database and the observed information (IDs). Therefore, the error distance is evaluated by comparing between true location and the estimated location. This estimated location will be shown in GUI including the group of detected tags and the number of detected tags as final.

4.1 Simulation Systems and Parameters

In this research, simulation has been conducted to observe the performance of our proposed method. Table 4.1 shows the experiment system for 2D indoor localization system including the number of fingerprint, number of observed locations and other specification of the experiment. For the 3D localization system, the description of experiment components is given in Table 4.2.

Table 4.1 Experiment systems for 2D indoor localization

Name of Components	Number and Explanation
RFID reader	1 RFID reader as the target location
RFID passive tags	64 RFID passive tags as the reference locations or fingerprint location (8 locations per each row)
Observed locations	80 locations (40 locations of forward direction and 40 locations for backward direction)
Reader height (observed height)	160 cm
Area of Interest	840 cm × 840 cm
Gap between RFID passive tags	120 cm
RFID reader frequency	902 MHz – 928 MHz
Hardware	RFID reader, RFID passive tags, Robot, RS232 port, USB cable and connector, PC (Notebook VAIO™ E Series VPCEG18FH), plug, power supply (battery), foam, scissor, future board, stair and glue, etc.,.
Software	Visual Basic 6.0 program (for GUT) and Visual Basic 2010 program (for robot controller), MATLAB 2010 program, Microsoft Office 2010

Table 4.2 Experiment component for 3D indoor localization

Name of Components	Number and Explanation
RFID Reader	1 RFID reader as the target location
Passive tags	64 Passive tags as the reference locations. 128 fingerprint information recorded from 64 passive tags as the reference locations in different height of the reader (100 cm and 160 cm)
Area of interest	840 cm × 840 cm × 300 cm (Length × Width × height)
Reader height (observed height)	80 cm, 100 cm, 120 cm, 140 cm, 160 cm, and 180 cm
Observed locations	128 observed location per level (768 locations for all)
Hardware and software	The same as 2D scenario for software and hardware

In this simulation, IDs information (detected tags) of the target location becomes the indoor localization parameter. The estimated location is given by comparing between fingerprint information in database (64 locations for 2D scenario and 128 locations for 3D scenario) and observed information as mention in the previous section. The simulation for GUI is done based on fingerprint technique and pattern matching algorithm.

4.2 2D Indoor Localization

In this subsection, the results of experiment system for 2D indoor localization will be given. The 64 fingerprint information and 80 observed locations are evaluated.

4.2.1 Fingerprint Database

In fingerprint technique, the offline phase is conducted to acquire the fingerprint database. In this phase, IDs information (decimal number of detected tags) were stored to the database. After five times for doing experiment and getting the data (IDs information), these data was union before saving to the database. Its processing time is approximately less than 1-2 seconds to provide the fingerprint information in each location. Fingerprint database for 2D indoor localization using 64 passive tags as reference locations are shown in Table 4.3.

Table 4.3 Fingerprint database for 64 reference locations in 2D

No.	Fingerprint Location	Fingerprint information (group of detected tags)
1	(0,0)	{9,1,17}
2	(120,0)	{2,10,9}
3	(240,0)	{3,2,10}
4	(360,0)	{29,12,4,21}
5	(480,0)	{13,5,4}
6	(600,0)	{14,6,5}
7	(720,0)	{7,23,15}
8	(840,0)	{16,7,8}
9	(0,120)	{17,9,1,25}
10	(120,120)	{18,2,10,9}
11	(240,120)	{19,11,3,2,27}
12	(360,120)	{12,4,20,29}
13	(480,120)	{5,13,21}
14	(600,120)	{14,22}
15	(720,120)	{7,24,15,23,39,31}
16	(840,120)	{32,16,7,15,24,8}
17	(0,240)	{25,26,9,17,33}
18	(120,240)	{26,18,17,10}
19	(240,240)	{27,19,11}
20	(360,240)	{28,20,4}
21	(480,240)	{44,21,13,29}
22	(600,240)	{14,30,22}
23	(720,240)	{15,23,31}
24	(840,240)	{16,32,24,23}
25	(0,360)	{42,33,17,25,26}
26	(120,360)	{17,18,34,26,9}
27	(240,360)	{27,19,35,26,10,44}
28	(360,360)	{36,28,20,27,44}

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Table 4.3 Fingerprint database for 64 reference locations in 2D (cont.)

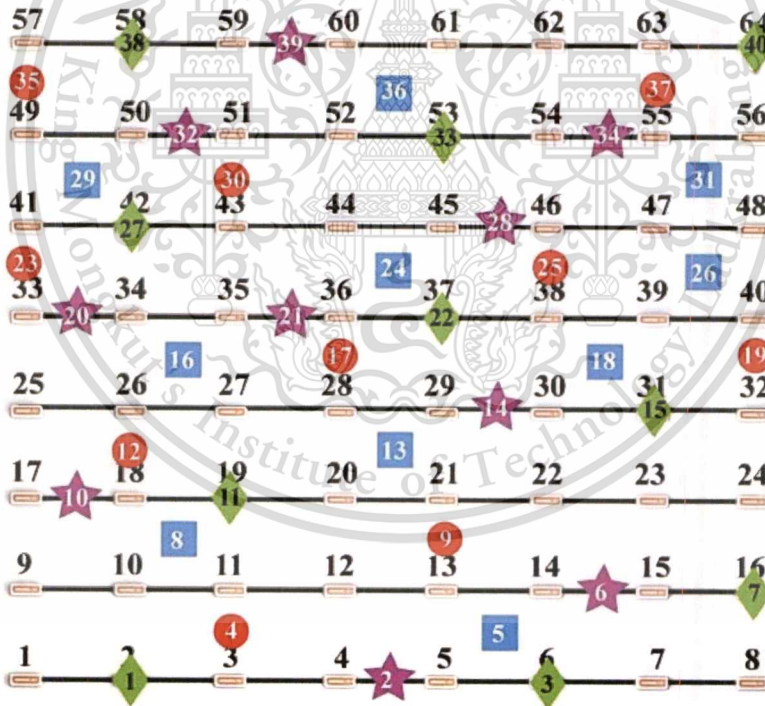
No.	Fingerprint Location	Fingerprint information
29	(480,360)	{29,28,37,21,45}
30	(600,360)	{30,22,29,38,47}
31	(720,360)	{23,31,14,30}
32	(840,360)	{31,40,32,24}
33	(0,480)	{33,25,49,41}
34	(120,480)	{34,42,26,35,33}
35	(240,480)	{35,27,43,34,51,42,52,44}
36	(360,480)	{44,36,28,52,35}
37	(480,480)	{37,52,45,36,29}
38	(600,480)	{46,38,30,37}
39	(720,480)	{31,39,47,55}
40	(840,480)	{40,48}
41	(0,600)	{49,33,41,58,25}
42	(120,600)	{34,50,59,42,41,35,43}
43	(240,600)	{34,43,51,42,60,35,58,59}
44	(360,600)	{43,52,44,59,61}
45	(480,600)	{53,46,45,37,62}
46	(600,600)	{54,46,61,63,52,45}
47	(720,600)	{39,64,47,55,46,62}
48	(840,600)	{31,47,48,56,63,39,40,64}
49	(0,720)	{57,49,41}
50	(120,720)	{58,50,42}
51	(240,720)	{59,51,43}
52	(360,720)	{52,60,51,43,44}
53	(480,720)	{61,53,52,45}
54	(600,720)	{62,46,53,54}
55	(720,720)	{47,55,63,54}
56	(840,720)	{64,48,56,55,47}
57	(0,840)	{57,49}
58	(120,840)	{58,50}
59	(240,840)	{59,51}
60	(360,840)	{59,51,60,52}
61	(480,840)	{53,61,52,60}

Table 4.3 Fingerprint database for 64 reference locations in 2D (cont.)

No.	Fingerprint Location	Fingerprint information
62	(600,840)	{54,62}
63	(720,840)	{63,54,62,48,55}
64	(840,360)	{64,56,63}

4.2.2 Estimated Results

In this subsection, the estimated results for 2D indoor localization from fingerprint technique and pattern matching algorithm are presented. The 80 observed locations have been tested (in the same location; only change the direction of the RFID reader. Number 1 to 40 are observed locations facing forward direction and number 41 to 80 are the observed locations going backward direction) as shown in fig. 4.1. Four cases of the observed locations are considered as mention in section 3.

**Figure 4.1** Four cases of the 80 observed locations

By using the method of maximum value and 2nd maximum value of the dot product, it can provide the estimated location of the target. Deploying the Norm Equation (Euclidean Distance) as

mentioned in section 3, it can provide the error distance between the true location and the estimated location.

In Table 4.4 shows the estimated location and the error distance of the target in forward and backward testing, respectively.

Table 4.4 The estimated results and error distance for 80 observed locations in 2D environment

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(120,0)	(160,120)	128.06
2	(420,0)	(444.71,141.18)	143.32
3	(600,0)	(627.69,60)	66.08
4	(240,60)	(196.36,120)	74.19
5	(540,60)	(552,96)	37.95
6	(660,120)	(570,120)	90
7	(840,120)	(840,120)	0
8	(180,180)	(220,220)	60
9	(480,180)	(516,276)	102.53
10	(60,240)	(80,280)	44.72
11	(240,240)	(204,252)	37.95
12	(120,300)	(106.67,346.67)	48.53
13	(420,300)	(435,360)	67.89
14	(540,360)	(546.67,373.33)	14.91
15	(720,360)	(698.57,300)	63.71
16	(180,420)	(195,525)	107.94
17	(360,420)	(313.85,424.62)	46.38
18	(660,420)	(685.71,488.57)	73.23
19	(840,420)	(805.71,411.43)	69.63
20	(60,480)	(55.38,553.85)	74.66
21	(300,480)	(320,440)	44.72
22	(480,480)	(458.18,447.27)	39.33
23	(0,540)	(50,570)	58.31
24	(420,540)	(428.57,582.86)	43.71

Table 4.4 The estimated results and error distance for 80 observed locations in 2D environment (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
25	(600,540)	(589.09,512.73)	29.37
26	(780,540)	(800,560)	28.28
27	(120,600)	(163.64,578.18)	48.79
28	(540,600)	(555,570)	33.54
29	(60,660)	(105,660)	45
30	(240,660)	(188.57,617.14)	66.94
31	(780,660)	(800,626.67)	38.87
32	(180,720)	(185.45,676.36)	48.31
33	(480,720)	(456,700)	31.24
34	(660,720)	(665.45,687.27)	33.18
35	(0,780)	(88,760)	90.24
36	(420,780)	(433.85,700)	81.19
37	(720,780)	(728,720)	60.53
38	(120,840)	(140,800)	53.85
39	(300,840)	(320,720)	123.29
40	(840,840)	(765.682.50)	184.48
41	(120,0)	(132,168)	168.43
42	(420,0)	(450,135)	138.29
43	(600,0)	(690,150)	174.93
44	(240,60)	(316.36,130.91)	104.21
45	(540,60)	(525,135)	76.49
46	(660,120)	(570,120)	90
47	(840,120)	(800,140)	44.72
48	(180,180)	(216,168)	37.95
49	(480,180)	(490,200)	22.36
50	(60,240)	(80,200)	44.72
51	(240,240)	(195.79,303.16)	77.09
52	(120,300)	(150,315)	33.54

Table 4.4 The estimated results and error distance for 80 observed in 2D environment (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
53	(420,300)	(413.33,306.67)	9.43
54	(540,360)	(580,360)	40
55	(720,360)	(732.63,391.58)	34.01
56	(180,420)	(192,456)	37.95
57	(360,420)	(348,372)	49.48
58	(660,420)	(660,405)	15
59	(840,420)	(792,396)	53.67
60	(60,480)	(110.77,461.54)	54.02
61	(300,480)	(293.33,453.33)	27.49
62	(480,480)	(440,300)	184.39
63	(0,540)	(53.33,506.67)	62.89
64	(420,540)	(435,510)	33.54
65	(600,540)	(600,580)	40
66	(780,540)	(737.14,531.43)	43.71
67	(120,600)	(171.43,565.71)	61.81
68	(540,600)	(560,546.67)	56.96
69	(60,660)	(51.43,685.71)	27.11
70	(240,660)	(240,560)	100
71	(780,660)	(792,648)	16.97
72	(180,720)	(180,660)	60
73	(480,720)	(375,675)	114.24
74	(660,720)	(660,660)	60
75	(0,780)	(80,653.33)	149.81
76	(420,780)	(420,648)	132
77	(720,780)	(754.29,702.86)	84.42
78	(120,840)	(73.85,800)	61.08
79	(300,840)	(333.33,693.33)	150.41
80	(840,840)	(788.57,685.71)	162.63

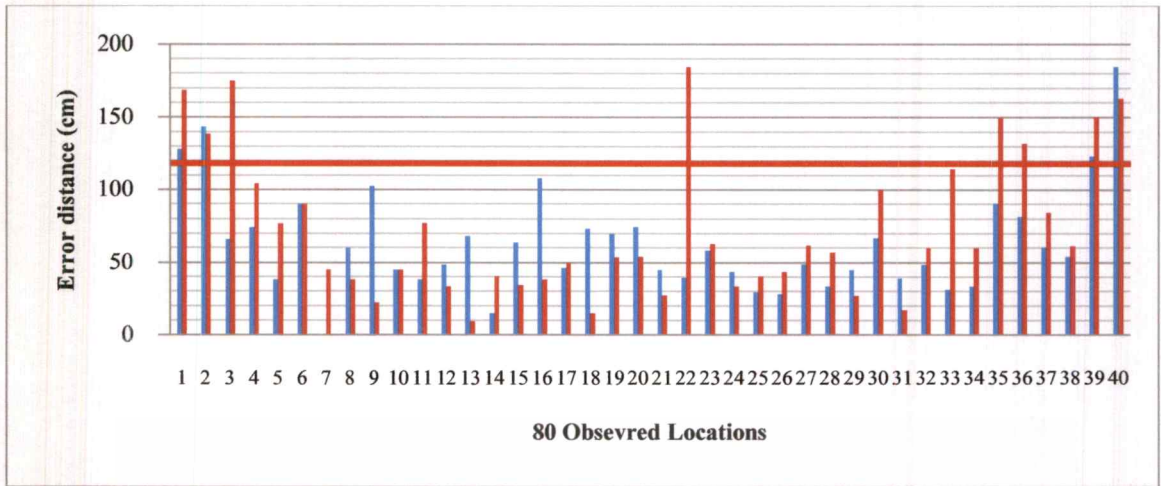


Figure 4.2 The error distance for 80 observed locations

Figure 4.2 depicts the error distance of 80 observed locations in forward and backward directions. The blue one represent as the observed locations in the forward direction and the observed locations in backward direction are red one instead. The results provided a similarity estimated location for both directions; only some observed locations provided the big error distance (more than the gap between two tags of 120 cm) such as $OL_1, OL_2, OL_{39}, OL_{40}$ for the observed locations in forward direction and $OL_1, OL_2, OL_3, OL_{22}, OL_{35}, OL_{36}, OL_{39}, OL_{40}$ for backward direction. Most of these OLs are placed at the same with FL . They are not satisfy our expectation since it placed as the same with FL . Especially, the OL_{22} which is placed in the same with FL_{37} provided the biggest error distance more than the other OL . The reasons of providing the biggest error distance are the similarity for the group of detected tags as each fingerprint locations provided the same maximum value and second maximum value of the dot product. The average of error distance for both of direction is approximately 69 cm. Some errors could be as results of indoor signal fluctuating propagation (such as propagation by metal media, lamp, ceiling itself), the similarity for the group of detected tags of nearby FL which was found as same as the observed location and the other reasons that we could not know.

4.3 3D Indoor Localization

In the 3D indoor localization, the system deployed the different height of the RFID reader (100 cm and 160 cm) for fingerprint information recording as shown in fig. 4.3. As the same manner with 2D localization, the fingerprint technique and the dot product algorithm are applied. The third dimension Z is applied in this localization as shown in Table 4.5.

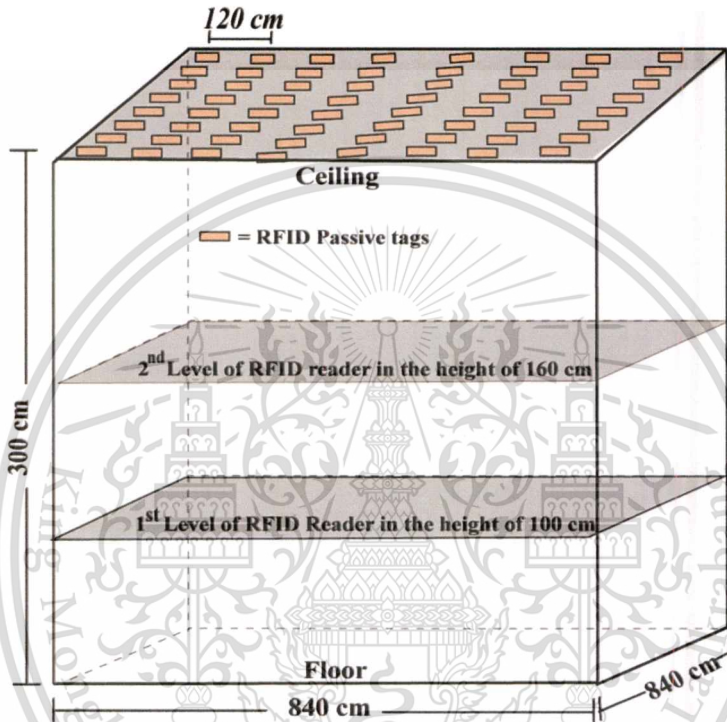


Figure 4.3 Fingerprint information recording outline in 3D localization

4.3.1 Fingerprint Database

In 3D indoor scenario, 128 fingerprint localizations are deployed. The fingerprint information number 1 to 64 are information from the height 100 cm of the RFID reader (target) and other left are from height at 160 cm of the target as shown in Table 4.5.

Table 4.5 Fingerprint database for 128 reference locations in 3D

No.	Fingerprint Location	Fingerprint information (group of detected tags)
1	(0,0,100)	{9,17,1}
2	(120,0,100)	{2,10,1,18}
3	(240,0,100)	{3,19}
4	(360,0,100)	{20,3,12}
5	(480,0,100)	{13,21,4}
6	(600,0,100)	{6,22,30,4}
7	(720,0,100)	{24,7,23,14}
8	(840,0,100)	{16,32,8,24}
9	(0,120,100)	{25,9,1,2}
10	(120,120,100)	{1,10,9,2}
11	(240,120,100)	{10,27,11,3}
12	(360,120,100)	{20,4,12,3}
13	(480,120,100)	{13,5,21,29,14}
14	(600,120,100)	{30,6,14,135}
15	(720,120,100)	{31,23,147}
16	(840,120,100)	{16,15,24,7,32}
17	(0,240,100)	{17,25,18}
18	(120,240,100)	{18,17,26,25,27}
19	(240,240,100)	{19,18,27,3}
20	(360,240,100)	{18,20,35,36,19}
21	(480,240,100)	{29,21,13,20}
22	(600,240,100)	{38,30,14,21,23,31}
23	(720,240,100)	{22,31,23,7,15}
24	(840,240,100)	{16,23,31,32,40,7}
25	(0,360,100)	{17,33}
26	(120,360,100)	{26,25,42,34,17}
27	(240,360,100)	{35,28,27}
28	(360,360,100)	{44,27,36,28,29}
29	(480,360,100)	{21,30,37,28,20}
30	(600,360,100)	{37,29,22,38,31}
31	(720,360,100)	{47,39,31,30,32,38}
32	(840,360,100)	{24,40,39,48,31}

Table 4.5 Fingerprint database for 128 reference locations in 3D (cont.)

No.	Fingerprint Location	Fingerprint information
33	(0,480,100)	{41,33}
34	(120,480,100)	{25,42,33,26}
35	(240,480,100)	{34,43,35,44}
36	(360,480,100)	{28,44,36,35,45}
37	(480,480,100)	{53,45,38,52,37,44,36}
38	(600,480,100)	{54,37,46,30,47,39}
39	(720,480,100)	{39,47,38,48,55}
40	(840,480,100)	{47,31,40,56,39}
41	(0,600,100)	{49,33,57,42}
42	(120,600,100)	{41,42,58,35,34,50}
43	(240,600,100)	{42,43,44,51,35,58}
44	(360,600,100)	{36,52,45,44,59}
45	(480,600,100)	{53,44,46,37,45,61}
46	(600,600,100)	{45,46,62,38,54,39}
47	(720,600,100)	{46,63,39,62,48,55,56}
48	(840,600,100)	{40,64,56,47}
49	(0,720,100)	{57,41,50}
50	(120,720,100)	{50,49,51,43,58}
51	(240,720,100)	{50,51,59,42}
52	(360,720,100)	{43,51,60,44,45,53}
53	(480,720,100)	{45,61,52,44}
54	(600,720,100)	{45,62}
55	(720,720,100)	{55,63,54,47}
56	(840,720,100)	{56,55,48,47}
57	(0,840,100)	{57}
58	(120,840,100)	{57,58,50}
59	(240,840,100)	{59,58}
60	(360,840,100)	{52,61,51,59}
61	(480,840,100)	{62,53,52,60,54}
62	(600,840,100)	{46,55,62,61}
63	(720,840,100)	{63,62,54}
64	(840,360,100)	{56,64,48}

Table 4.5 Fingerprint database for 128 reference locations in 3D (cont.)

65	(0,0,160)	{9,1,17}
66	(120,0,160)	{2,10,9}
67	(240,0,160)	{3,2,10}
68	(360,0,160)	{29,12,4,21}
69	(480,0,160)	{13,5,4}
70	(600,0,160)	{14,6,5}
71	(720,0,160)	{7,23,15}
72	(840,0,160)	{16,7,8}
73	(0,120,160)	{17,9,1,25}
74	(120,120,160)	{18,2,10,9}
75	(240,120,160)	{19,11,3,2,27}
76	(360,120,160)	{12,4,20,29}
77	(480,120,160)	{5,13,21}
78	(600,120,160)	{14,22}
79	(720,120,160)	{7,24,15,23,39,31}
80	(840,120,160)	{32,16,7,15,24,8}
81	(0,240,160)	{25,26,9,17,33}
82	(120,240,160)	{26,18,17,10}
83	(240,240,160)	{27,19,11}
84	(360,240,160)	{28,20,4}
85	(480,240,160)	{44,21,13,29}
86	(600,240,160)	{14,30,22}
87	(720,240,160)	{15,23,31}
88	(840,240,160)	{16,32,24,23}
89	(0,360,160)	{42,33,17,25,26}
90	(120,360,160)	{17,18,34,26,9}
91	(240,360,160)	{27,19,35,26,10,44}
92	(360,360,160)	{36,28,20,27,44}
93	(480,360,160)	{29,28,37,21,45}
94	(600,360,160)	{30,22,29,38,47}
95	(720,360,160)	{23,31,14,30}
96	(840,360,160)	{31,40,32,24}
97	(0,480,160)	{33,25,49,41}
98	(120,480,160)	{34,42,26,35,33}

Table 4.5 Fingerprint database for 128 reference locations in 3D (cont.)

