Indoor Localization System using Wireless Sensor Networks for Stationary and Moving Target

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***Abstract*— The recent research in localization technique has been supported by the emerging of wireless sensor network (WSN) technology. The issues of the estimated location accuracy have becoming the main research topics in WSN-based localization technique. In this paper, the application of WSN for localization technique using IEEE 802.15.4 standard is proposed. As IEEE 802.15.4 standard, ZigBee is widely used because of its advantages. It specially provides useful parameters for location estimation, i.e. received signal strength indicator (RSSI) and link quality indicator (LQI). In this paper, the simple but effective localization system is proposed. Range-based and location fingerprint-based are implemented. The different set of the reference nodes is applied. The effectiveness of this method is verified by data obtained from an indoor experiment in the 5m × 5m observed area. The error from estimated locations using both techniques is analyzed. The estimated location results from different amount of reference nodes are compared. The results show that the error from the observed area is less than 1.2 m for both localization techniques, respectively. The GUI is created to help the experiments in the visualization and for showing the estimated location. From this result, the simple but effective system is really beneficial for the real application.**

***Keywords*—Indoor Localization; Wireless Sensor Network; ZigBee; Range-based; Location Fingerprint Technique**

I. Introduction

Radio localization using smart sensor nodes in WSNs has become popular in recent years. It is supported by the advancement of micro-mechanical systems and development of digital electronics technology. Radio localization is realized to be an important application for daily life and WSNs is popularly selected to be used for a localization system. ZigBee as IEEE 802.15.4 standard is widely used because of its various advantages, i.e. cost-effective, low-power consumption, security, robustness, reliability and supporting low data rates. ZigBee provides useful parameters for location estimation, i.e. RSSI and LQI [1], [2].

Localization technique can be classified into several categories based on the parameter that is used. Range-based and location fingerprint technique are most common technique in WSN applications. In this paper, an indoor scenario is applied. In the indoor scenario, many issues such as diffraction at edges, refraction by media with different propagation velocity and reflection in metallic objects. These issues affect to the localization system performance [3].

In this paper, we implement the user-friendly GUI for sending commands, receiving and calculating data based on the initial algorithm. For the experiment, we use the range-based and fingerprint-based techniques. The command data is sent to the reference nodes then it will initialize the position of reference nodes. Then, the reference nodes will transmit parameter that will be received by the target node as received power. The received signal power that is received by the target node will be transferred to personal computer (PC) through serial communication. The GUI for this experiment has the serial communication connection to provide the communication between PC and the target node. The GUI will display the position estimation results and has ability to store the experiment data result. The experiment is evaluated using two different types of the target node, i.e., stationary and moving target node.

The paper is organized as follow: Section 2 presents the description of the algorithm model. The experiment setup is explained in Section 3. Result and discussion are described in Section 4. Finally, in Section 5, we conclude this paper with plans for future work.

II. Description Of Algorithm Model

A. RSSI Definition

RSSI in dBm is defined as ten times the logarithm of the ratio of power (P) at the receiving end and the reference power ($Pref$). Power at the receiving end is inversely proportional to the square of distance. The received signal strength depends on the transmitted power and the distance between the transmitter and the receiver. In the embedded devices, the received signal strength is converted to RSSI. The relationship between RSSI and distance can be determined as equation [4].

$$RSSI[dBm] = A - [10 \cdot n \cdot log_{10}(d/d_0)], \tag{1}$$

where n is the path loss exponent or the signal propagation constant, d is the distance from transmitter in meter, d_0 is a reference distance, typically 1 meter, and A is the received signal strength at 1 meter distance, in dBm.

B. Range-based Localization

In this paper, the maximum likelihood algorithm is applied as range-based localization. In Range-based, the node distance is acquired through measurement of RSSI without additional node hardware design. Fig. 1 depicts the illustration of measurement system.

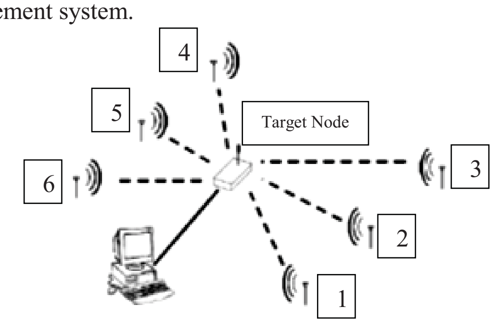

Figure 1. The illustration of measurement system

Suppose coordinate of reference nodes are $B1(x_1, y_1), B2(x_2, y_2)$,... and $Bn(x_n, y_n)$. And coordinate of the unknown node is determined as $O(x, y)$, the distance between the unknown node and reference nodes are $d_1, \dots, d_n$, respectively. A group of non-linear equation can be obtained according to the following formula in a two-dimensional space as shown [5]:

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = d_2^2 \\ \vdots \\ (x - x_n)^2 + (y - y_n)^2 = d_n^2 \end{cases} \tag{2}$$

When the last equation is subtracted from the other equations in turn beginning from the first equation, hence

$$\begin{cases} x^2 - x_n^2 - 2(x_1 - x_n)x + y_1^2 \\ -y_n^2 - 2(y_1 - y_n)y = d_1^2 - d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 - 2(x_{n-1} - x_n)x + y_{n-1}^2 \\ -y_n^2 - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2 \end{cases} \tag{3}$$

Linear equation in equation (3) can be represented as

$$\boldsymbol{Xb} = \boldsymbol{a}$$

where

$$\boldsymbol{X} = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \vdots & \vdots \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix},$$

$$\boldsymbol{a} = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 - d_1^2 + d_n^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 - d_{n1}^2 + d_n^2 \end{bmatrix},$$

$$\boldsymbol{b} = \begin{bmatrix} x \\ y \end{bmatrix}.$$

The error of the node estimation location can be obtained by applying the standard minimum mean square error as

$$\hat{\boldsymbol{b}} = (\boldsymbol{X^T X})^{-1} \boldsymbol{X^T a}\,. \tag{4}$$

C. Location Fingerprint Technique

Location fingerprinting is a location sensing technique which involves a two-phase process. First, during the off-line calibration phase the received signals at selected locations are recorded in a database. 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 commonly used of pattern matching algorithm as shown in Figure 1 [6], [7].