99	(240,480,160)	{35,27,43,34,51,42,52,44}
100	(360,480,160)	{44,36,28,52,35}
101	(480,480,160)	{37,52,45,36,29}
102	(600,480,160)	{46,38,30,37}
103	(720,480,160)	{31,39,47,55}
104	(840,480,160)	{40,48}
105	(0,600,160)	{49,33,41,58,25}
106	(120,600,160)	{34,50,59,42,41,35,43}
107	(240,600,160)	{34,43,51,42,60,35,58,59}
108	(360,600,160)	{43,52,44,59,61}
109	(480,600,160)	{53,46,45,37,62}
110	(600,600,160)	{54,46,61,63,52,45}
111	(720,600,160)	{39,64,47,55,46,62}
112	(840,600,160)	{31,47,48,56,63,39,40,64}
113	(0,720,160)	{57,49,41}
114	(120,720,160)	{58,50,42}
115	(240,720,160)	{59,51,43}
116	(360,720,160)	{52,60,51,43,44}
117	(480,720,160)	{61,53,52,45}
118	(600,720,160)	{62,46,53,54}
119	(720,720,160)	{47,55,63,54}
120	(840,720,160)	{64,48,56,55,47}
121	(0,840,160)	{57,49}
122	(120,840,160)	{58,50}
123	(240,840,160)	{59,51}
124	(360,840,160)	{59,51,60,52}
125	(480,840,160)	{53,61,52,60}
126	(600,840,160)	{54,62}
127	(720,840,160)	{63,54,62,48,55}
128	(840,360,160)	{64,56,63}

The fingerprint database is obtained by conducting five times experiment and five times acquiring data for each fingerprint location. The interval time between 1 data to another data is

approximately 1-2 minutes (including processing time). The data is stored to the PC directly via the RFID reader supported software (UHF Integrated Reader).

4.3.2 Estimated Results for 3D Indoor Localization

In this subsection, the estimated results from fingerprint technique and pattern matching algorithm are presented for 3D indoor localization. As mentioned in the previous section, there are six levels for observed locations in this scenario such as 80 cm, 100 cm, 120 cm, 140 cm, 160 cm, and 180 cm of the reader height. In the same manner, these levels are divided into four cases; firstly, they are 80 randomly locations testing. Secondly, the 16 observed locations were placed at left-right diagonal as the same with *FL*. Thirdly, 16 observed locations in horizontal plane are estimated. Finally, the 16 observed locations the vertical plane which placed at the same with *FL* are considered. The estimated results and discussion will be given as follow by the target height (80 cm, 100 cm, 120 cm, 140 cm, 160 cm, and 180 cm, respectively).

4.3.2.1 Estimated Results for 3D Indoor Localization of Height at 80 cm

4.3.2.1.1 Estimated Results for Random Locations Testing

In the same manner with 2D localization, these locations are considered in four cases as mentioned before. The difference is that the *Z* dimension will be added including the true location and the estimated location. The *Z* dimension of the estimated target can be 100, 160, and the average of both. The estimated results and error distance for 80 observed locations are shown in Table 4.6

Table 4.6 The estimated results and error distance for random locations testing of height at 80 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(120,0,80)	(120,105,130)	116.30
2	(420,0,80)	(472.94,134.12,128.24)	152.04
3	(600,0,80)	(582.86,120,125.71)	129.55
4	(240,60,80)	(261.82,109.09,130)	73.39
5	(540,60,80)	(590.77,101.54,123.08)	78.48
6	(660,120,80)	(670,200,120)	90
7	(840,120,80)	(810,105,130)	60.21
8	(180,180,80)	(140.87,166.96,128.70)	63.82
9	(480,180,80)	(495,135,122.50)	63.69

Table 4.6 The estimated results and error distance for random locations testing of height at 80cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
10	(60,240,80)	(60,180,130)	78.10
11	(240,240,80)	(240,184,120)	68.82
12	(120,300,80)	(144,312,136)	62.10
13	(420,300,80)	(456,288,112)	49.64
14	(540,360,80)	(536.25,258.75,124.38)	110.61
15	(720,360,80)	(728,360,124)	44.72
16	(180,420,80)	(177.14,371.43,131.43)	70.80
17	(360,420,80)	(360,386.67,120)	52.07
18	(660,420,80)	(640,380,110)	53.85
19	(840,420,80)	(795,375,122.50)	76.53
20	(60,480,80)	(56.47,465.88,124.71)	47.01
21	(300,480,80)	(294.55,436.36,127.27)	64.56
22	(480,480,80)	(420,520,120)	82.46
23	(0,540,80)	(82.11,543.16,131.58)	97.01
24	(420,540,80)	(450,510,115)	55
25	(600,540,80)	(618.46,563.08,123.08)	52.24
26	(780,540,80)	(795,600,122.50)	75.04
27	(120,600,80)	(180,600,130)	78.10
28	(540,600,80)	(517.50,570,126.25)	59.54
29	(60,660,80)	(83.08,627.69,132.31)	65.67
30	(240,660,80)	(200,600,130)	87.75
31	(780,660,80)	(795,600,122.50)	75.04
32	(180,720,80)	(188.57,617.14,125.71)	112.88
33	(480,720,80)	(460.60,710,117.14)	43.08
34	(660,720,80)	(676.36,665.45,121.82)	70.65
35	(0,780,80)	(55.38,701.54,132.31)	109.36
36	(420,780,80)	(384,680,128)	116.62
37	(720,780,80)	(766.15,729.23,127.69)	83.56
38	(120,840,80)	(110.77,760,100)	82.98
39	(300,840,80)	(305.45,760,120)	89.61
40	(840,840,80)	(825,800,122.50)	60.26
41	(120,0,80)	(160,110,125)	125.40
42	(420,0,80)	(499.20,163.20,128.80)	187.85

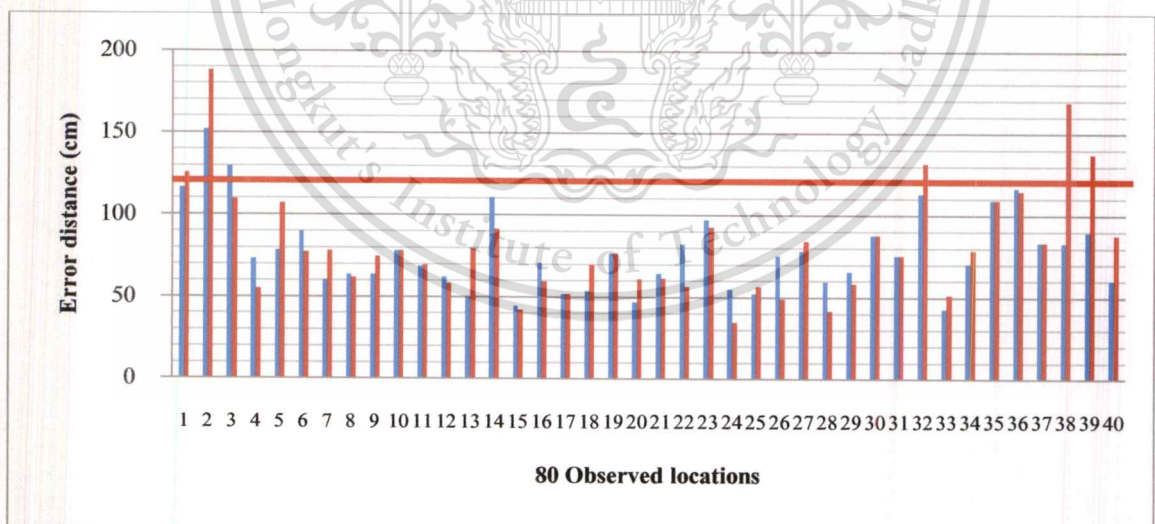
Table 4.6 The estimated results and error distance for random locations testing of height at 80cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
43	(600,0,80)	(624,100,118)	109.64
44	(240,60,80)	(249.23,73.85,132.31)	54.89
45	(540,60,80)	(618.95,113.68,128.42)	107.05
46	(660,120,80)	(720,152.73,116.36)	77.42
47	(840,120,80)	(840,180,130)	78.10
48	(180,180,80)	(210,150,125)	61.85
49	(480,180,80)	(540,200,120)	74.83
50	(60,240,80)	(60,180,130)	78.10
51	(240,240,80)	(260,180,110)	70
52	(120,300,80)	(150,300,130)	58.31
53	(420,300,80)	(453.33,360,120)	79.44
54	(540,360,80)	(557.65,282.35,124.71)	91.32
55	(720,360,80)	(720,368.57,121.43)	42.31
56	(180,420,80)	(216,426,127)	59.51
57	(360,420,80)	(360,386.67,120)	52.07
58	(660,420,80)	(630,360,100)	70
59	(840,420,80)	(795,375,122.50)	76.53
60	(60,480,80)	(84.71,458.82,131.76)	61.14
61	(300,480,80)	(331.76,451.76,124.71)	61.68
62	(480,480,80)	(480,520,120)	56.57
63	(0,540,80)	(70,571.76,131.76)	92.67
64	(420,540,80)	(440,520,100)	34.64
65	(600,540,80)	(565.71,514.29,117.14)	56.71
66	(780,540,80)	(800,560,120)	48.99
67	(120,600,80)	(188.57,617.14,125.71)	84.18
68	(540,600,80)	(548.57,617.14,117.14)	41.80
69	(60,660,80)	(85.71,634.29,125.71)	58.41
70	(240,660,80)	(200,600,130)	87.75
71	(780,660,80)	(795,600,122.50)	75.04
72	(180,720,80)	(200,600,130)	131.53
73	(480,720,80)	(493.33,690,120)	51.75
74	(660,720,80)	(698.18,665.45,121.82)	78.62
75	(0,780,80)	(55.38,701.54,132.31)	109.36

Table 4.6 The estimated results and error distance for random locations testing of height at 80cm (cont.)

76	(420,780,80)	(460,680,120)	114.89
77	(720,780,80)	(766.15,729.23,127.69)	83.56
78	(120,840,80)	(198.26,699.13,131.30)	169.12
79	(300,840,80)	(296.47,712.94,131.76)	137.24
80	(840,840,80)	(825,765,122.50)	87.50

Figure 4.4 depicts the error distance of 80 observed locations in forward and backward direction. In the same manner with 2D localization, the blue one are the observed locations in forward direction and red one are observed locations in backward direction. As known, these observed locations are not in the same height with fingerprint information. The results provided a similarity estimated location between observed locations in forward and backward direction. There are OL_2 and OL_3 provided the big error distance more than 120 cm for forward direction observation. For observed locations in backward direction, there are five locations provided the big error distance such as $OL_1, OL_2, OL_{32}, OL_{38}$ and OL_{39} . As mentioned before, the similarity for the group of detected tags makes the big error distance in this case. Especially, the OL_{11}, OL_3 and OL_{38} which are placed as the same with $FL(x, y)$. The average of error distance equals to 79.76 cm. They are satisfied our expectation.

**Figure 4.4** The error distance for 80 random observed locations testing of height at 80 cm

4.3.2.1.2 Estimated Results for Left-Right Diagonal Locations Testing

The observed location numbers 1 to 8 are the observed locations which placed at the left diagonal. From number 9 to 16 are placed at the right diagonal as shown in fig. 4.5. The reason to place the observed locations in left and right diagonal is to observe our techniques and to support in the real situation (system), when the target (people) comes inside the room and might walk in the diagonal.

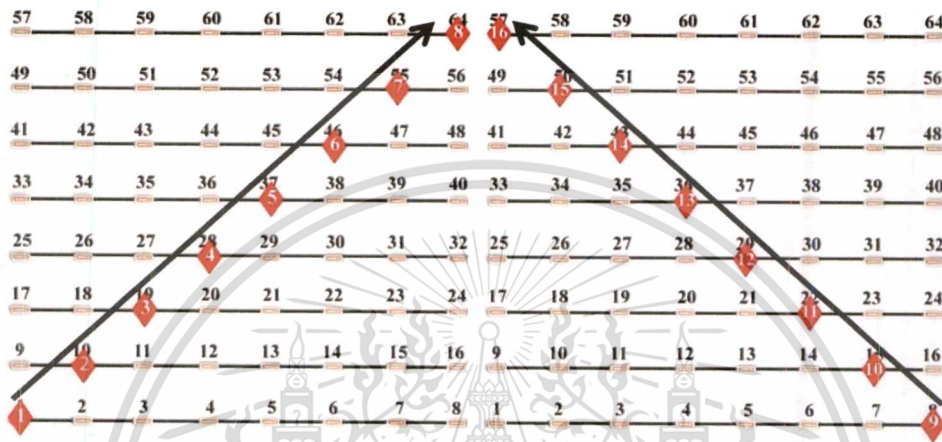


Figure 4.5 The 16 observed locations in left and right diagonal locations testing

Figure 4.6 depicts the estimate results for 16 OLs , the red diamond refers to the true location and the green star is the estimated locations. The GUI windows will be explained only in diagonal plane for every observed location height, for save a space of our thesis and give more for explanation in the text instead. This GUI windows shows the estimated results for OL_{16} which is provided the biggest error distance in this plane equals 186.82 cm. The estimated results and error distance of 16 OLs are shown in Table 4.7.

Table 4.7 The estimated results and error distance for diagonal locations of height at 80 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,0,80)	(40,60,120)	82.46
2	(120,120,80)	(120,60,100)	63.25
3	(240,240,80)	(240,240,100)	20
4	(360,360,80)	(360,360,100)	20
5	(480,480,80)	(480,480,100)	20
6	(600,600,80)	(600,600,100)	20
7	(720,720,80)	(720,660,100)	63.25
8	(840,840,80)	(840,720,130)	130
9	(840,0,80)	(840,120,115)	125

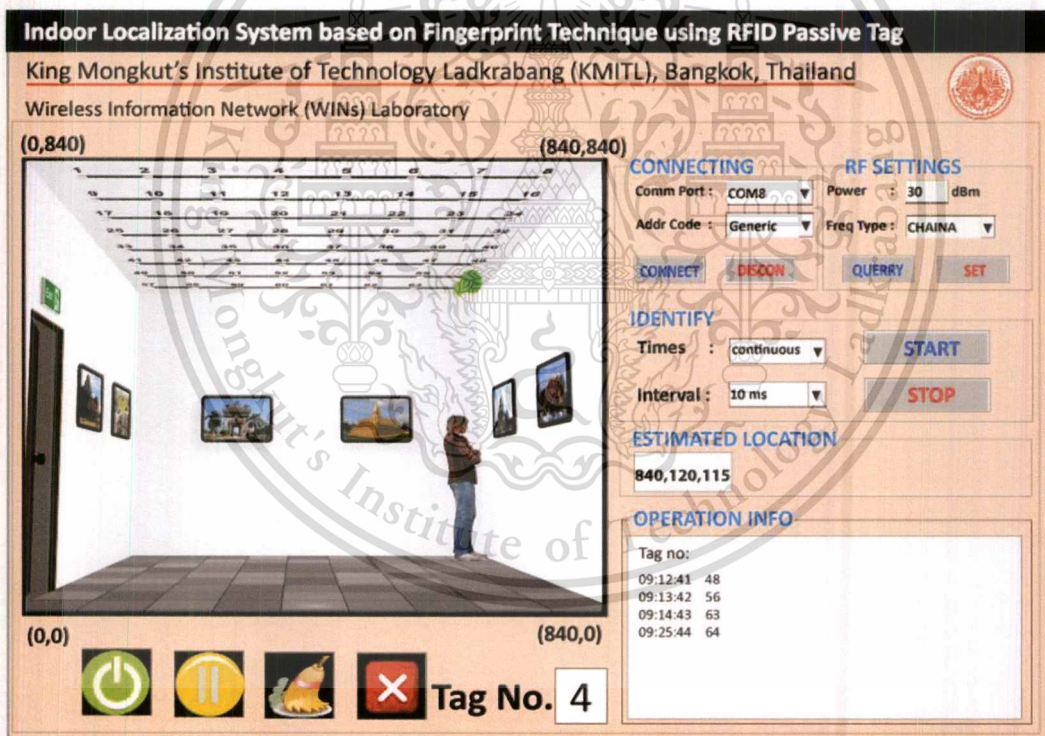
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Table 4.7 The estimated results and error distance for diagonal locations of height at 80 cm (cont.)

10	(720,120,80)	(720,120,100)	20
11	(600,240,80)	(600,240,100)	20
12	(480,360,80)	(480,360,100)	20
13	(360,480,80)	(360,480,100)	20
14	(240,600,80)	(240,600,100)	20
15	(120,720,80)	120,660,100)	63.25
16	(0,840,80)	(0,660,130)	186.82

The reason that OL_9 and OL_{16} are provided the big error distance, is the less detected tags member which are detected in these locations makes the similarity. So the averages from those FLs are provided the big error distance that unsatisfied our expectation.

**Figure 4.6** GUI windows for OL_8 of height at 80 cm in diagonal plane

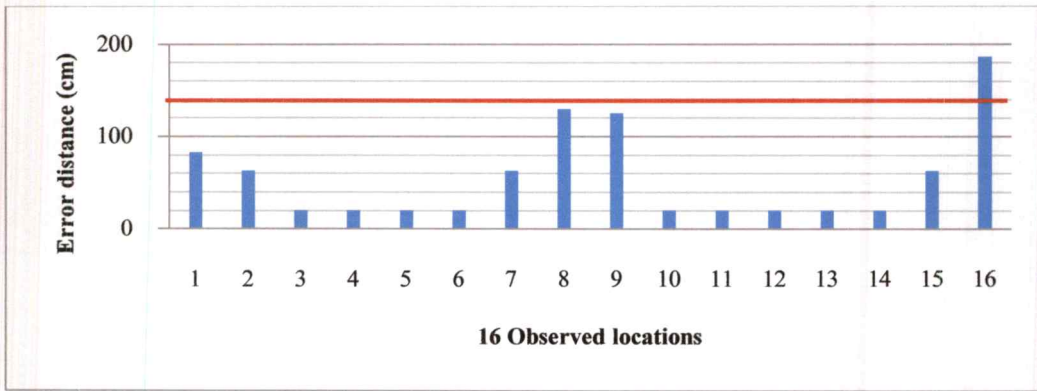


Figure 4.7 The error distance in left-right diagonal of height at 80 cm

There are several locations provided the big error distance. OL_{16} is provided the biggest error distance. Since its true location is placed at $(0,840,80)$ and the estimated location is $(0,660,130)$. Therefore, its error distance equals to 186.82 cm. The average of the error distance for 16 observed locations is 55.87 cm. It is satisfies our expectation since it is not more than the gap between two tags.

4.3.2.1.3 Estimated Results for Vertical Locations Testing

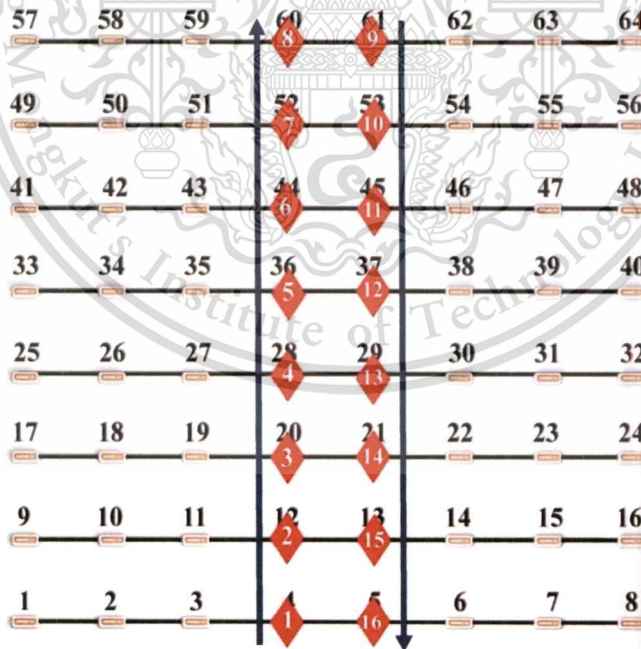


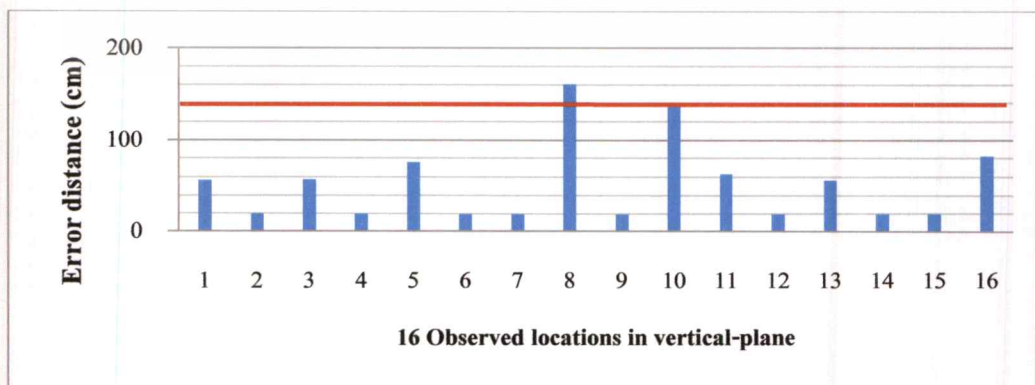
Figure 4.8 The 16 observed locations in vertical plane

There are OL_8 and OL_{10} provided the big error distance. The physical factors of these FLs are will be explained in two cases; firstly, OL_8 since we know it placed near the border as corner.

Table 4.8 The estimated results and error distance in vertical plane of height at 80 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(360,0,80)	(360,40,120)	56.57
2	(360,120,80)	(360,120,100)	20
3	(360,240,80)	(312,264,100)	57.27
4	(360,360,80)	(360,360,100)	20
5	(360,480,80)	(390,420,115)	75.66
6	(360,600,80)	(360,600,100)	20
7	(360,720,80)	(360,720,100)	20
8	(360,840,80)	(330,690,130)	160.93
9	(480,840,80)	(480,840,100)	20
10	(480,720,80)	(540,600,100)	135.65
11	(480,600,80)	(480,540,100)	63.25
12	(480,480,80)	(480,480,100)	20
13	(480,360,80)	(520,360,120)	56.57
14	(480,240,80)	(480,240,100)	20
15	(480,120,80)	(480,120,100)	20
16	(480,0,80)	(540,40,120)	82.46

They have less reference locations, so the similarity can be provided the big error distance in this location. Secondly, OL_{16} which is placed not so near the border but still provided the big error distance. In case of this location is out of experiment system control. We could not know the reason, the error may come from the propagation of environment nearby or the similarity for the group of detected tags same as the OL_8 . Even the results provide the big error in some locations but they are still reasonable.

**Figure 4.9** The error distance in vertical plane of height at 80 cm

4.3.2.1.4 Estimated Results for Horizontal Locations Testing

The observed location numbers 1 to 8 are the observed locations which placed at the left horizontal (move from left to right plane). From number 9 to 16 are placed at the right horizontal (move from right to left plane). The reason to place the observed locations in left and right horizontal direction is to observe our techniques and to support in the real situation (system), when the tourist comes inside the museum and might walk in the horizontal plane.

In this plane, the results provided good estimated results more than the other plane in this observed locations height. The average error distance equals to 50.48 cm. There is only one observed location provided the error distance more than the gap between tags.

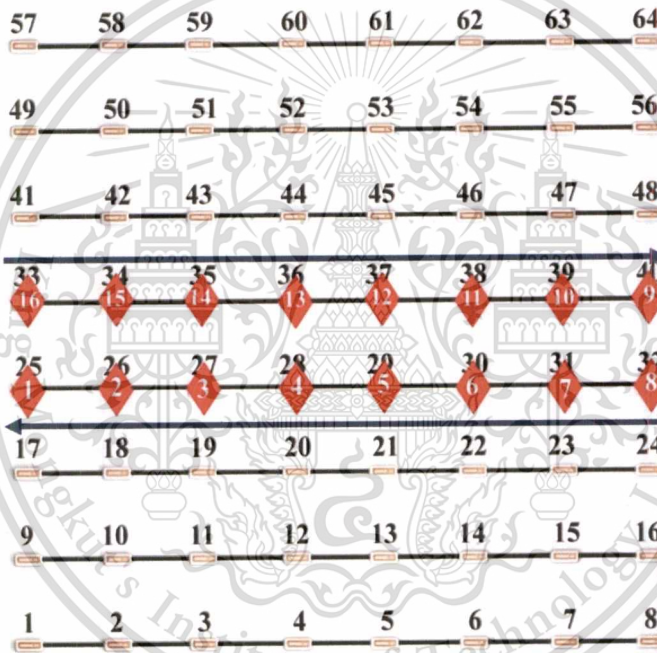
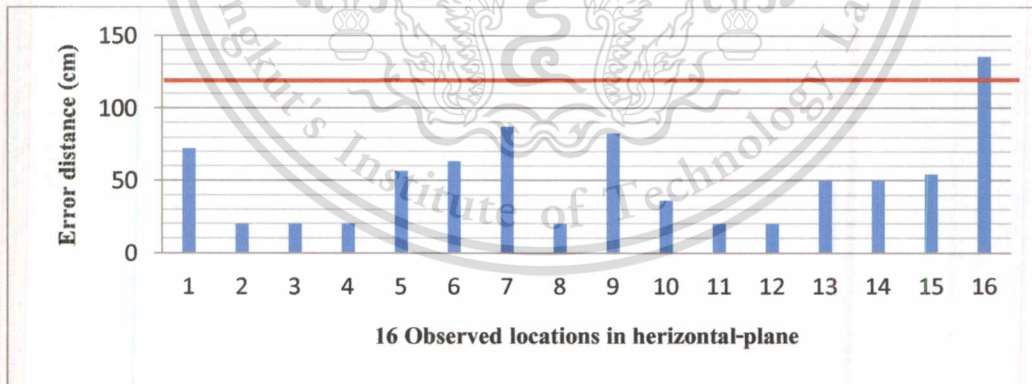


Figure 4.10 The 16 observed locations in horizontal plane of height at 80 cm

Table 4.9 The estimated results and error distance in horizontal plane of height at 80 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,360,80)	(0,320,140)	72.11
2	(120,360,80)	(120,360,100)	20
3	(240,360,80)	(240,360,100)	20
4	(360,360,80)	(360,360,100)	20
5	(480,360,80)	(520,360,120)	56.57
6	(600,360,80)	(600,300,100)	63.25
7	(720,360,80)	(780,300,100)	87.18
8	(840,360,80)	(840,360,100)	20
9	(840,480,80)	(840,400,100)	82.46
10	(720,480,80)	(720,460,110)	36.06
11	(600,480,80)	(600,480,100)	20
12	(480,480,80)	(480,480,100)	20
13	(360,480,80)	(360,456,124)	50.12
14	(240,480,80)	(240,480,130)	50
15	(120,480,80)	(120,480,134.29)	54.29
16	(0,480,80)	(60,360,100)	135.65

**Figure 4.11** The error distance in horizontal plane of height at 80 cm

4.3.2.2 Estimated Results for 3D Indoor Localization of Height at 100 cm

4.3.2.2.1 Estimated Results for Random Locations Testing

In the same manner of 80 cm height, the 80 observed locations are placed in the area of interest to observe our techniques and to provide the accuracy estimated location of the target. Then the results are shown on GUI based on fingerprint technique and pattern matching algorithm. The estimate result and error distance for 80 observed locations are shown in Table 4.10.

Table 4.10 The estimated results and error distance for random locations testing of height at 100 cm

No.	True Locations	Estimated Locations	Error Distance(cm)
1	(120,0,100)	(120,60,100)	60
2	(420,0,100)	(480,120,100)	134.16
3	(600,0,100)	(600,120,100)	120
4	(240,60,100)	(240,120,130)	67.08
5	(540,60,100)	(600,120,100)	84.85
6	(660,120,100)	(660,240,100)	120
7	(840,120,100)	(840,120,130)	30
8	(180,180,100)	(160,120,115)	65
9	(480,180,100)	(480,120,100)	60
10	(60,240,100)	(120,240,130)	67.08
11	(240,240,100)	(280,280,100)	56.57
12	(120,300,100)	(120,300,100)	0
13	(420,300,100)	(480,360,130)	90
14	(540,360,100)	(480,360,100)	60
15	(720,360,100)	(720,360,100)	0
16	(180,420,100)	(150,480,160)	90
17	(360,420,100)	(360,360,100)	60
18	(660,420,100)	(640,400,100)	28.28
19	(840,420,100)	(840,360,100)	60
20	(60,480,100)	(80,560,130)	87.75
21	(300,480,100)	(240,480,160)	84.85
22	(480,480,100)	(480,480,100)	0
23	(0,540,100)	(0,600,100)	60
24	(420,540,100)	(480,480,100)	84.85
25	(600,540,100)	(600,480,100)	60

Table 4.10 The estimated results and error distance for random testing of height at 100cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
26	(780,540,100)	(760,520,115)	32.02
27	(120,600,100)	(120,600,100)	0
28	(540,600,100)	(480,600,130)	67.08
29	(60,660,100)	(120,600,100)	84.85
30	(240,660,100)	(240,660,136)	36
31	(780,660,100)	(720,600,130)	90
32	(180,720,100)	(200,680,160)	74.83
33	(480,720,100)	(480,720,100)	0
34	(660,720,100)	(720,680,100)	72.11
35	(0,780,100)	(80,760,100)	82.46
36	(420,780,100)	(400,840,100)	63.25
37	(720,780,100)	(720,600,100)	180
38	(120,840,100)	(120,780,100)	60
39	(300,840,100)	(300,720,160)	134.16
40	(840,840,100)	(840,840,130)	30
41	(120,0,100)	(120,60,100)	60.00
42	(420,0,100)	(495,45,115)	88.74
43	(600,0,100)	(648,48,112)	68.93
44	(240,60,100)	(288,72,124)	54.99
45	(540,60,100)	(600,120,100)	84.85
46	(660,120,100)	(720,120,100)	60.00
47	(840,120,100)	(840,80,120)	44.72
48	(180,180,100)	(240,120,130)	90.00
49	(480,180,100)	(480,120,100)	60.00
50	(60,240,100)	(120,240,100)	60.00
51	(240,240,100)	(240,200,100)	40.00
52	(120,300,100)	(180,300,130)	67.08
53	(420,300,100)	(480,360,100)	84.85
54	(540,360,100)	(600,360,100)	60.00
55	(720,360,100)	(780,360,100)	60.00
56	(180,420,100)	(216,384,136)	62.35
57	(360,420,100)	(360,360,100)	60.00

Table 4.10 The estimated results and error distance for random testing of height at 100 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
58	(660,420,100)	(720,360,100)	84.85
59	(840,420,100)	(840,360,100)	60.00
60	(60,480,100)	(60,460,100)	20.00
61	(300,480,100)	(360,400,100)	100.00
62	(480,480,100)	(480,360,115)	120.93
63	(0,540,100)	(40,480,130)	78.10
64	(420,540,100)	(480,480,100)	84.85
65	(600,540,100)	(600,480,100)	60.00
66	(780,540,100)	(840,480,120)	87.18
67	(120,600,100)	(120,600,100)	0.00
68	(540,600,100)	(600,580,100)	63.25
69	(60,660,100)	(120,600,100)	84.85
70	(240,660,100)	(240,600,100)	60.00
71	(780,660,100)	(840,600,100)	84.85
72	(180,720,100)	(240,700,100)	63.25
73	(480,720,100)	(480,600,100)	120.00
74	(660,720,100)	(660,700,130)	36.06
75	(0,780,100)	(0,700,120)	82.46
76	(420,780,100)	(440,680,100)	101.98
77	(720,780,100)	(720,700,100)	80.00
78	(120,840,100)	(192,800,112)	83.23
79	(300,840,100)	(288,800,136)	55.14
80	(840,840,100)	(840,720,130)	123.69

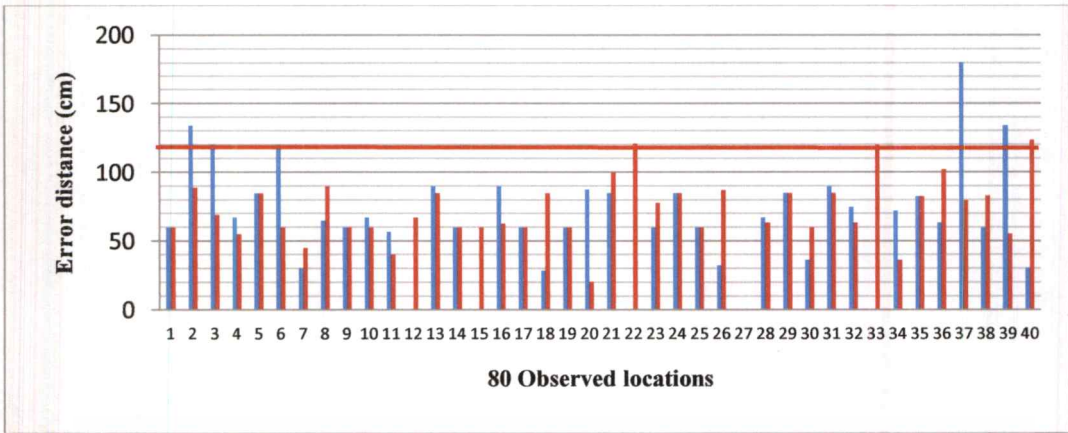


Figure 4.12 The error distance for random locations testing of height at 100 cm

Even though, these observed locations are placed at the same height with fingerprint height in database. They are still provided the big error distance in some locations. Since they have more than one fingerprint locations provided the maximum value and 2nd maximum value of the dot product. The average from those locations provided the different locations and also different height (z) with the true location such as $OL_{16}, OL_{21}, OL_{32}, OL_{39}$ are given the Z axes in 160. It means these locations refer to the fingerprint information 160 cm of the target height. They are not satisfied our expectation. OL_{37} is the OL provided the biggest error distance equals to 180 cm. The average error distance is 68.48 cm.

4.3.2.2.2 Estimated Results for Left-Right Diagonal Locations Testing

The observed locations which starts from number 1 to 16 follows the direction from left to right 8 numbers then starts new from right to left at number 9 to 16. The estimated results and the error distance are shown as Table 4.11.

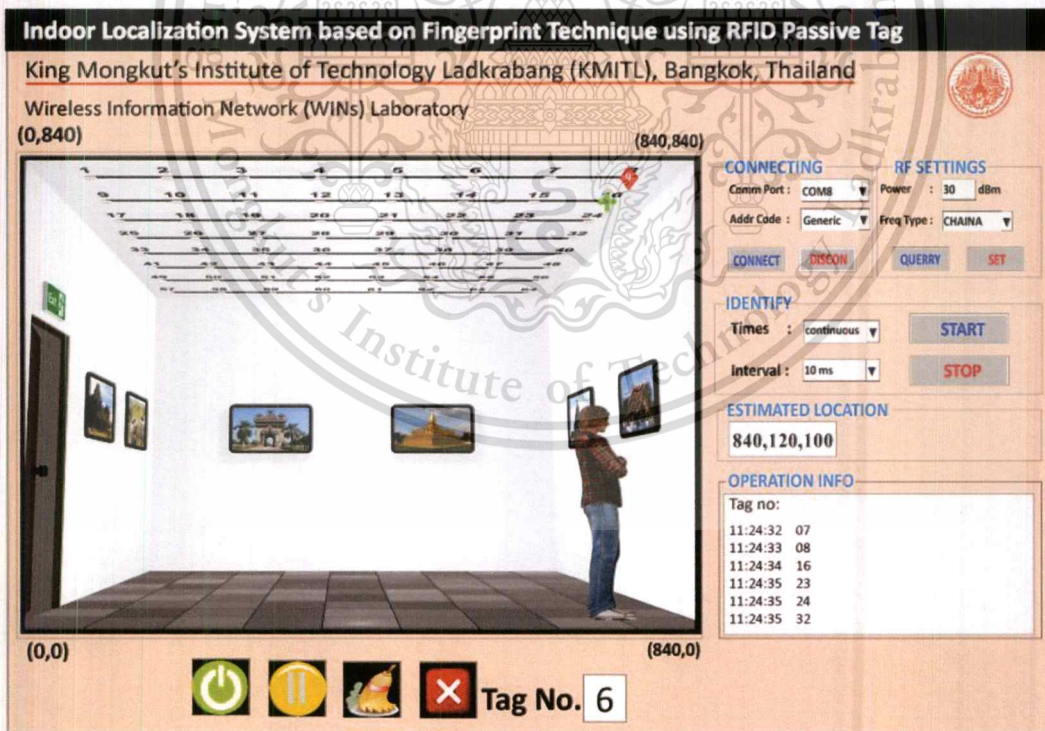
Table 4.11 The estimated results and error distance in left-right diagonal of height at 100 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,0,100)	(0,60,100)	60
2	(120,120,100)	(120,60,100)	60
3	(240,240,100)	(240,240,100)	0
4	(360,360,100)	(360,360,100)	0
5	(480,480,100)	(480,480,100)	0
6	(600,600,100)	(600,600,100)	0
7	(720,720,100)	(720,660,100)	60
8	(840,840,100)	(840,840,100)	0

Table 4.11 The estimated results and error distance in left-right diagonal of height at 100 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
9	(840,0,100)	(840,120,100)	120
10	(720,120,100)	(720,180,100)	60
11	(600,240,100)	(600,240,100)	0
12	(480,360,100)	(480,360,100)	0
13	(360,480,100)	(320,480,100)	40
14	(240,600,100)	(240,600,100)	0
15	(120,720,100)	(120,660,100)	60
16	(0,840,100)	(0,780,100)	60

In this plane, the results give good estimated results. There are 8 OLs given the estimated result equals to 0 cm and only OL_9 provided the big error distance equals to 120 cm. The other OLs are given the error distance less than 60 cm. The average of error distance equals to 32.5 cm. The groups of detected tags are found in this OL consist of $OL_7, OL_8, OL_{16}, OL_{23}, OL_{24}$, and OL_{32} .

**Figure 4.13** GUI windows for OL_9 of height at 100 cm in left-right diagonal plane

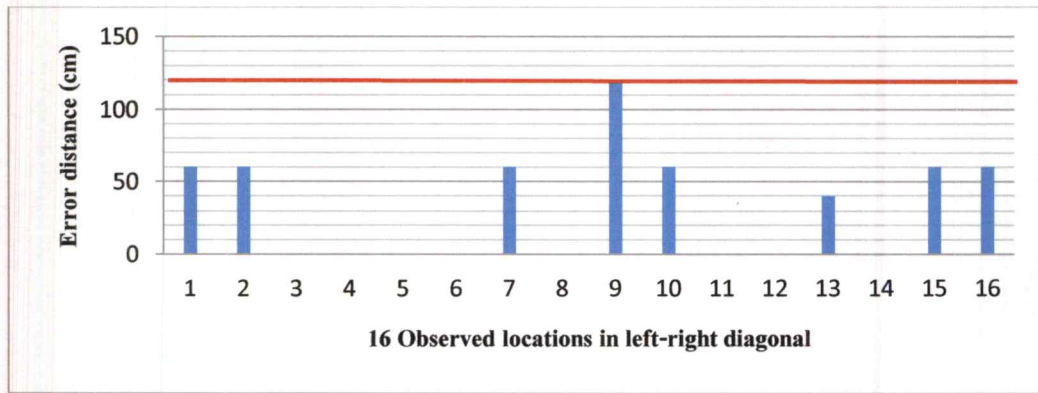


Figure 4.14 The error distance in left-right diagonal of height at 100 cm

4.3.2.2.3 Estimated Results for Vertical Locations Testing

Since this plane is the same level as fingerprint location, the estimated results for this plane are very good. More than a half of the OL are given the error distance equals to 0 cm as shown in Table 4.12. The quite big error distance are given by the OL near the border of area of interest such as OL_9 and OL_{16} . The average of error distance equals to 26.55 cm.

Table 4.12 The estimated results and error distance in vertical plane of height at 100 cm

No.	True Locations	Estimated Locations	Error Distance(cm)
1	(360,0,100)	(360,60,100)	60
2	(360,120,100)	(360,120,100)	0
3	(360,240,100)	(360,240,100)	0
4	(360,360,100)	(360,360,100)	0
5	(360,480,100)	(360,480,100)	0
6	(360,600,100)	(360,600,100)	0
7	(360,720,100)	(360,720,100)	0
8	(360,840,100)	(360,840,100)	0
9	(480,840,100)	(480,720,100)	120
10	(480,720,100)	(480,700,100)	20
11	(480,600,100)	(480,540,100)	60
12	(480,480,100)	(480,480,100)	0
13	(480,360,100)	(480,360,100)	0
14	(480,240,100)	(480,220,100)	20
15	(480,120,100)	(480,60,100)	60
16	(480,0,100)	(540,60,100)	84.85

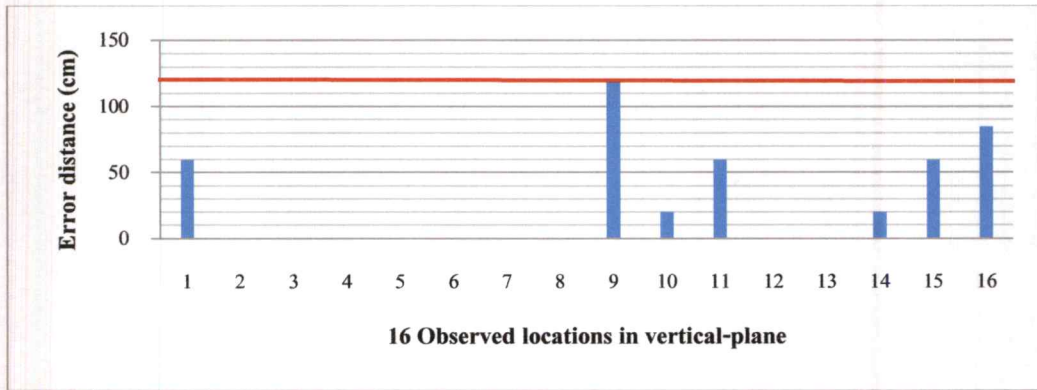


Figure 4.15 The error distance in vertical plane of height at 100 cm

4.3.2.2.4 Estimated Results for Horizontal Locations Testing

The estimated results in horizontal plane are a good one. Although, it is placed in different direction with fingerprint locations, it still provides good estimated results compared with the other planes in this height.

Table 4.13 The estimated results and error distance in horizontal plane of height at 100 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,360,100)	(120,300,100)	134.16
2	(120,360,100)	(120,300,100)	60
3	(240,360,100)	(240,300,100)	60
4	(360,360,100)	(360,360,100)	0
5	(480,360,100)	(480,360,100)	0
6	(600,360,100)	(600,360,100)	0
7	(720,360,100)	(700,360,100)	20
8	(840,360,100)	(840,300,100)	60
9	(840,480,100)	(840,420,100)	60
10	(720,480,100)	(720,420,100)	60
11	(600,480,100)	(600,480,100)	0
12	(480,480,100)	(480,480,100)	0
13	(360,480,100)	(360,480,100)	0
14	(240,480,100)	(240,480,100)	0
15	(120,480,100)	(120,480,100)	0
16	(0,480,100)	(60,420,100)	84.85

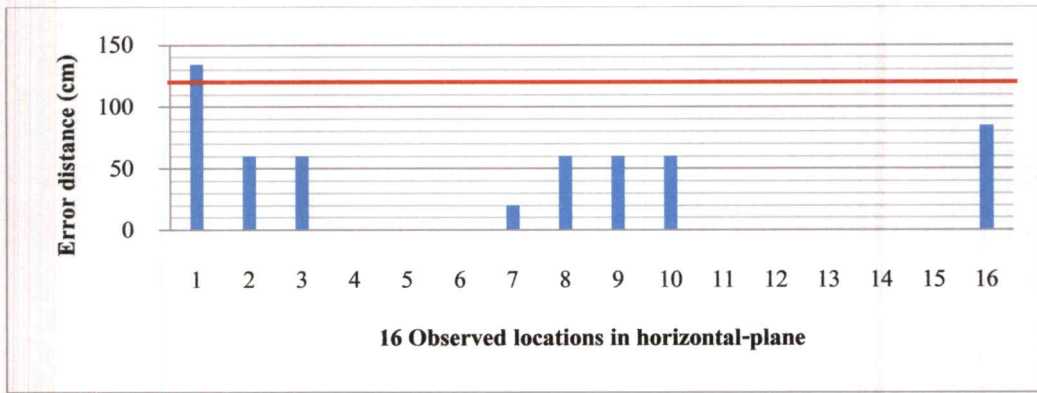


Figure 4.16 The error distance in horizontal plane of height at 100 cm

There are a half of them provide the error distance equals to 0 cm, only OL_9 and OL_{16} are provided the big error distance since it is placed at the border of the area of interest. The average of error distance equals to 33.68 cm.

4.3.2.3 Estimated Results for 3D Indoor Localization of Height at 120 cm

4.3.2.3.1 Estimated Results for Random Locations Testing

Based on information in Table 4.14, the estimated results provided good results. Especially, the value of z direction which are not more than 130 cm is has more than half OLs . It shows that our expectation to recognize the height of the target is satisfied. From the results, there are 10 OLs provided the big error distance, for example, OL_3 , OL_{38} , OL_{39} , OL_{40} , OL_{42} , OL_{43} , OL_{66} , OL_{78} , OL_{79} and OL_{80} . The average of error distance for all 80 OLs equals to 80.06 cm.

Table 4.14 The estimated results and error distance for random locations testing of height at 120 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(120,0,120)	(96,72,124)	63.25
2	(420,0,120)	(444,84,124)	135.65
3	(600,0,120)	(582.86,120,125.71)	121.66
4	(240,60,120)	(193.85,147.69,127.69)	60.83
5	(540,60,120)	(540,75,122.50)	87.18
6	(660,120,120)	(664.62,184.62,123.08)	84.85
7	(840,120,120)	(840,120,115)	10.00
8	(180,180,120)	(135,195,130)	87.18

Table 4.14 The estimated results and error distance for random testing of height at 120cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
9	(480,180,120)	(480,156,124)	63.25
10	(60,240,120)	(73.04,281.74,126.09)	63.25
11	(240,240,120)	(274.29,325.71,125.71)	60.00
12	(120,300,120)	(75,315,130)	20.00
13	(420,300,120)	(426.67,373.33,120)	85.44
14	(540,360,120)	(567.27,392.73,116.36)	48.99
15	(720,360,120)	(675,330,115)	20.00
16	(180,420,120)	(145.71,445.71,134.29)	43.59
17	(360,420,120)	(394.29,394.29,117.14)	63.25
18	(660,420,120)	(651.43,360,108.57)	87.18
19	(840,420,120)	(840,408,124)	63.25
20	(60,480,120)	(91.76,522.35,131.76)	63.25
21	(300,480,120)	(312,504,124)	20.00
22	(480,480,120)	(453.33,586.67,113.33)	63.25
23	(0,540,120)	(50,570,130)	63.25
24	(420,540,120)	(420,570,115)	63.25
25	(600,540,120)	(570,570,122.50)	63.25
26	(780,540,120)	(770,540,120)	5.00
27	(120,600,120)	(160,600,140)	20.00
28	(540,600,120)	(540,696,124)	63.25
29	(60,660,120)	(60,660,130)	87.18
30	(240,660,120)	(265.71,668.57,130)	60.00
31	(780,660,120)	(792,648,136)	87.18
32	(180,720,120)	(232,704,128)	140.00
33	(480,720,120)	(369.23,692.31,127.69)	120.42
34	(660,720,120)	(672,684,124)	135.65
35	(0,780,120)	(88,704,128)	54.14
36	(420,780,120)	(440,710,130)	85.44
37	(720,780,120)	(728,720,132)	181.11

Table 4.14 The estimated results and error distance for random testing of height at 120cm (cont.)

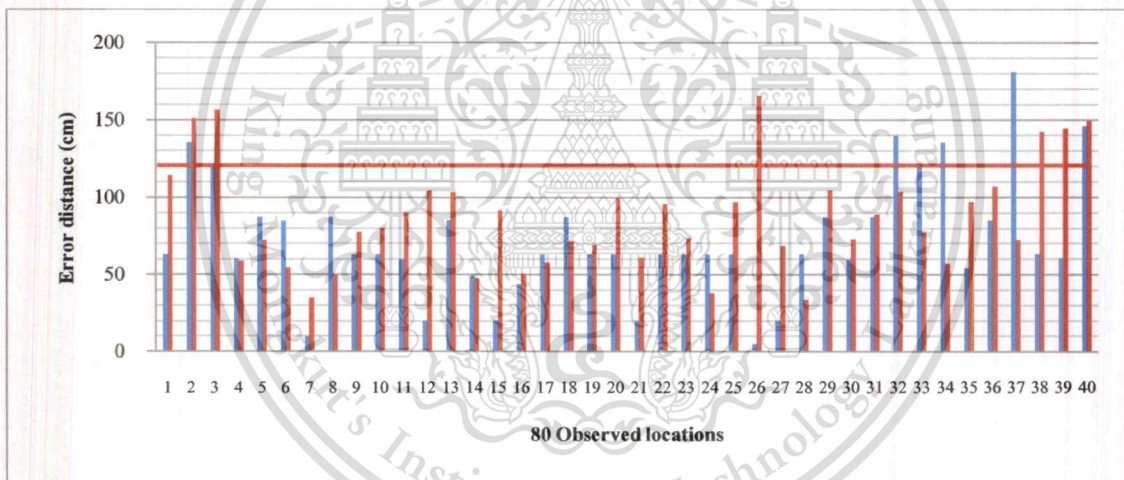
No.	True Locations	Estimated Locations	Error Distance (cm)
38	(120,840,120)	(104,720,124)	63.25
39	(300,840,120)	(320,720,132)	60.83
40	(840,840,120)	(780,685.71,125.71)	146.04
41	(120,0,120)	(160,106.67,126.67)	114.11
42	(420,0,120)	(526.67,106.67,130)	151.18
43	(600,0,120)	(700,120,126.67)	156.35
44	(240,60,120)	(271.30,109.57,128.70)	59.26
45	(540,60,120)	(590.77,110.77,127.69)	72.21
46	(660,120,120)	(711.43,137.14,125.71)	54.51
47	(840,120,120)	(810,105,130)	35
48	(180,180,120)	(227.37,164.21,122.11)	49.98
49	(480,180,120)	(528,120,112)	77.25
50	(60,240,120)	(60,160,125)	80.16
51	(240,240,120)	(330,240,127)	90.27
52	(120,300,120)	(150,200,125)	104.52
53	(420,300,120)	(411.43,197.14,125.71)	103.37
54	(540,360,120)	(582.86,342.86,108.57)	47.55
55	(720,360,120)	(810,345,130)	91.79
56	(180,420,120)	(215,385,130)	50.50
57	(360,420,120)	(403.64,381.82,121.82)	58.01
58	(660,420,120)	(720,381.82,110.91)	71.70
59	(840,420,120)	(805.71,360,125.71)	69.34
60	(60,480,120)	(97.14,388.57,131.43)	99.34
61	(300,480,120)	(327.27,425.45,121.82)	61.01
62	(480,480,120)	(467.37,385.26,125.26)	95.72
63	(0,540,120)	(70.59,522.35,131.76)	73.71
64	(420,540,120)	(432,504,124)	38.16
65	(600,540,120)	(648,456,118)	96.77
66	(780,540,120)	(795,375,122.50)	165.70
67	(120,600,120)	(186.67,586.67,126.67)	68.31
68	(540,600,120)	(570,585,125)	33.91
69	(60,660,120)	(77.14,557.14,130)	104.75
70	(240,660,120)	(200,600,130)	72.80

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Table 4.14 The estimated results and error distance for random testing of height at 120cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
71	(780,660,120)	(800,573.33,120)	88.94
72	(180,720,120)	(188.57,617.14,125.71)	103.37
73	(480,720,120)	(425.45,665.45,121.82)	77.16
74	(660,720,120)	(676.36,665.45,121.82)	56.98
75	(0,780,120)	(55.38,701.54,132.31)	96.83
76	(420,780,120)	(433.85,673.85,123.08)	107.10
77	(720,780,120)	(760,720,125)	72.28
78	(120,840,120)	(183.53,712.94,128.24)	142.29
79	(300,840,120)	(304,696,132)	144.55
80	(840,840,120)	(813.33,693.33,126.67)	149.22

**Figure 4.17** The error distance in random testing locations of height at 120 cm

4.3.2.3.2 Estimated Results for Left-Right Diagonal Locations Testing

There is one OL provided coordinate in Z axes more than 120 cm. It is OL_{14} , it refers to the fingerprint height at 160 cm. Anyway, its error distance is acceptable. OL_8 and OL_{16} are provided the big error distance more than 120 cm. The average error distance for these OL is 56.36 cm.

Table 4.15 The estimated results and error distance for diagonal locations of height at 120 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,0,120)	(0,60,130)	60.83
2	(120,120,120)	(120,60,100)	63.25
3	(240,240,120)	(240,160,120)	80
4	(360,360,120)	(360,360,100)	20
5	(480,480,120)	(480,460,100)	28.28
6	(600,600,120)	(600,600,100)	20
7	(720,720,120)	(720,700,100)	28.28
8	(840,840,120)	(840,720,130)	120.42
9	(840,0,120)	(840,80,120)	80
10	(720,120,120)	(720,120,100)	20
11	(600,240,120)	(600,240,100)	20
12	(480,360,120)	(440,400,100)	60
13	(360,480,120)	(336,432,136)	56
14	(240,600,120)	(200,600,160)	56.57
15	(120,720,120)	(120,700,100)	28.28
16	(0,840,120)	(0,680,120)	160

Figure 4.18 shows the GUI windows for OL_{11} at height of 120 cm in diagonal plane. This observed location is given the error distance only 20 cm and the group of detected tags are included OL_{14} , OL_{21} , OL_{22} , OL_{30} , OL_{31} and OL_{38} .

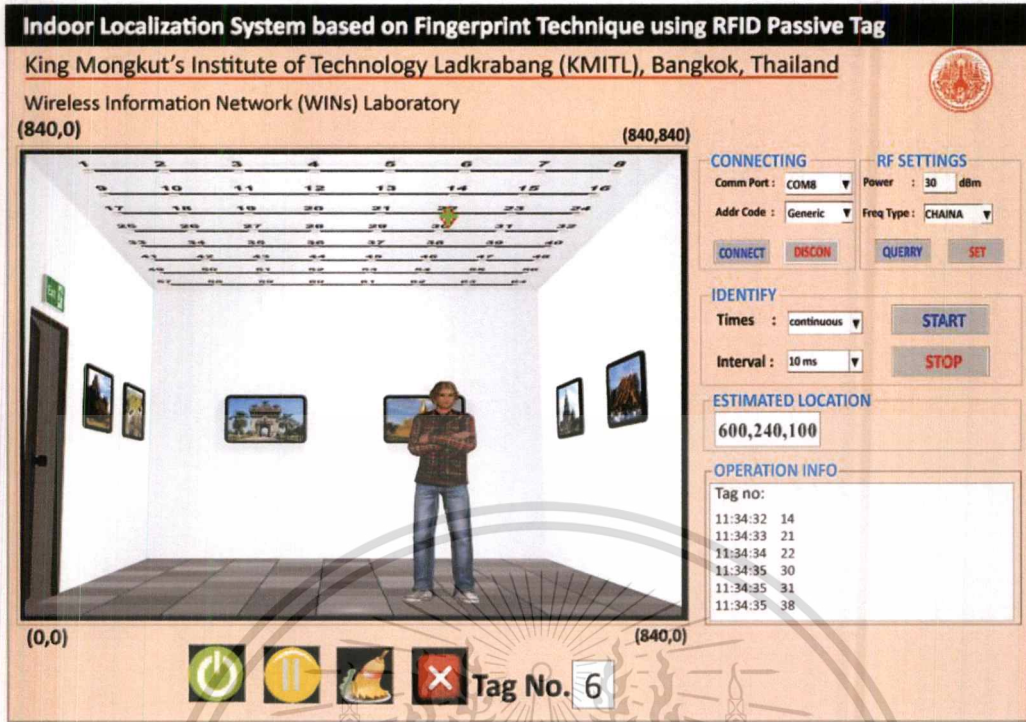


Figure 4.18 GUI windows for OL_{11} of height at 120 cm in diagonal plane

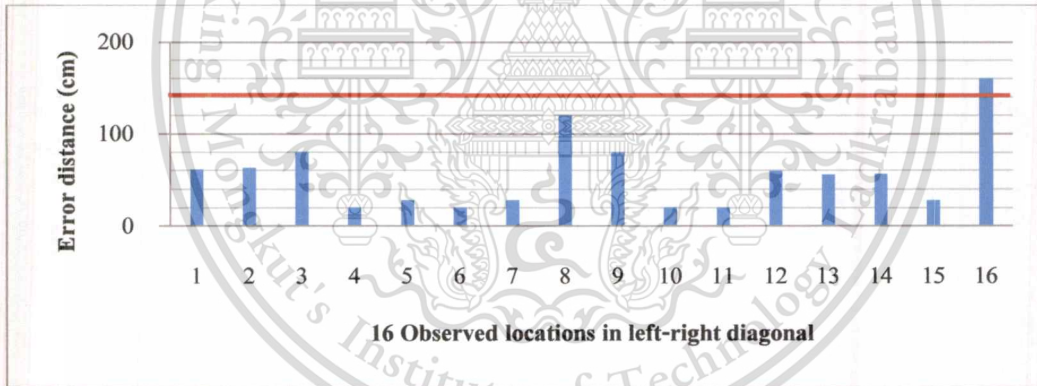


Figure 4.19 The error distance in left-right diagonal plane of height at 120 cm

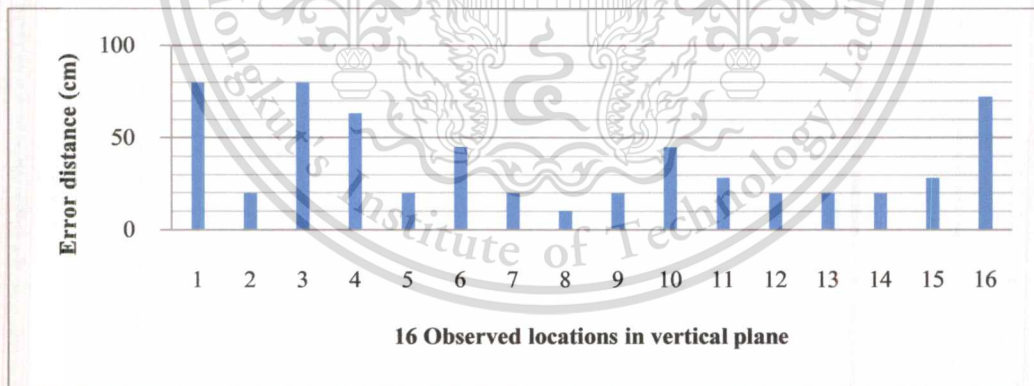
4.3.2.3.3 Estimated Results for Vertical Locations Testing

The results in vertical plane are not too much different with the other planes, since it is placed at the same direction with fingerprint locations. It can give the good estimated results.

Table 4.16 shows the estimated results and error distance for 16 observed locations. Figure 4.20 depicts the error distance for all observed locations in vertical plane. The observed locations are provided the error distance less than 80 cm. The average error distance equals to 36.96 cm.

Table 4.16 The estimated results and error distance in vertical plane of height at 120 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(360,0,120)	(360,80,120)	80
2	(360,120,120)	(360,120,100)	20
3	(360,240,120)	(360,320,120)	80
4	(360,360,120)	(360,300,100)	63.25
5	(360,480,120)	(360,480,100)	20
6	(360,600,120)	(400,600,100)	44.72
7	(360,720,120)	(360,720,100)	20
8	(360,840,120)	(360,840,130)	10
9	(480,840,120)	(480,840,100)	20
10	(480,720,120)	(520,700,120)	44.72
11	(480,600,120)	(480,580,100)	28.28
12	(480,480,120)	(480,480,100)	20
13	(480,360,120)	(480,360,100)	20
14	(480,240,120)	(480,240,100)	20
15	(480,120,120)	(480,100,100)	28.28
16	(480,0,120)	(540,40,120)	72.11

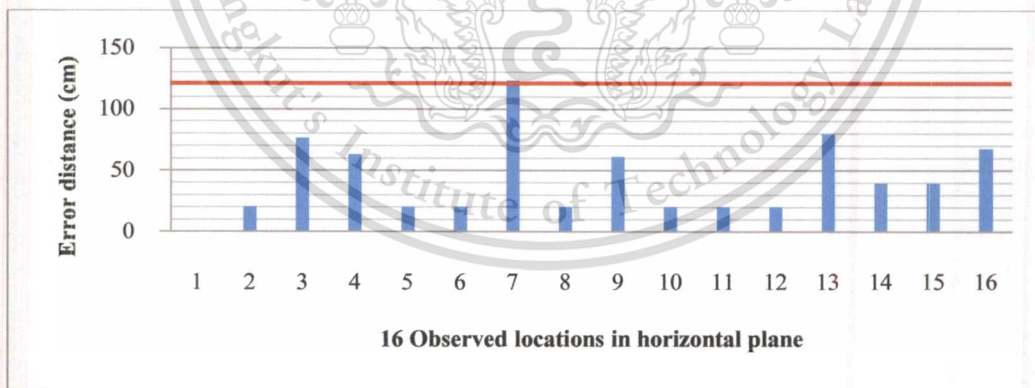
**Figure 4.20** The error distance in vertical plane of height at 120 cm

4.3.2.3.4 Estimated Results for Horizontal Locations Testing

There are two observed locations given the big error in this plane, OL_1 and OL_7 which are placed near the border of the area of interest. There are more than two fingerprint locations nearby them provide the maximum value and 2nd maximum value, they makes the estimated results are more than the gap between two tags. The average error distance equals to 50.80 cm.

Table 4.17 The estimated result and error distance in horizontal plane of height at 120 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,360,120)	(120,360,100)	121.66
2	(120,360,120)	(120,360,100)	20
3	(240,360,120)	(312,336,124)	76
4	(360,360,120)	(360,300,100)	63.25
5	(480,360,120)	(480,360,100)	20
6	(600,360,120)	(600,360,100)	20
7	(720,360,120)	(840,340,100)	123.29
8	(840,360,120)	(840,360,100)	20
9	(840,480,120)	(840,540,130)	60.83
10	(720,480,120)	(720,480,100)	20
11	(600,480,120)	(600,480,100)	20
12	(480,480,120)	(480,480,100)	20
13	(360,480,120)	(360,400,120)	80
14	(240,480,120)	(240,480,160)	40
15	(120,480,120)	(120,440,120)	40
16	(0,480,120)	(30,420,130)	67.82

**Figure 4.21** The error distance in horizontal plane of height at 120 cm

4.3.2.4 Estimated Results for 3D Indoor Localization of Height at 140 cm

4.3.2.4.1 Estimated Results for Random Locations Testing

This estimated results should be the results of fingerprint location in 160 of the reader's height, it means all or most of the z dimension should be referred to 160. The estimated results and error distance for 80 observed locations are shown in Table 4.18.

Table 4.18 The estimated results and error distance for random testing of height at 140 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(120,0,140)	(80,53.33,133.33)	67
2	(420,0,140)	(460,70,130)	81.24
3	(600,0,140)	(624,132,124)	135.11
4	(240,60,140)	(196.36,120,132.73)	74.55
5	(540,60,140)	(526.15,110.77,132.31)	53.18
6	(660,120,140)	(669.47,183.16,128.42)	64.91
7	(840,120,140)	(805.71,85.71,125.71)	50.55
8	(180,180,140)	(176,224,124)	46.99
9	(480,180,140)	(458.57,218.57,125.71)	46.38
10	(60,240,140)	(60,210,126.25)	33
11	(240,240,140)	(201.82,229.09,127.27)	41.70
12	(120,300,140)	(120,351.43,130)	52.39
13	(420,300,140)	(435,360,122.50)	64.27
14	(540,360,140)	(531.43,325.71,125.71)	38.12
15	(720,360,140)	(727.50,360,118.75)	22.53
16	(180,420,140)	(180,504,130)	84.59
17	(360,420,140)	(324,408,124)	41.18
18	(660,420,140)	(683.08,470.77,123.08)	58.28
19	(840,420,140)	(795,375,122.50)	66
20	(60,480,140)	(77.14,480,134.29)	18.07
21	(300,480,140)	(290.53,505.26,128.42)	29.36
22	(480,480,140)	(432,528,112)	73.43
23	(0,540,140)	(50,570,130)	59.16
24	(420,540,140)	(420,570,115)	39.05
25	(600,540,140)	(570,570,122.50)	45.89
26	(780,540,140)	(800,560,120)	34.64

Table 4.18 The estimated results and error distance for random testing of height at 140 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
27	(120,600,140)	(200,600,130)	80.62
28	(540,600,140)	(510,645,122.50)	56.84
29	(60,660,140)	(60,660,130)	10
30	(240,660,140)	(188.57,617.14,125.71)	68.45
31	(780,660,140)	(792,648,136)	17.44
32	(180,720,140)	(207.27,698.18,130)	36.33
33	(480,720,140)	(317.14,702.86,130)	164.06
34	(660,720,140)	(624,688,124)	50.75
35	(0,780,140)	(84.71,684.71,128.24)	128.04
36	(420,780,140)	(440,710,130)	73.48
37	(720,780,140)	(728,720,132)	61.06
38	(120,840,140)	(98.82,698.82,128.24)	143.24
39	(300,840,140)	(320,720,132)	121.92
40	(840,840,140)	(755.29,677.65,128.24)	183.50
41	(120,0,140)	(192,120,124)	140.85
42	(420,0,140)	(526.67,106.67,130)	151.18
43	(600,0,140)	(701.05,126.32,128.42)	162.18
44	(240,60,140)	(271.30,109.57,128.70)	59.70
45	(540,60,140)	(531.43,51.43,125.71)	18.74
46	(660,120,140)	(732,108,124)	74.73
47	(840,120,140)	(810,105,130)	35
48	(180,180,140)	(196.36,141.82,127.27)	43.45
49	(480,180,140)	(548.57,120,117.14)	93.94
50	(60,240,140)	(108,228,130)	50.48
51	(240,240,140)	(308.57,222.86,121.43)	73.08
52	(120,300,140)	(171.43,274.29,125.71)	59.25
53	(420,300,140)	(468,300,124)	50.60
54	(540,360,140)	(600,360,110)	67.08
55	(720,360,140)	(766.15,304.62,127.69)	73.14
56	(180,420,140)	(193.33,366.67,130)	55.88
57	(360,420,140)	(420,390,115)	71.59
58	(660,420,140)	(651.43,360,108.57)	68.27

Table 4.18 the estimated results and error distance for random testing of height at 140 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
59	(840,420,140)	(804,324,124)	103.77
60	(60,480,140)	(129.23,415.38,127.69)	95.50
61	(300,480,140)	(347.14,467.14,125.71)	50.91
62	(480,480,140)	(505.71,420,125.71)	66.82
63	(0,540,140)	(72,486,130)	90.55
64	(420,540,140)	(426.67,466.67,120)	76.30
65	(600,540,140)	(654.55,480,116.36)	84.46
66	(780,540,140)	(792,456,118)	87.66
67	(120,600,140)	(186.67,586.67,126.67)	69.28
68	(540,600,140)	(546,642,121)	46.49
69	(60,660,140)	(85.71,557.14,125.71)	106.98
70	(240,660,140)	(315,585,130)	106.54
71	(780,660,140)	(795,600,122.50)	64.27
72	(180,720,140)	(207.27,698.18,130)	36.33
73	(480,720,140)	(410,680,125)	82.01
74	(660,720,140)	(654,678,127)	44.37
75	(0,780,140)	(90,690,130)	127.67
76	(420,780,140)	(440,710,130)	73.48
77	(720,780,140)	(760,720,125)	73.65
78	(120,840,140)	(160,706.67,130)	139.56
79	(300,840,140)	(332.31,701.54,132.31)	142.39
80	(840,840,140)	(796.36,665.45,127.27)	180.37

The estimated results for these OLs are given the big results for the observed locations which are near the border such as $OL_1, OL_2, OL_3, OL_{33}, OL_{35}, OL_{38}, OL_{39}, OL_{40}, OL_{41}, OL_{42}, OL_{43}, OL_{75}, OL_{78}, OL_{79}$ and OL_{80} . Even the Z dimension is not referred to fingerprint height 160, but it still acceptable for the error distance. Since the estimated results are given by the average of fingerprint height 100 cm and 160 cm, most of the Z dimension are referred in between 120 to 130 cm. The average error distance is approximately 74 cm. The results still satisfied our expectation.

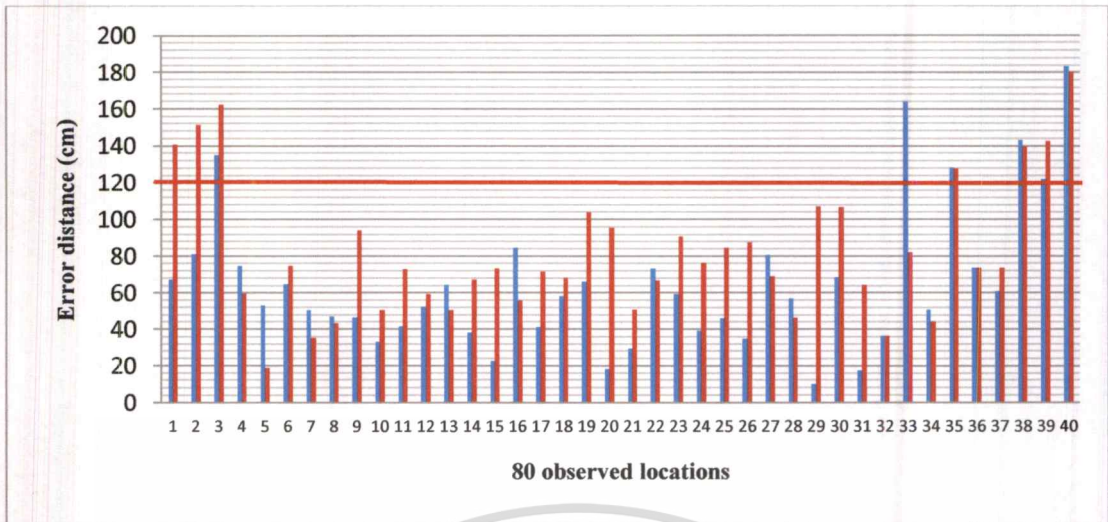


Figure 4.22 The error distance for random testing locations of height at 140 cm

4.3.2.4.2 Estimated Results for Left-Right Diagonal Locations Testing

The observed locations are placed in left and right diagonal. Some of the observed locations are referred to fingerprint height 100 such as OL_3 , OL_6 , OL_{10} , and OL_{11} . However, the estimated results for x and y axes are acceptable as shown in Table 4.19, the average error distance for these observed locations equals 59.34 cm. Figure 4.21 shows GUI windows for OL_{12} at height of 140 cm in diagonal plane which is provided the estimated results in coordinate (456,408,124) and error distance equals 56 cm. The group of detected tags consists of OL_{20} , OL_{21} , OL_{27} , OL_{28} , OL_{29} , OL_{36} , OL_{37} , OL_{45} , and OL_{52} .

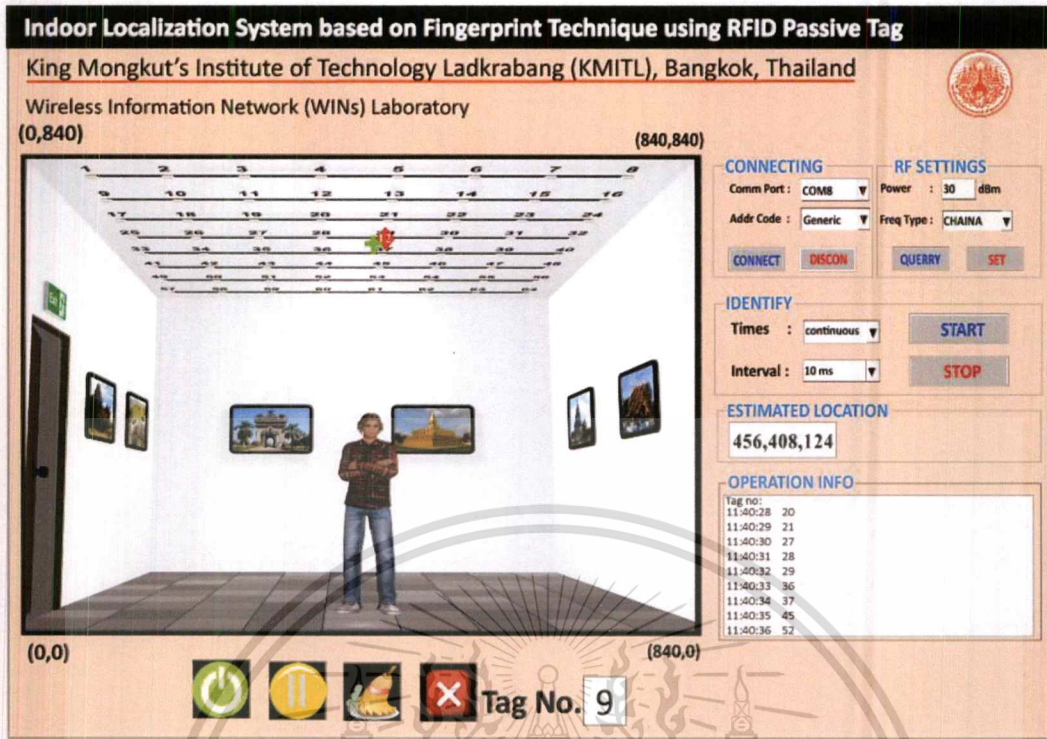


Figure 4.23 GUI windows for OL_{12} of height at 140 cm in diagonal plane

Table 4.19 The estimated results and error distance in diagonal of height at 140 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,0,140)	(40,60,120)	74.83
2	(120,120,140)	(120,80,120)	44.72
3	(240,240,140)	(240,260,100)	44.72
4	(360,360,140)	(360,320,120)	44.72
5	(480,480,140)	(480,440,140)	40
6	(600,600,140)	(600,600,100)	40
7	(720,720,140)	(760,700,140)	44.72
8	(840,840,140)	(816,696,124)	146.86
9	(840,0,140)	(840,120,130)	120.42
10	(720,120,140)	(720,120,100)	40
11	(600,240,140)	(600,240,100)	40
12	(480,360,140)	(456,408,124)	56
13	(360,480,140)	(300,480,160)	63.25
14	(240,600,140)	(240,600,160)	20
15	(120,720,140)	(100,720,115)	32.02
16	(0,840,140)	(0,744,124)	97.32

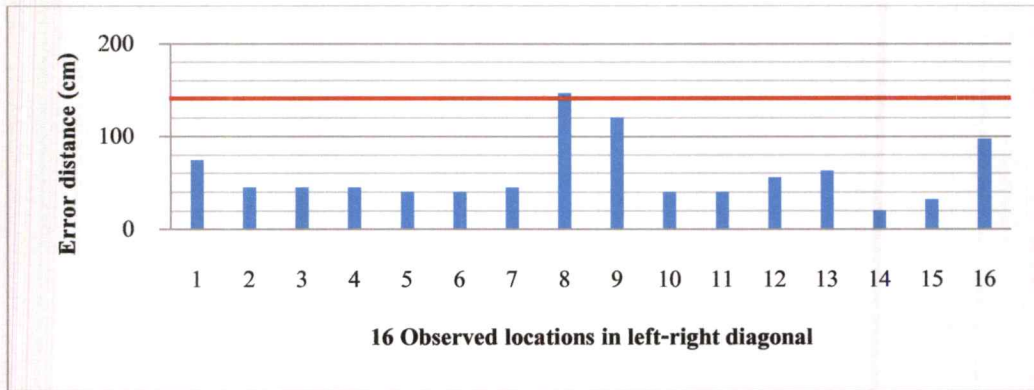


Figure 4.24 The error distance in left-right diagonal of height at 140 cm

4.3.2.4.3 Estimated Results for Vertical Locations Testing

One of these observed locations give a wonder error distance value, it is OL_8 given the error distance equals 10 cm, while this location in the other height is given the big error. It is very satisfied our expectation. The average error distance for these OLs is equal to 50.77 cm.

Table 4.20 The estimated results and error distance in vertical plane of height at 140 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(360,0,140)	(360,0,160)	20
2	(360,120,140)	(360,120,100)	40
3	(360,240,140)	(360,240,100)	40
4	(360,360,140)	(360,240,100)	126.49
5	(360,480,140)	(360,480,100)	40
6	(360,600,140)	(386.67,573.33,120)	42.69
7	(360,720,140)	(360,760,120)	44.72
8	(360,840,140)	(360,840,130)	10
9	(480,840,140)	(480,840,100)	40
10	(480,720,140)	(480,680,120)	44.72
11	(480,600,140)	(520,600,120)	44.72
12	(480,480,140)	(480,480,100)	40
13	(480,360,140)	(540,360,100)	72.11
14	(480,240,140)	(480,240,160)	20
15	(480,120,140)	(540,120,100)	72.11
16	(480,0,140)	(560,80,120)	114.89

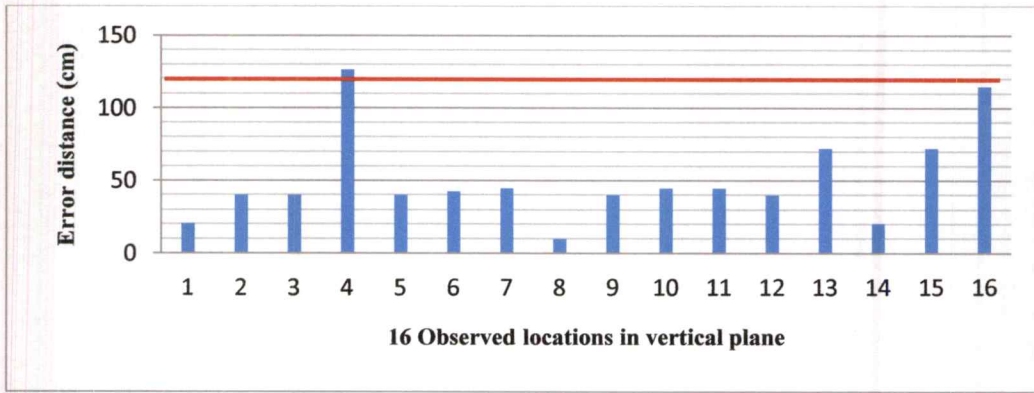


Figure 4.25 The error distance in vertical plane of height at 140 cm

4.3.2.4.4 Estimated Results for Horizontal Locations Testing

Since the fluctuation of the signal information, these *OLs* are given a big error distance for the *z* dimension which is our expectation to get in height of 160. Most of these *OLs* provided the *z* dimension in height of 100. However, *x* and *y* axes are given a good estimated results. Therefore, the average of error distance equals 67.97 cm.

Table 4.21 The estimated results and error distance in horizontal plane of height at 140 cm

No.	True Locations	Estimated Locations	Error Distance(cm)
1	(0,360,140)	(120,360,100)	126.49
2	(120,360,140)	(150,330,130)	43.59
3	(240,360,140)	(240,300,100)	72.11
4	(360,360,140)	(360,360,100)	40
5	(480,360,140)	(480,360,100)	40
6	(600,360,140)	(600,400,120)	44.72
7	(720,360,140)	(840,240,100)	174.36
8	(840,360,140)	(840,240,100)	126.49
9	(840,480,140)	(810,480,115)	39.05
10	(720,480,140)	(720,420,100)	72.11
11	(600,480,140)	(600,480,100)	40
12	(480,480,140)	(420,420,100)	93.81
13	(360,480,140)	(360,480,100)	40
14	(240,480,140)	(240,480,160)	20
15	(120,480,140)	(120,480,100)	40
16	(0,480,140)	(60,440,120)	74.83

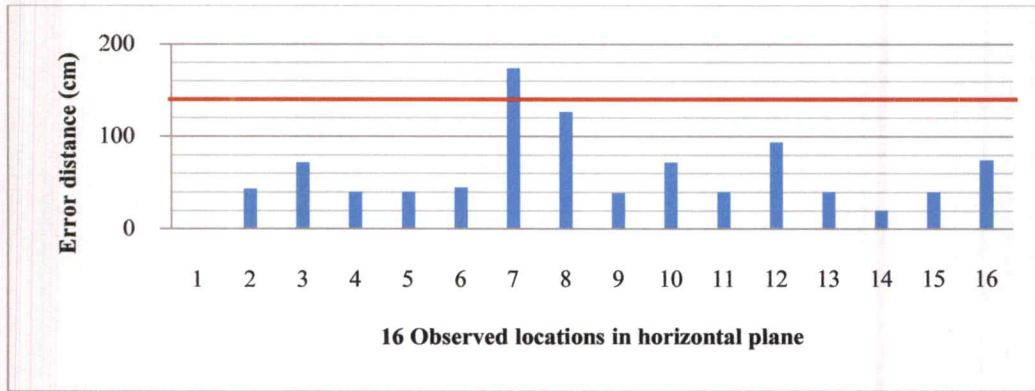


Figure 4.26 The error distance in horizontal plane of height at 140 cm

4.3.2.5 Estimated Results for 3D Indoor Localization of Height at 160 cm

4.3.2.5.1 Estimated Results for Random Locations Testing

These *OL* are placed at the same height with fingerprint locations, the estimated results should refer to fingerprint information 160 cm height of reader. It means most or all of the *OLs* should be referred to 160 as the Z axes.

Table 4.22 The estimated results and error distance for random locations testing of height at 160 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(120,0,160)	(160,120,140)	128.06
2	(420,0,160)	(444.71,141.18,160)	143.32
3	(600,0,160)	(627.69,60,160)	66.08
4	(240,60,160)	(196.36,120,160)	74.19
5	(540,60,160)	(552,96,160)	37.95
6	(660,120,160)	(570,120,160)	90
7	(840,120,160)	(840,120,160)	0
8	(180,180,160)	(220,220,140)	60
9	(480,180,160)	(516,276,160)	102.53
10	(60,240,160)	(80,280,160)	44.72
11	(240,240,160)	(204,252,160)	37.95
12	(120,300,160)	(106.67,346.67,160)	48.53
13	(420,300,160)	(435,360,132)	67.89
14	(540,360,160)	(546.67,373.33,160)	14.91
15	(720,360,160)	(698.57,300,160)	63.71
16	(180,420,160)	(195,525,140)	107.94

Table 4.22 The estimated results and error distance for random testing of height at 160 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
17	(360,420,160)	(313.85,424.62,160)	46.38
18	(660,420,160)	(685.71,488.57,160)	73.23
19	(840,420,160)	(805.71,411.43,100)	69.63
20	(60,480,160)	(55.38,553.85,150)	74.66
21	(300,480,160)	(320,440,160)	44.72
22	(480,480,160)	(458.18,447.27,160)	39.33
23	(0,540,160)	(50,570,160)	58.31
24	(420,540,160)	(428.57,582.86,160)	43.71
25	(600,540,160)	(589.09,512.73,160)	29.37
26	(780,540,160)	(800,560,160)	28.28
27	(120,600,160)	(163.64,578.18,160)	48.79
28	(540,600,160)	(555,570,160)	33.54
29	(60,660,160)	(105,660,160)	45
30	(240,660,160)	(188.57,617.14,160)	66.94
31	(780,660,160)	(800,626.67,160)	38.87
32	(180,720,160)	(185.45,676.36,140)	48.31
33	(480,720,160)	(456,700,160)	31.24
34	(660,720,160)	(665.45,687.27,160)	33.18
35	(0,780,160)	(88,760,160)	90.24
36	(420,780,160)	(433.85,700,160)	81.19
37	(720,780,160)	(728,720,160)	60.53
38	(120,840,160)	(140,800,130)	53.85
39	(300,840,160)	(320,720,140)	123.29
40	(840,840,160)	(765,682.50,100)	184.48
41	(120,0,160)	(132,168,140)	169.61
42	(420,0,160)	(450,135,160)	138.29
43	(600,0,160)	(690,150,160)	174.93
44	(240,60,160)	(316.36,130.91,160)	104.21
45	(540,60,160)	(525,135,160)	76.49
46	(660,120,160)	(570,120,160)	90
47	(840,120,160)	(800,140,160)	44.72
48	(180,180,160)	(216,168,140)	42.90
49	(480,180,160)	(490,200,160)	22.36

Table 4.22 The estimated results and error distance for random testing of height at 160 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
50	(60,240,160)	(80,200,160)	44.72
51	(240,240,160)	(195.79,303.16,160)	77.09
52	(120,300,160)	(150,315,160)	33.54
53	(420,300,160)	(413.33,306.67,132)	29.54
54	(540,360,160)	(580,360,160)	40
55	(720,360,160)	(732.63,391.58,160)	34.01
56	(180,420,160)	(192,456,140)	42.90
57	(360,420,160)	(348,372,160)	49.48
58	(660,420,160)	(660,405,160)	15
59	(840,420,160)	(792,396,100)	80.50
60	(60,480,160)	(110.77,461.54,150)	54.94
61	(300,480,160)	(293.33,453.33,160)	27.49
63	(0,540,160)	(53.33,506.67,160)	62.89
64	(420,540,160)	(435,510,160)	33.54
65	(600,540,160)	(600,580,160)	40
66	(780,540,160)	(737.14,531.43,160)	43.71
67	(120,600,160)	(171.43,565.71,160)	61.81
68	(540,600,160)	(560,546.67,160)	56.96
69	(60,660,160)	(51.43,685.71,160)	27.11
70	(240,660,160)	(240,560,160)	100
71	(780,660,160)	(792,648,160)	16.97
72	(180,720,160)	(180,660,140)	63.25
73	(480,720,160)	(375,675,160)	114.24
74	(660,720,160)	(660,660,160)	60
75	(0,780,160)	(80,653.33,160)	149.81
76	(420,780,160)	(420,648,160)	132
77	(720,780,160)	(754.29,702.86,160)	84.42
78	(120,840,160)	(73.85,800,130)	68.05
79	(300,840,160)	(333.33,693.33,140)	151.73
80	(840,840,160)	(788.57,685.71,100)	173.35

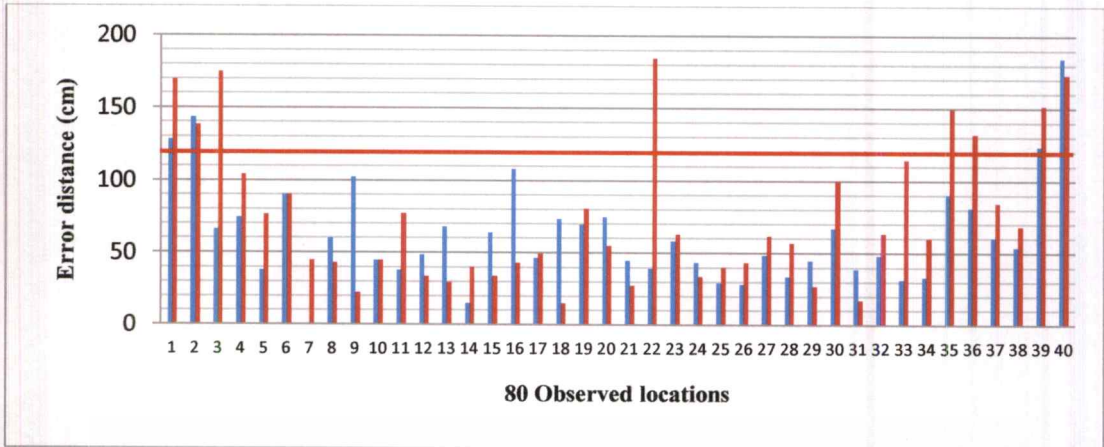


Figure 4.27 The error distance for random locations testing of height at 160 cm

From Table 4.22, most of the estimated results are referred to 160 for the z axes. There are four *OLs* refers to 100 such as OL_{19} , OL_{40} , OL_{59} and OL_{80} . Therefore, it still provide the big error distance in some observed locations, for example, OL_1 , OL_2 , OL_{39} , OL_{40} , OL_{41} , OL_{42} , OL_{43} , OL_{62} , OL_{75} , OL_{76} , OL_{79} and OL_{80} . These 12 *OLs* are provided the error distance more than 120 cm, the biggest error distance is given by OL_{62} . This *OL* is really not satisfy our expectation, since it placed at the same with *FL* but provides the error distance equals 184.39 cm. The average error distance for 80 *OLs* is 69.39 cm.

4.3.2.5.2 Estimated Results for Left-Right Diagonal Locations Testing

Nine observed locations are given the error distance equals 0 cm in this plane. The other *OLs* are given an acceptable error distance except four *OLs* which are placed near the border of area of interest.

Table 4.23 The estimated results and error distance in diagonal plane of height at 160 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,0,160)	(30,120,160)	123.6931688
2	(120,120,160)	(120,120,160)	0
3	(240,240,160)	(240,180,160)	60
4	(360,360,160)	(360,360,160)	0
5	(480,480,160)	(480,480,160)	0
6	(600,600,160)	(600,600,160)	0
7	(720,720,160)	(720,720,160)	0
8	(840,840,160)	(840,720,160)	120
9	(840,0,160)	(840,120,160)	120
10	(720,120,160)	(720,120,160)	0

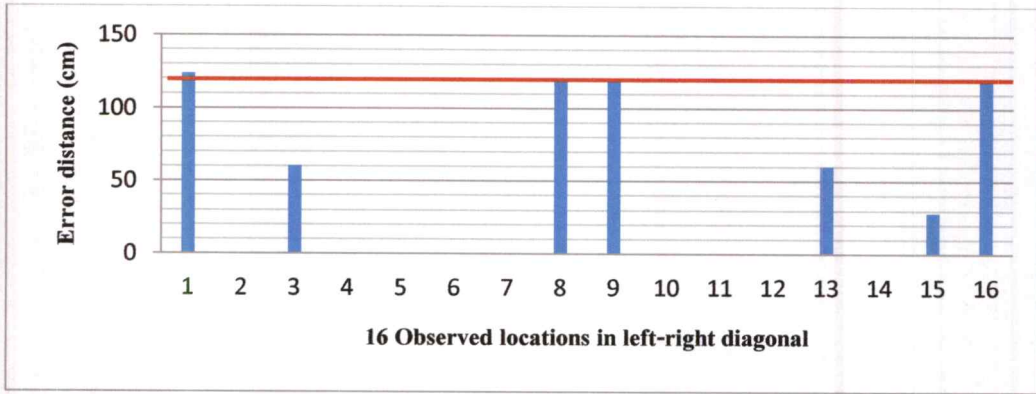


Figure 4.29 The error distance in left-right diagonal plane of height at 160 cm

4.3.2.5.3 Estimated Results for Vertical Locations Testing

Even this plane is the same direction with fingerprint locations, some of the OLs are provided the big error distance. $OL_7, OL_8, OL_9, OL_{11}$ and OL_{16} are given unsatisfied error distance. Especially, OL_{11} which is placed at the same with FL and it is not near the border, but provides the error distance equals 84.85 cm.

Table 4.24 The estimated results and error distance in vertical plane of height at 160 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(360,0,160)	(360,60,160)	60
2	(360,120,160)	(360,120,160)	0
3	(360,240,160)	(360,240,160)	0
4	(360,360,160)	(360,360,160)	0
5	(360,480,160)	(360,540,160)	60
6	(360,600,160)	(360,600,160)	0
7	(360,720,160)	(440,680,160)	89.44
8	(360,840,160)	(300,720,160)	134.16
9	(480,840,160)	(450,690,160)	152.97
10	(480,720,160)	(480,720,160)	0
11	(480,600,160)	(540,660,160)	84.85
12	(480,480,160)	(480,480,160)	0
13	(480,360,160)	(480,360,160)	0
14	(480,240,160)	(480,240,160)	0
15	(480,120,160)	(480,140,160)	20
16	(480,0,160)	(480,120,160)	120

It could be the error distance from signal fluctuation, a similarity for the group of detected tags, setting of experiment or the other reason that we could not know. The average error distance for these OLs equals to 45.48 cm.

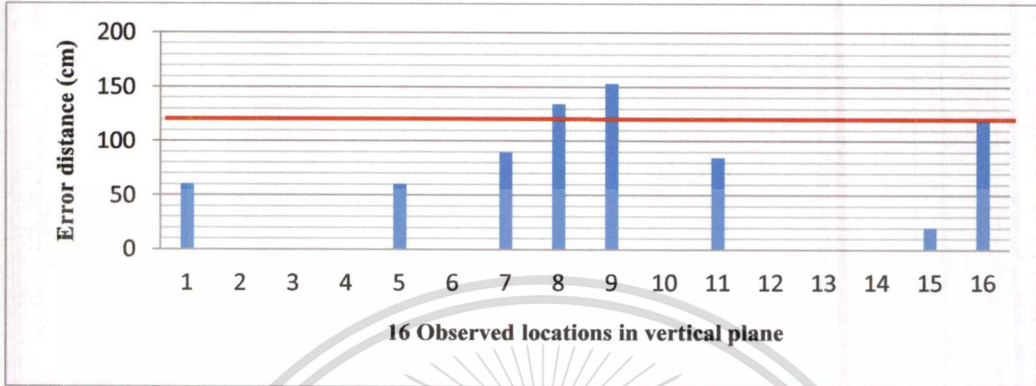


Figure 4.30 The error distance in vertical plane of height at 160 cm

4.3.2.5.4 Estimated Results for Horizontal Locations Testing

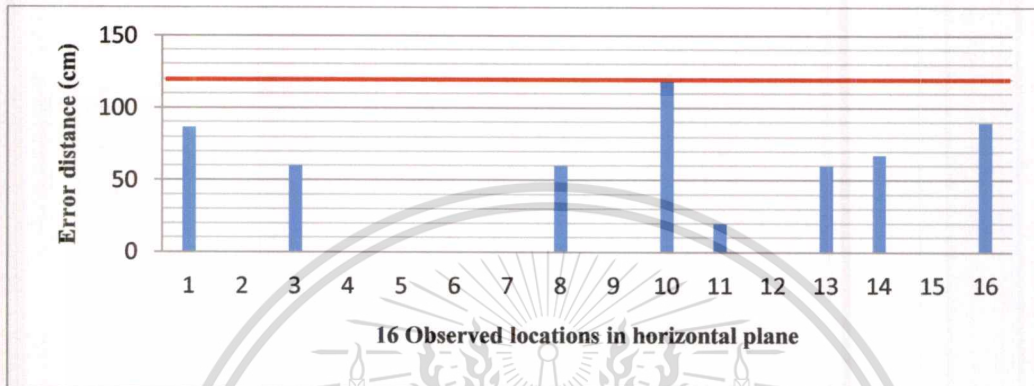
The OLs in this plane are given a good estimated results if compare with the results from other plane in same height testing. The average error distance for all is equal to 35.19 cm. the biggest error distance is given by OL_{10} as shown in Table 4.25.

Table 4.25 The estimated results and error distance in horizontal plane of height at 160 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,360,160)	(48,288,160)	86.53
2	(120,360,160)	(120,360,160)	0
3	(240,360,160)	(240,300,160)	60
4	(360,360,160)	(360,360,160)	0
5	(480,360,160)	(480,360,160)	0
6	(600,360,160)	(600,360,160)	0
7	(720,360,160)	(720,360,160)	0
8	(840,360,160)	(840,420,160)	60
9	(840,480,160)	(840,480,160)	0
10	(720,480,160)	(720,600,160)	120
11	(600,480,160)	(600,460,160)	20
12	(480,480,160)	(480,480,160)	0
13	(360,480,160)	(360,420,160)	60

Table 4.25 The estimated results and error distance in horizontal plane of height at 160 cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
14	(240,480,160)	(180,510,160)	67.08
15	(120,480,160)	(120,480,160)	0
16	(0,480,160)	(40,560,160)	89.44

**Figure 4.31** The error distance in horizontal plane of height at 160 cm

4.3.2.6 Estimated Results for 3D Indoor Localization of Height at 180 cm

4.3.2.6.1 Estimated Results for Random Locations Testing

These *OLs* are placed at the average height of adult as well as European or American. Since the ceiling of our experiment area is only 300 cm of the reader height, when we placed the target as the height of 180 cm. The similarity for the group of detected tags is given more and the signal fluctuation also provides more. The signal fluctuation could be comes from the ceiling, metal, lamp, etc. However, these *OLs* still provided the estimated results which it can acceptable and satisfies. The details for estimated results and error distance are given more detail in Table 4.26.

Table 4.26 The estimated results and error distance for random locations testing of height at 180 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(120,0,180)	(160,106.67,160)	115.66
2	(420,0,180)	(462.86,94.29,130)	115.01
3	(600,0,180)	(700,120,160)	157.48
4	(240,60,180)	(272.73,163.64,160)	110.51
5	(540,60,180)	(526.15,110.77,132.31)	71.02
6	(660,120,180)	(720,173.33,160)	82.73

Table 4.26 The estimated results and error distance for random testing of height at 180cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
7	(840,120,180)	(805.71,120,125.71)	64.21
8	(180,180,180)	(196.36,141.82,127.27)	67.13
9	(480,180,180)	(488.57,214.29,160)	40.61
10	(60,240,180)	(70,210,130)	59.16
11	(240,240,180)	(258.46,276.92,160)	45.87
12	(120,300,180)	(171.43,360,160)	81.52
13	(420,300,180)	(435,360,160)	65
14	(540,360,180)	(546.67,373.33,160)	24.94
15	(720,360,180)	(728,344,160)	26.83
16	(180,420,180)	(169.41,465.88,128.24)	69.98
17	(360,420,180)	(365.45,485.45,160)	68.66
18	(660,420,180)	(683.08,470.77,160)	59.25
19	(840,420,180)	(792,456,118)	86.28
20	(60,480,180)	(86.67,533.33,130)	77.82
21	(300,480,180)	(320,440,160)	48.99
22	(480,480,180)	(493.33,553.33,160)	77.17
23	(0,540,180)	(48,520,128)	73.54
24	(420,540,180)	(480,570,160)	70
25	(600,540,180)	(620,550,160)	30
26	(780,540,180)	(792,564,124)	62.10
27	(120,600,180)	(120,630,160)	36.06
28	(540,600,180)	(546.67,640,160)	45.22
29	(60,660,180)	(83.08,627.69,132.31)	62.06
30	(240,660,180)	(195,630,160)	57.66
31	(780,660,180)	(820,620,120)	82.46
32	(180,720,180)	(185.45,676.36,160)	48.31
33	(480,720,180)	(480,700,160)	28.28
34	(660,720,180)	(665.45,687.27,127.27)	62.30
35	(0,780,180)	(84.71,684.71,160)	129.06
36	(420,780,180)	(433.85,673.85,160)	108.91
37	(720,780,180)	(744,720,130)	81.71
38	(120,840,180)	(105,712.50,160)	129.93
39	(300,840,180)	(320,720,160)	123.29

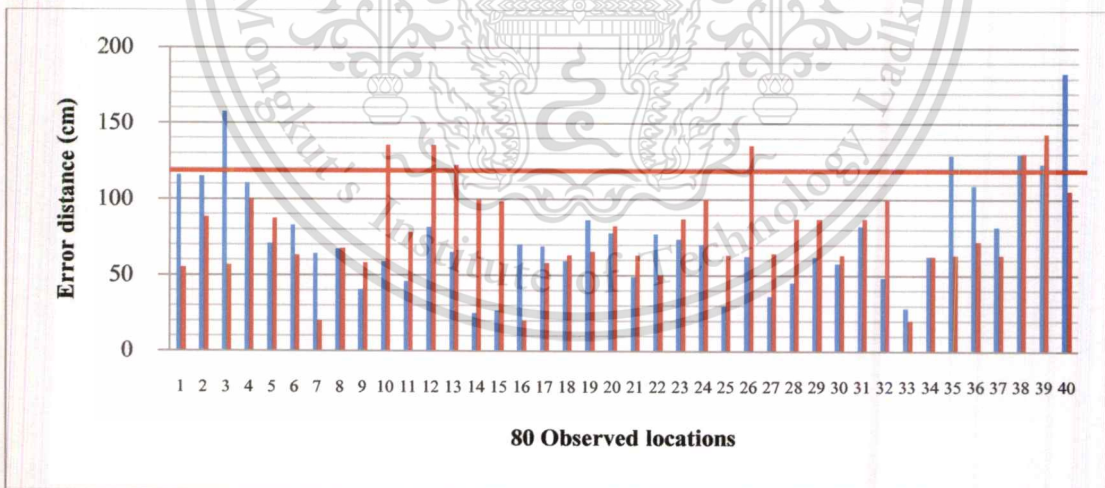
Table 4.26 The estimated results and error distance for random testing of height at 180cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
40	(840,840,180)	(813.33,666.67,126.67)	183.30
41	(120,0,180)	(150,30,145)	55
42	(420,0,180)	(428.57,68.57,125.71)	87.88
43	(600,0,180)	(600,40,140)	56.57
44	(240,60,180)	(255,135,115)	100.37
45	(540,60,180)	(480,0,160)	87.18
46	(660,120,180)	(600,120,160)	63.25
47	(840,120,180)	(840,120,160)	20
48	(180,180,180)	(216,168,124)	67.65
49	(480,180,180)	(480,150,130)	58.31
50	(60,240,180)	(120,120,160)	135.65
51	(240,240,180)	(240,180,130)	78.10
52	(120,300,180)	(240,360,160)	135.65
53	(420,300,180)	(408,408,124)	122.25
54	(540,360,180)	(600,360,100)	100
55	(720,360,180)	(660,300,130)	98.49
56	(180,420,180)	(180,420,160)	20
57	(360,420,180)	(390,420,130)	58.31
58	(660,420,180)	(660,480,160)	63.25
59	(840,420,180)	(810,450,130)	65.57
60	(60,480,180)	(120,440,140)	82.46
61	(300,480,180)	(300,420,160)	63.25
62	(480,480,180)	(480,504,136)	50.12
63	(0,540,180)	(60,600,160)	87.18
64	(420,540,180)	(420,600,100)	100
65	(600,540,180)	(600,480,160)	63.25
66	(780,540,180)	(840,660,160)	135.65
67	(120,600,180)	(165,570,145)	64.42
68	(540,600,180)	(600,540,160)	87.18
69	(60,660,180)	(120,600,160)	87.18
70	(240,660,180)	(240,600,160)	63.25
71	(780,660,180)	(840,720,160)	87.18
72	(180,720,180)	(120,720,100)	100

Table 4.26 The estimated results and error distance for random testing of height at 180cm (cont.)

No.	True Locations	Estimated Locations	Error Distance (cm)
73	(480,720,180)	(480,720,160)	20
74	(660,720,180)	(672,744,124)	62.10
75	(0,780,180)	(0,840,160)	63.25
76	(420,780,180)	(420,720,140)	72.11
77	(720,780,180)	(720,760,120)	63.25
78	(120,840,180)	(120,720,130)	130
79	(300,840,180)	(240,720,130)	143.18
80	(840,840,180)	(840,744,136)	105.60

A half of the estimated results are referred to the 160 cm height of the reader, the reason is the group of detected tags in *OL* are similar with the group of detected tags at *FL* nearby more than one locations. Even the estimated results in *z* are difference from the true location and gives some error, therefore, the estimated results in *x* and *y* axes still provide a good estimated. There are 11 *OLs* given a big error distance such as $OL_3, OL_{35}, OL_{38}, OL_{39}, OL_{40}, OL_{50}, OL_{52}, OL_{53}, OL_{66}, OL_{78}$, and OL_{79} . The average error distance is 77.92 cm, they are satisfied our expectation.

**Figure 4.32** The error distance for random locations testing of height at 180 cm

4.3.2.6.2 Estimated Results for Left-Right Diagonal Locations Testing

There are only two *OLs* given the big error distance more than 120 cm. The *z* dimension is no problem in this plane because all estimated results provides 160. The average error distance equals 57.51 cm. It is reasonable and satisfying value for finding the location of the target in 3D localization.

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Table 4.27 The estimated results and error distance in diagonal plane of height at 180 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,0,180)	(40,60,160)	74.83
2	(120,120,180)	(120,80,160)	44.72
3	(240,240,180)	(240,160,160)	82.46
4	(360,360,180)	(360,360,160)	20
5	(480,480,180)	(480,440,160)	44.72
6	(600,600,180)	(600,600,160)	20
7	(720,720,180)	(720,680,160)	44.72
8	(840,840,180)	(840,696,160)	145.38
9	(840,0,180)	(840,80,160)	82.46
10	(720,120,180)	(720,120,160)	20
11	(600,240,180)	(600,360,160)	121.66
12	(480,360,180)	(480,360,160)	20
13	(360,480,180)	(360,420,160)	63.25
14	(240,600,180)	(240,600,160)	20
15	(120,720,180)	(120,700,160)	28.28
16	(0,840,180)	(30,760,160)	87.75

The estimated results for OL_5 is shown in fig. 4.30. It placed at (480,480,180) for the true location and the estimated locations is referred to (480,440,160). The error distance is 44.72 cm. The group of detected tags consists of $OL_{29}, OL_{37}, OL_{45}, OL_{54}$.

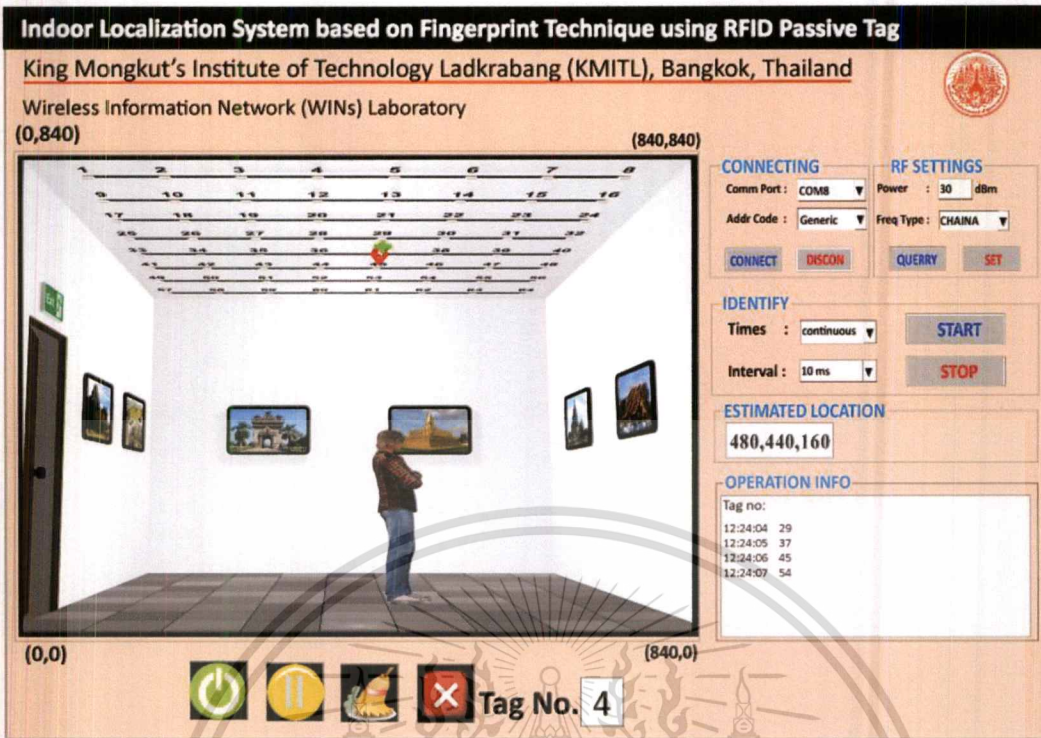


Figure 4.33 GUI windows for OL_5 of height at 180 cm in diagonal plane

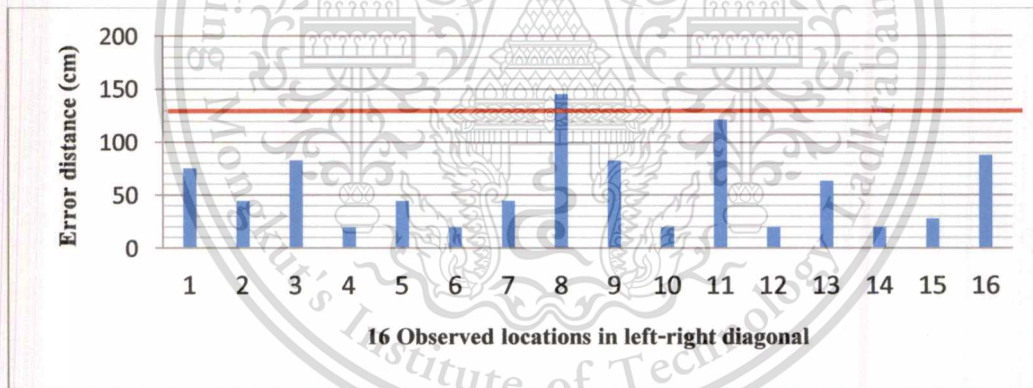


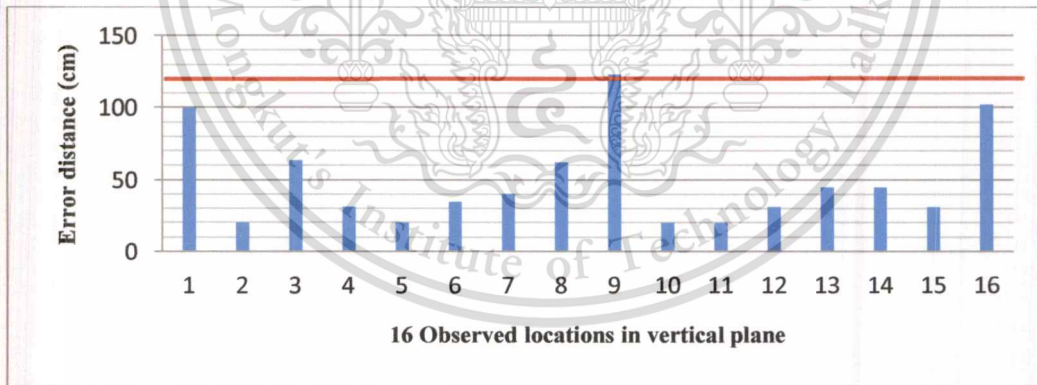
Figure 4.34 The error distance in left-right diagonal of height at 180 cm

4.3.2.6.3 Estimated Results for Vertical Locations Testing

Since it placed the same with fingerprint locations direction, its average error distance is better than in diagonal plane. Anyway, for Z dimension is not so good in this plane, there are several observed locations provided the 100 of height for the estimated locations. The average error distance is 49.28 cm. Four OLs are provided a good as results in this plane such as OL_2 , OL_5 , OL_{10} and OL_{11} .

Table 4.28 The estimated results and error distance in vertical plane of height at 180 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(360,0,180)	(360,80,120)	100
2	(360,120,180)	(360,120,160)	20
3	(360,240,180)	(360,180,160)	63.25
4	(360,360,180)	(360,384,160)	31.24
5	(360,480,180)	(360,480,160)	20
6	(360,600,180)	(380,580,160)	34.64
7	(360,720,180)	(360,720,140)	40
8	(360,840,180)	(400,800,154)	62.26
9	(480,840,180)	(460,720,160)	123.29
10	(480,720,180)	(480,720,160)	20
11	(480,600,180)	(480,600,160)	20
12	(480,480,180)	(480,504,160)	31.24
13	(480,360,180)	(520,360,160)	44.72
14	(480,240,180)	(480,200,160)	44.72
15	(480,120,180)	(480,144,160)	31.24
16	(480,0,180)	(480,100,160)	101.98

**Figure 4.35** The error distance in vertical plane of height at 180 cm

4.3.2.6.4 Estimated Results for Horizontal Locations Testing

This plane is the last plane which will discuss about the estimated results. As shown in Table 4.29, there are four *OLs* given good results and four *OLs* provided the *z* dimension in less than 160. There are two *OLs* provided the estimated results more than 120, it is *OL₇* and *OL₉*. However, the

average error distance equals 53.84 cm. This error distance is satisfied our expectation since it less than the gap between tags.

Table 4.29 The estimated results and error distance in horizontal plane of height at 180 cm

No.	True Locations	Estimated Locations	Error Distance (cm)
1	(0,360,180)	(17.14,394.29,160)	43.24
2	(120,360,180)	(120,300,160)	63.25
3	(240,360,180)	(240,360,160)	20
4	(360,360,180)	(360,360,160)	20
5	(480,360,180)	(480,360,154)	26
6	(600,360,180)	(600,300,160)	63.25
7	(720,360,180)	(760,240,160)	128.06
8	(840,360,180)	(840,320,130)	64.03
9	(840,480,180)	(840,360,160)	121.66
10	(720,480,180)	(660,420,160)	87.18
11	(600,480,180)	(600,480,160)	20
12	(480,480,180)	(480,480,160)	20
13	(360,480,180)	(360,460,160)	28.28
14	(240,480,180)	(240,480,160)	20
15	(120,480,180)	(120,510,120)	67.08
16	(0,480,180)	(0,540,145)	69.46

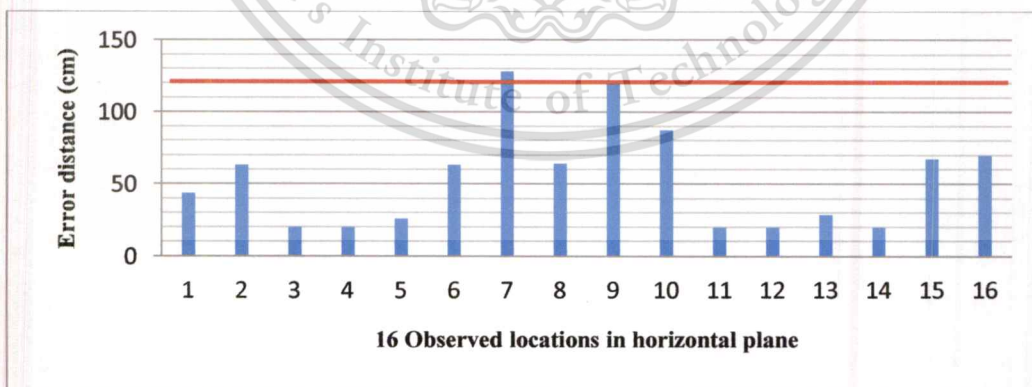


Figure 4.36 The error distance in horizontal plane of height at 180 cm

In addition, the results of Z direction are considered and discussed in this chapter. 40 observed locations for random locations in forward direction in each target height are considered. The comparing

error distance are classified in two observed locations group, firstly, to observed the similarity height of fingerprint information at 100 cm. They are included in height at 80 cm, 100 cm and 120 cm for the first group. Secondly, to observed the similarity height of fingerprint information at 160 cm the error distance from observed locations in height at 140 cm, 160 cm and 180 cm are compared and discussed.

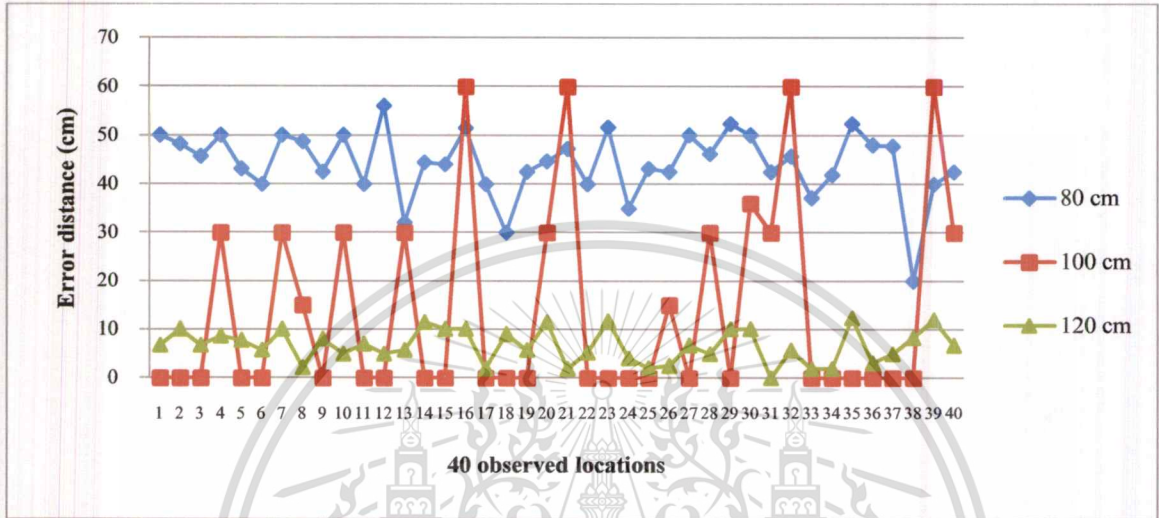


Figure 4.37 The comparison of error distance for z direction in height of 80 cm, 100 cm, and 120 cm

In case of 40 *OLs* in height at 80 cm, as the blue solid line indicates that its mean of error is settled on 45 cm and its range of error distance is 35 cm. For 40 *OLs* in height of 100 cm as the red solid line are given mean value of error distance settled on around 20 cm and its range of error distance is approximately 30 cm. As final the *OLs* in height of 120 cm are provided the good estimated results more than the others height, since its mean value of error distance is given between 0-10 and the range of error distance is less than 10 cm.

Figure 4.38 shows the comparison of error distance for z direction in height of 140 cm, 160 cm, and 180 cm. In case of 40 *OLs* in height at 140 cm, as the blue solid line indicates that its mean of error is settled on 15 cm and its range of error distance is 20 cm. For 40 *OLs* in height of 160 cm as the red solid line are given mean value of error distance settled on around 20 cm and its range of error distance is approximately 30 cm. since we compared the mean value between the maximum value and minimum value. As final the *OLs* in height of 180 cm are provided mean value of error distance in between 20-50 and the range of error distance is less than 30 cm.

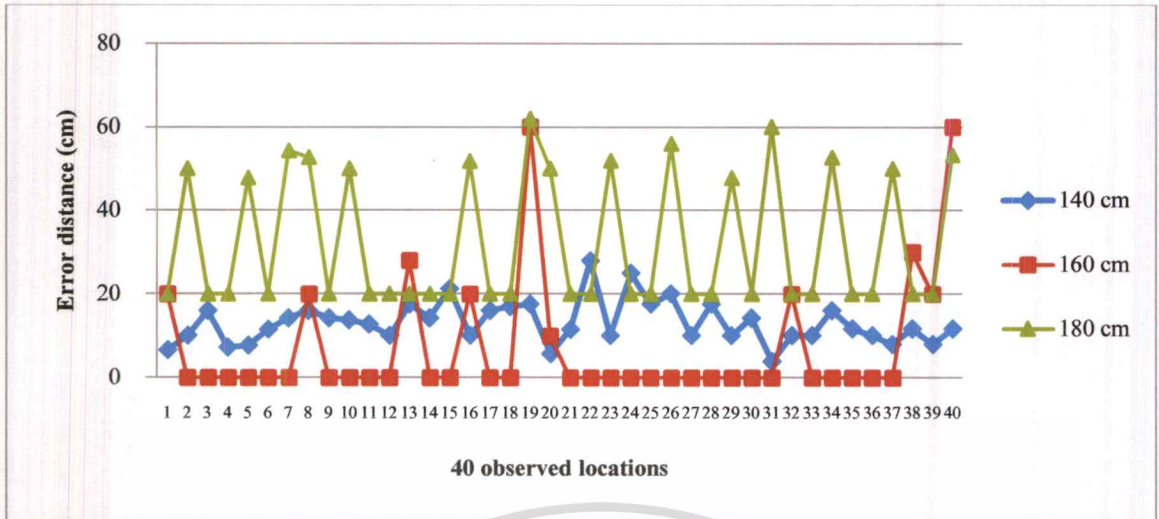
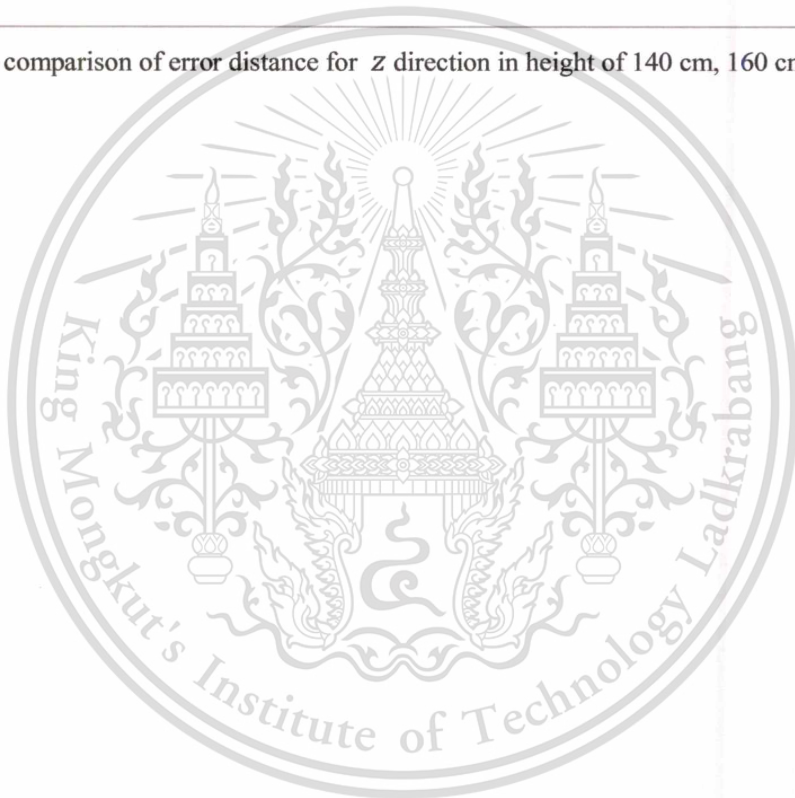


Figure 4.38 The comparison of error distance for z direction in height of 140 cm, 160 cm, and 180 cm



CHAPTER 5

CONCLUSIONS AND DISCUSSION

This thesis proposed the simple method of the indoor localization estimation. The fingerprint technique and dot product algorithm are used as the pattern matching. The 64 RFID passive tags are deployed as the reference locations for 2D and 3D, respectively. Manual robot is deployed as stationary and moving target instead of human. The results divided in two parts, firstly, is the result for 2D indoor localization. The average of the error distance for these observed locations is approximately 65 cm. Secondly, for 3D indoor localization, the average of the error distance for all observed locations in height of 80 cm is approximately 77 cm, 66 cm for the observed locations in height of 100 cm, the error distance is approximately 80.06 cm for the observed locations in height of 120 cm, approximately 66 cm for the observed locations in height of 140 cm, for the observed locations in height of 160 cm is approximately 64 cm and finally, observed locations in height of 180 cm is provided the average of the error distance approximately 76 cm. Some errors could be as result of indoor signal fluctuating propagation (such as propagation by metal media, lamp, ceiling itself), the similarity for the group of detected tags of nearby *FL* which was found as same as the observed location, setting of experiment and the other reasons that we could not know.

These results satisfied our expectation, since the average error distance is given a good estimated less than the gap between two tags (120 cm). From the results, our proposed method can be applied in real situation (Indoor localization such as visitor tracking in museum). The estimated results are shown in the GUI reach to support the suitable information (text, voice, video, etc.) for the target locations (human) in the future work.

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Abbreviations and Acronyms

2D	2 Dimension
3D	3 Dimension
AC	Alternating Current
AOA	Angle of Arrival
ATM	Automated Teller Machine
AUN/SEED-Net	ASEAN University Network/Southeast Asia Engineering Education Development Network
BS	Base Stations
CDMA	Code Division Multiple Access
CG	Center of Gravity
DC	Direct current
EHF	Extremely high frequency
ELF	Extremely low frequency
EPC	Electronic Product Code
GPS	Global Positioning System
GUI	Graphic User Interface
HF	High frequency
IC	Integrated Circuit
IF	Identification Friend or Foe
IR	Infrared Radiation
ISO	International Standard Organization
KMITL	King Mongkut's Institute of Technology Ladkrabang
LF	Location Fingerprinting
LF	Low Frequency
MF	Medium frequency
MS	Mobile Station
NLOS	None Line of Sight
PCB	Printed Circuit Board
RFID	Radio Frequency Identification
RS-232	Recommended Standard 232
RSS	Receive Signal Strength
RSSI	Receive Signal Strength Indication
RTLSS	Real-Time Location System

RTOF	Roundtrip Time of Flight
SHF	Super high frequency
SLF	Super low frequency
TDOA	Time Difference of Arrival
TOA	Time of Arrival
ULF	Ultralow Frequency
USB	Universal Serial Bus
UWB	Ultra Wide Band
VB	Visual Basic
VHF	Very high frequency
VLF	Very Low Frequency
WLAN	Wireless Local Area Network





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Author Biography

Personal Information

Name	SISONGKHAM PHIMMASEAN
Nationality	Lao
Date of birth	July 26, 1988
Place of birth	Ban Simmano neua, Hatxayfong district, Vientiane Capital, Laos P.D.R

Education

Bachelor degree

Field	Information Technology Engineering
Duration	2005-2010
Department	Department of Computer Engineering and Information Technology
University	Faculty of Engineering, National University of Laos (NUOL)

Master degree

Field	Computer Engineering
Duration	2011-2013
Department	School of Computer Engineering
Faculty	International College
University	King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand

Research Interests

Wireless Communication Systems: wireless sensor networks, target finding algorithm, wireless module and hardware applications, fingerprinting techniques supported Indoor and outdoor localization. 2D and 3D indoor localization, algorithm model using in indoor localization, RFID technology and Zigbee technology.



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List of Publications

- [1] **Sisongkham Phimmasen**, Dwi Joko suroso, and Panarat Chernthanomwong, *“Development of User-friendly GUI for Indoor Localization using RFID Passive Tag,”* Copyright © 2012 Universal Association of Computer and Electronics Engineers. All rights reserved. ISBN: 978-981-07-2683-6 doi:10.3850/978-981-07-2683-6 AIT-108, Bangkok, Thailand.
- [2] **Sisongkham Phimmasen**, Dwi Joko suroso, and Panarat Chernthanomwong, *“Fingerprint Technique for Indoor Localization in RFID Passive Tag Using Dot Product,”* Thailand-Japan MicroWave 2012 Conference (TJMW 2012), Copyright©2012 by IEICE, August 7-10, 2012, Bangkok, Thailand. (*Won Young Research Best Presentation Award*).
- [3] **Sisongkham Phimmasen**, Dwi Joko suroso, Thanapong Chuenurajit, and Panarat Chernthanomwong, *“3D Fingerprint-based Indoor Localization using RFID Passive Tag,”* International Conference on Engineering, Applied Sciences, and Technology (ICEAST 2012). November 21 – 24, 2012, Swissotel Le Concorde, Bangkok, Thailand.
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Thailand – Japan MicroWave 2012



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Fingerprint Technique for Indoor Localization in RFID Passive Tag Using Dot Product

Sisongkham PHIMMASEAN[†] Dwi Joko SUROSO[†] and Panarat CHERNTANOMWONG[‡]

[†]International College, KMITL 10520, Bangkok, Thailand

[‡]Dept. of Computer Engineering, KMITL 10520, Bangkok, Thailand

E-mail: [†]{s4601103, s3601152}@kmitl.ac.th, [‡]{krpanara}@kmitl.ac.th

Abstract Radio Frequency Identification (RFID) is technology that can track people and objects. In this paper, RFID passive tag-based indoor localization is utilized. Cost-effective and low power consumption system is the advantages. Simulation of the fingerprint-based localization technique in indoor environment using the dot product is applied. This algorithm is used to find the estimated location by multiplying the matrices of all fingerprint locations with the observed location. Norm equation is employed to find the error distance. The average error of this proposed method is approximately 14 cm. We can get conclusion that our proposed method can be applied in real application.

Keyword Indoor localization, RFID passive tag, Fingerprint Technique, Dot Product

1. ALGORITHM MODEL

1.1. FINGERPRINT LOCATION TECHNIQUE

Scene Analysis some time refers as Fingerprint Technique algorithm. For estimating the location, it has two-step process. First step, record the signal information at known location and represented as fingerprint location is called off line phase. Second step it is called online phase. In is phase, the information of fingerprint location is matched with the observed location [1]-[2]. The accuracy of the estimated location depends on the database that recorded in the first step. Table I shows the fingerprint (FP) database model. In this research, 81 passive tags are deployed as fingerprint node and the RFID reader as the target.

FP Location	FP Information
FL_1	$D_1 = \{\text{tags that detected at } FL_1\}$
FL_2	$D_2 = \{\text{tags that detected at } FL_2\}$
...	...
FL_{81}	$D_{81} = \{\text{tags tag that detected at } FL_{81}\}$

where FL is fingerprint locations and D_i ($i = 1, 2, \dots, 81$) is the fingerprint information (detected tags in FL_i ($i = 1, 2, \dots, 81$)). For instance, FL_1 is FP that located at $(0cm, 0cm)$. D_1 is FP information using detected tags in FL_1 as $D_1 = \{1, 2, 4, 10, 19, 20\}$.

1.2. DOT PRODUCT ALGORITHMS

Dot product is an algebraic operation that takes two equal-length sequences of numbers

and returns a single number obtained by multiplying corresponding entries. In this research, this algorithm applies scalar product or dot product to find the location of the target. By using FL matrices dot with the observed location matrix, the summation of those products will be provided. For example, given $a = [a_1, a_2, a_3, \dots, a_n]$ and $b = [b_1, b_2, b_3, \dots, b_n]$. The dot product is represented as

$$ab = \sum_{i=1}^n a_i b_i = a_1 b_1 + a_2 b_2 + \dots + a_n b_n \quad (1)$$

Where ($i = 1, 2, \dots, n$) and n is a dimension of the vector space, in this case $n = 81$.

Finally, after we get the coordinate of estimated location. We can find the error distance by using norm equation as shown below

$$\text{Error distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (2)$$

From Equation (2), x_1 and y_1 represent as the true target location. x_2 and y_2 are the coordinate of the estimated location.

2. Measurement System and Setup

In order to deploy 81 tags as FP nodes, those tags will be written the ID information by using the reader. These tags will be attached to the ceiling. 300 cm is the height from ceiling to floor. The area of interest is $400cm \times 400cm$ and the gap between tags is 50cm. The 15 observed locations $O_i = (i = 1, 2, \dots, 15)$ are shown in Fig.1. These locations can be estimated by multiplying it with all of FL using dot product

that has been previously explained. Here is the result for this matching, if the detected tag has same number with the fingerprint, it will be converted as 1. In the other hand are 0.

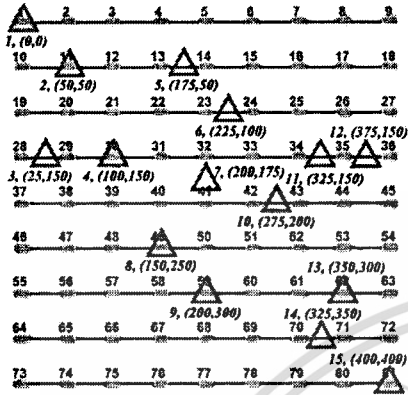


Fig.1. The 15 observed locations in the fingerprint locations.

3. RESULTS AND DISCUSSION

In this paper, the results will be shown in two cases. First, the observed locations (O) that have only one FP provided the maximum number ($O_1, O_2, O_4, O_5, O_6, O_8, O_9, O_{10}, O_{11}, O_{12}, O_{13}$) and the other observed locations include in case no.2 (O_3, O_7, O_{15}).

For instance, in the first case, the observed location, $O_4(100,150)$ and the O information, $Ob_4 = \{11,22,29,30,38,39,57\}$. After matching with number 1 to 81, the new matrix is obtained. By multiplying this matrix $[1 \times 81]$ by FP matrices $[81 \times 81]$, we will get the maximum number. In the result, FL_{30} is the only one FP that provides the maximum number equal to 7. Its coordinate (100,150) is represented as the estimated location. By using the Norm Distance in equation (2), it denotes that the error distance equal to 0cm.

Second case, it has sub two cases, there are two and more than two FP provide the maximum number. For case no.2(a), coordinate (25,150) refers as O_3 and $Ob_3 = \{10,11,19,20,28,29,37,38\}$. After using the dot product method, $FL_{28}, (0,150)$ and $FL_{29}, (50,150)$ are the FP that provided the maximum number equal to 8. The estimated location is (25,150) and 0cm is the error distance.

For case that has more than two FPs provide the maximum number, it is called case no2(b). In this case, $O_{15}, (400,400)$ and the $Ob_{15} = \{53,72,79,80,81\}$. $FL_{71}, FL_{79}, FL_{80}$ and FL_{81} are the FLS that provide the maximum number equal to 4. (350,387.50) is the coordinate of estimated

location. Since it uses more than two FPs which provide maximum number, the error distance is 51.53 cm.

Fig. 2 depicts the error distance graph for 15 observed locations.

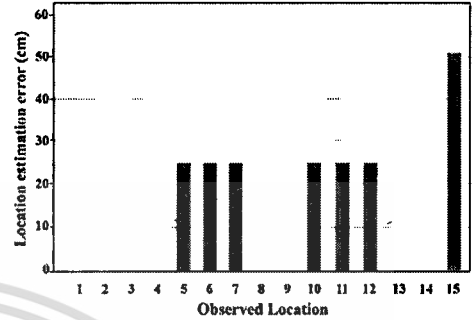


Fig.2. The error distance of 15 observed locations

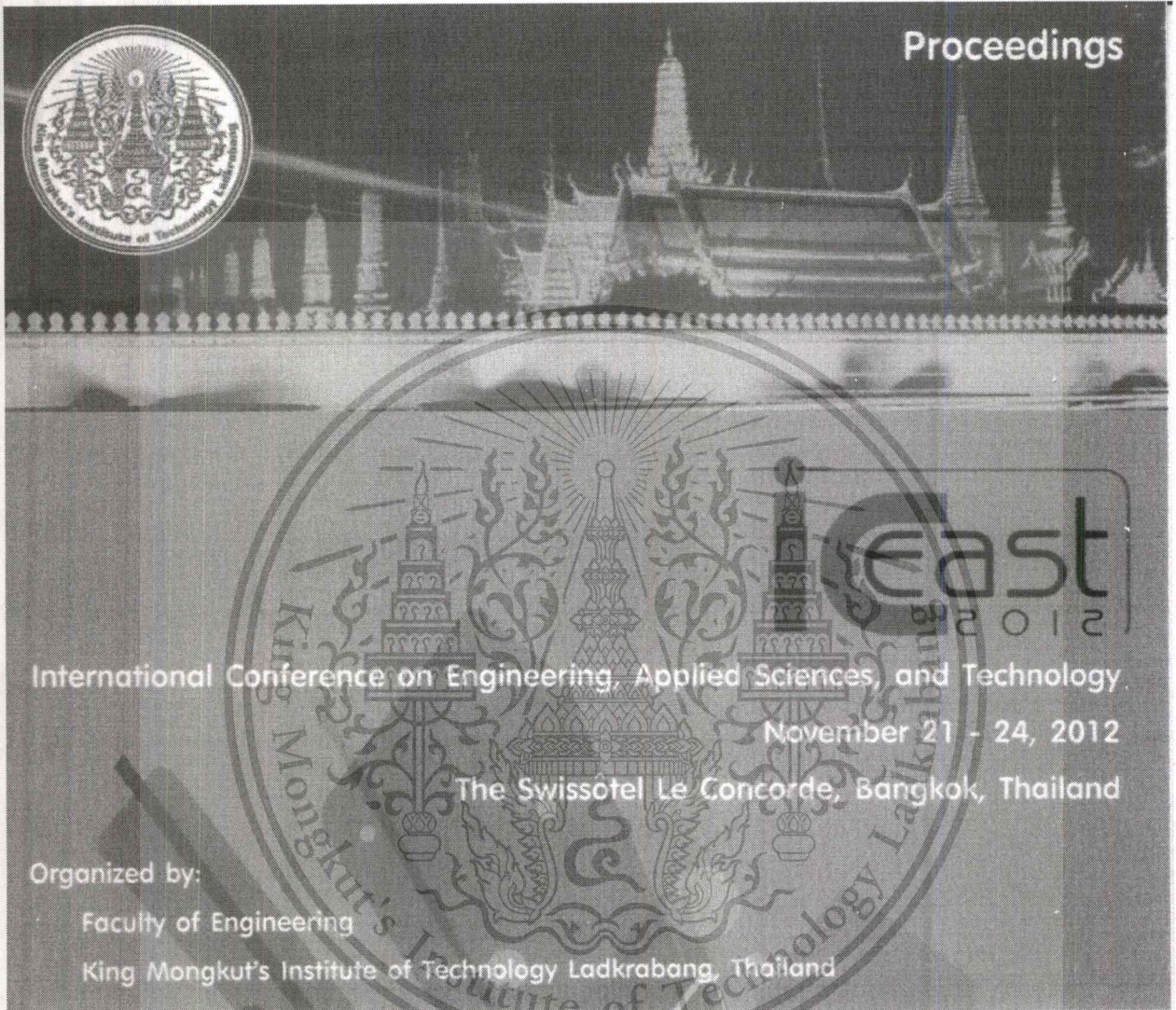
From Fig. 2 some errors could be as result of indoor signal propagation, such as propagation by metal media, lamp and the ceiling itself.

4. CONCLUSION

In this paper, the dot product algorithm is proposed. The localization algorithm using fingerprint technique and the passive tags RFID are deployed for the indoor environment. The location can be estimated by multiplying matrix between observed location matrix and fingerprint locations matrices. In this paper, dot product algorithm is applied to solve two cases in the indoor experiment. The results show the averages of the error distance is less than 50 cm (the gap between tags). That is satisfied our expectation. From this result, our proposed method can be applied in real situation.

5. References

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3D Fingerprint-based Indoor Localization using RFID Passive Tag

Sisongkham Phimmasean
and Dwi Joko Suroso
International College, KMITL
Bangkok 10520, Thailand
{s4601103, s3601152}@kmitl.ac.th

Thanapong Chuenurajit
and Panarat Chertnanomwong
Faculty of Engineering, KMITL
Bangkok 10520, Thailand
{s4611407, krpanara}@kmitl.ac.th

Abstract— Radio Frequency Identification (RFID) technologies are very popular in recent days. This technology leads the research in location finding or localization of objects. Nowadays, 2D indoor localization has been published in many well reviewed papers. However, publication of 3D indoor localization is still limited. This research proposes 3D indoor localization using fingerprint technique to solve the problem of difference target height. Fingerprint technique is used to find the location of the target by comparing its signal (or information) pattern with a previously recorded database of known signal (or information)-location data. In this paper, the Dot Product is used as the pattern matching method. Its benefit is to support the mapping of two row vectors that have the same length and it will provide only the maximum value for the result. This method has an idea to compare the vector containing the group of detected tags at the observed location and vectors containing fingerprints at each fingerprint location. The fingerprint location that provides the maximum value of the dot product is assigned as the location of the target. The effectiveness of this method is verified by an indoor experiment. The average error distance in the estimated result is approximately 30 cm. This result shows a good estimation result since the error of target estimation not more than the gap between fingerprint locations (60 cm). From the result, we can conclude that our purposed method can be applied in 3D indoor localization.

Keywords-component; Indoor localization; fingerprint technique; RFID passive tag; dot product.

I. INTRODUCTION

Growth trends of wireless network applications have very quickly emerged and it becomes the recently topics of the researchers. For example, the application includes vital researches in finding the location of victims in case of fire disaster, tsunami and earthquake. Global Positioning System (GPS) is the most well-known among wireless network applications, because of its effectiveness and its endurance.

The disadvantage of this system is unsuitable for using in indoor environment. There are many technologies that support indoor localization such as Wireless Local Area Network (WLAN), Ultra Wideband (UWB), Bluetooth (IEEE 802.15) and Radio Frequency Identification (RFID). Some well-reviewed localization papers can be found in [1], [2]. These technologies have been developed for indoor localization system such as patient tracking in the hospital, location finding of the product, visitor tracking in the museum, etc. Most of these technologies are supported by RFID, because of its abilities to maintain data security, its cost-effective and its endurance. Furthermore, it can identify the difference of objects. This paper presents 3 Dimension (3D) fingerprint-based indoor localization using RFID passive tag. The RFID tag serves the same purpose as a barcode or a magnetic strip on the back of the credit card or ATM card, it provides a unique identifier for an object. Likewise, a barcode or magnetic strip must be scanned to get the information, so the RFID tag must be scanned or read to retrieve the identifying information. There are many types of RFID tags i.e., active tag, passive tag and semi-active tag [3]. In this work, RFID passive tags are deployed. The factors of cost-effective and power consumption are the reason deploying this RFID passive tag. As known, it gains energy from the electromagnetic wave transmitted by the RFID reader [4].

In this work, the fingerprint technique is used to find the location of the target. This technique gains the idea from the human fingerprint. As the human fingerprint, it uses the unique pattern to identify people [5]. This method has been developed in applications of image processing. The difference in our research is using radio frequency pattern for identification. This pattern could be Receive Strength Signal Information (RSSI), tag information, etc. In this research, ID information from tags is applied as pattern likewise in human fingerprint identification.

The RFID reader is employed as the target in each level (50 cm, 100 cm and 150 cm high), for recording the fingerprint information. The RFID reader as fingerprint locations (108 locations) is scattered in the area of interest. The area of interest consists of (300 cm × 300 cm × 50 cm), (300 cm × 300 cm × 100 cm) and (300 cm × 300 cm × 150 cm). The observed location is placed on five levels (same with three

levels of the recorded fingerprint information and two additional levels: 75 cm and 125 cm in the height). The 12 observed locations are located in each level. It means that 60 locations for all observed locations are obtained. Our objective placing the observed locations in difference level is to validate the performance of our proposed algorithm. We expect to get the good results to support 3D indoor localization and to know the location of the target in 3D.

This paper is organized as follows. Section II describes the algorithm model. Measurement system and setup are presented in section III. The results and discussion are explained in section IV. Finally, conclusion is given in section V.

II. THE ALGORITHM MODEL

A. Fingerprint Technique

The simple explanation of the fingerprint algorithm is shown in Fig. 1. Fingerprint technique involves two-phase process. For the first phase process, it is the offline or training phase process. In this phase, the data from every tag locations in the experiment area is recorded in the database. The steps of database recording in detail are; firstly, setting the location of desired fingerprints. For this paper, the 108 locations of the fingerprint are applied. The information of the fingerprint that have relation with the location of the fingerprint will be stored in the database as shown in Table I, the number of fingerprint location as $FL(FL_1, FL_2, \dots, FL_{108})$. Secondly, recording ID of all tags represent as $D(D_1, D_2, \dots, D_{108})$. D is the information of the fingerprint location in all of 108 locations.

Known Location	Fingerprint Information
Location 1	Information 1
Location 2	Information 2
...	...
Location L-1	Information L-1
Location L	Information L



Figure 1. Location fingerprint technique [6]

TABLE I. FINGERPRINT DATABASE MODEL

FP Location	FP Information
FL_1	$D_1 = \{\text{ID tags that detected at } FL_1\}$
FL_2	$D_2 = \{\text{ID tags that detected at } FL_2\}$
...	...
FL_{107}	$D_{107} = \{\text{ID tags tag that detected at } FL_{107}\}$
FL_{108}	$D_{108} = \{\text{ID tags tag that detected at } FL_{108}\}$

The second phase is called the online phase. In this phase, the estimated location is measured by comparing the current ID

tags information with those that are in the fingerprint database by using the dot product that will be explained in the next section.

B. The dot product

The dot product or scalar product is the single number result provided by an algebraic operation that takes two equal-length sequences of numbers. The result is provided by multiplying corresponding entries [7]. In this research, the dot product is used as the pattern matching algorithm to find the location of the target. Given O is the observed locations (O_1, O_2, \dots, O_{60}) and DO_i be the group of detected tags at the i the observed location, where ($i = 1, 2, \dots, 60$). Recall that D_k be the group of detected tags at the fingerprint location ($k = 1, 2, \dots, 108$). After that D is mapped to the row vector $M_{1 \times n}$ in which its number becomes "1" at the fingerprint location that the RFID tag can be detected and becomes "0" elsewhere. In the same manner, DO is mapped to the row vector $N_{1 \times n}$ of the observed location and becomes 1 or 0 in the same manner as the vector M . Then the location of the target can be obtained from the location of the fingerprint providing

$$\max(M \cdot N). \quad (1)$$

To acquire the error distance between the estimated locations with the actual location, the Norm equation is used as

$$\text{Error dist} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}. \quad (2)$$

x_1, y_1 and z_1 represent as the actual locations and x_2, y_2 and z_2 represent as the estimated locations of the target in x, y, z axes, respectively. For example, the observed location number 10 at the height of 50 cm with $O_{10} = (60, 240, 50)$, the group of detected tags is, $DO_{10} = \{2\ 3\ 8\ 14\ 16\ 17\ 19\ 20\ 21\ 22\ 23\ 25\ 26\ 27\ 28\ 31\ 32\ 33\ 34\}$, then it is mapped to row vector for support the dot product. So, in this case, $N = [0\ 1\ 1\ 0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 1\ 0\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 0\ 0\ 1\ 1\ 1\ 1\ 0\ 0\ 0\ 1\ 1\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 1\ 0\ 0\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 1\ 1\ 1\ 1\ 0\ 0\ 0\ 1\ 1\ 1\ 0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 1\ 0\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 1\ 1\ 1\ 1\ 0\ 0\ 1\ 1\ 1\ 1\ 0\ 0]$. After $M \cdot N$, it is found that FL_{26} is only one FL gives the maximum value equal to 18. Therefore, the target location is referred to the coordinate of (60, 240, 50) and it is found that there is no error at this observed location.

III. MEASUREMENT SYSTEM AND SETUP

The RFID based localization system consists of the reader, the computer with the software collecting the data received by the reader and tags. In order to deploy 108 tags as fingerprint nodes, those tags will be written the ID information by using the reader and it will be attached to the ceiling. Fig. 2 illustrates the used passive tag with linear polarization and Fig. 3 shows the 36 fingerprint locations in the area of interest in each height level. The height from the floor to the ceiling is 300 cm and the area of interest is of 300 cm by 300 cm. The gap between tags is 60 cm, the reason is to make easier correcting and measuring data. The grid of the ceiling itself is

60 cm. We recorded the fingerprint information to the database by placing the reader on the camera tripod facing directly to the tags on the ceiling (36 tags per levels and 108 tags for all) as shown in Fig 4 and 5. The height of the reader classifies into 3 levels (50 cm, 100 cm and 150 cm) for recording fingerprint information as shown in Fig 6.

The 60 observed locations $O_i = (i = 1, 2, \dots, 60)$ are scattered in to 5 levels (these height are the same as recording fingerprint information and additional height at 75 cm and 125 cm, 12 observed locations per level). These locations can be estimated by multiplying its group of detected tags (observed information) with entire the group of detected tags (fingerprint information) at FL .



Figure 2. Passive tag with linear polarization

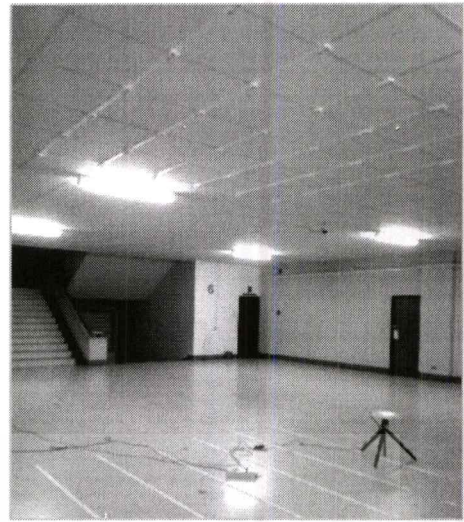


Figure 5. Experiment system outline

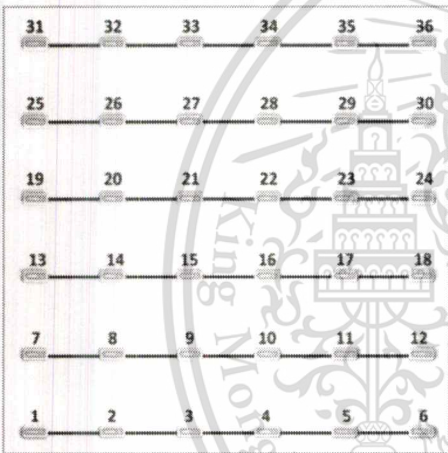


Figure 3. Illustration of passive tags in the area of interest
300 cm x 300 cm

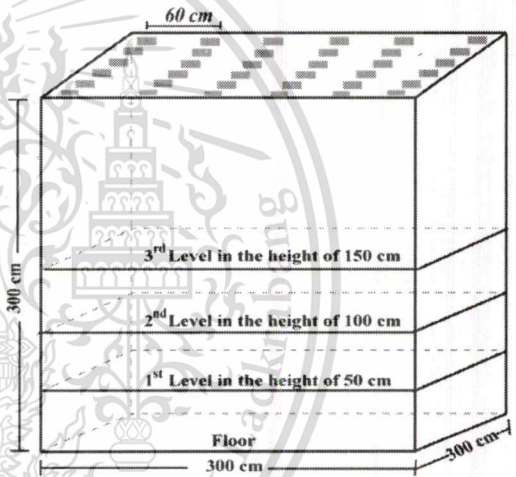


Figure 6. Fingerprint information recording outline



Figure 4. The reader facing directly to tags

The gray rectangle represents the RFID passive tags that are attached on the ceiling and it becomes the reference nodes.

In addition, for each level, observed locations are placed in 4 difference places. First, it is in the same as FL ; second, it is in between two FL s in the horizontal plane; Third, it is in between FL s in the vertical plane and the last, it is in the center of 4 FL s.

IV. RESULT AND DISCUSSION

A. Observed locations at the height of 50 cm

For the O at the height of 50 cm, its average of the error distance is 20.60 cm, the positions that provide the big error are at O_2, O_5 and O_8 . These O are placed in between four

fingerprint locations and it has more than one *FLs* providing the maximum value as show in Fig.7.

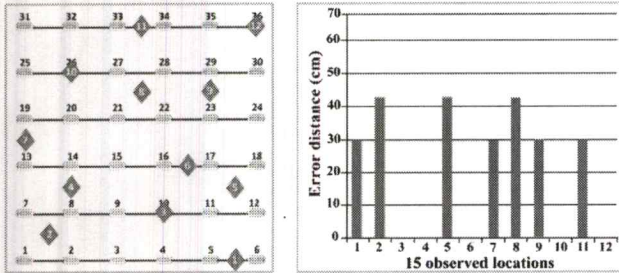


Figure 7. The error distance for the observed locations at the 50 cm height

The gray rectangle represents the fingerprint locations in the area of interest 300 cm by 300 cm and the red diamond is the observed locations O_i , ($i = 1, 2, \dots, 60$).

B. Observed locations at the height of 75 cm

This O provides the big error distance. Its average of the error distance is 39.94 cm, the O_{14} provides the biggest error distance equal to 71.58 cm as show in Fig.8. Some errors could be effects of indoor signal propagation, such as propagation by metal media, lamp and the ceiling itself.

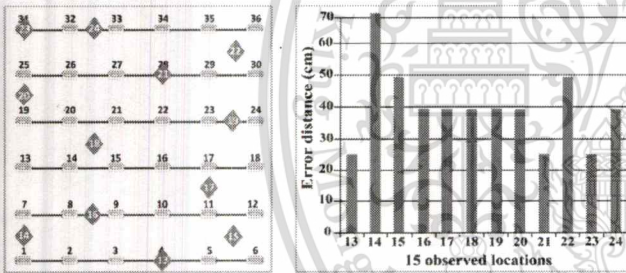


Figure 8. The error distance for the observed locations at the 75 cm height

C. Observed locations at the height of 100 cm

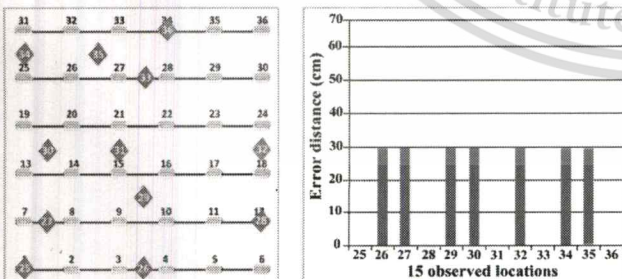


Figure 9. The error distance for the observed locations at the 100 cm height

Fig.9 shows the average of the error distance is 17.50 cm.

The results show that the propagation effect does not affect much in these observed locations.

D. Observed locations at the height of 125 cm

In this height, the average of the error distance is 36.91 cm. At the O_{38} , O_{42} and O_{45} are provided the big error distance in this height equal to 42.42 cm as show in Fig.10. The results show that all of the O_s are refer as the fingerprint information at the height of 100 cm, it means that the z coordinate of the estimated location of the target becomes to 100.

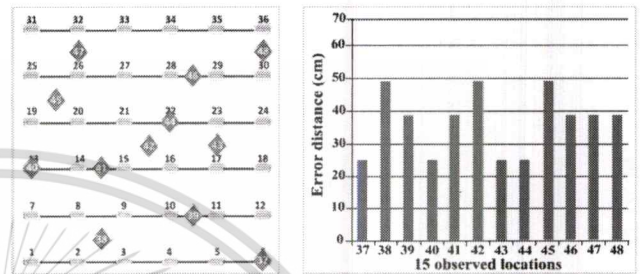


Figure 10. The error distance for the observed locations at the 125 cm height

E. Observed locations at the height of 150 cm

The observed locations in this height provide the average of the error distance equal to 25.60 cm as show in Fig.11. The results show that these observed locations providing bigger error distance than the other levels (height of 50 cm and 100 cm) that are placed in the fingerprint database height.

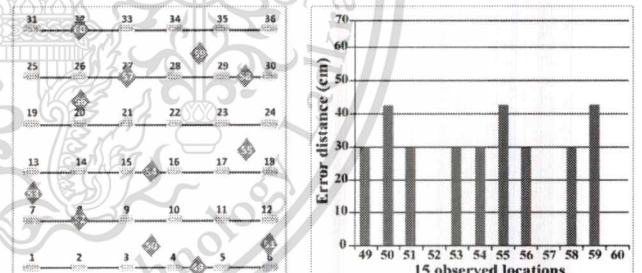


Figure 11. The error distance for observed locations at the 150 cm height

V. CONCLUSION

This paper proposed the simple method of the indoor localization estimation. The fingerprint technique is used as the localization algorithm. The RFID passive tags are deployed. In this work, the dot product is applied as pattern matching. The results show the averages of the error distance of 22 cm approximately for the observed locations in height of 50 cm, 100 cm and 150 cm. For the observed locations at the height of 75 cm and 125 cm provide the average of the error distance of 39 cm approximately, these results satisfy our expectation.

From the results, our proposed method can be applied in real situation, especially in 3D indoor localization.

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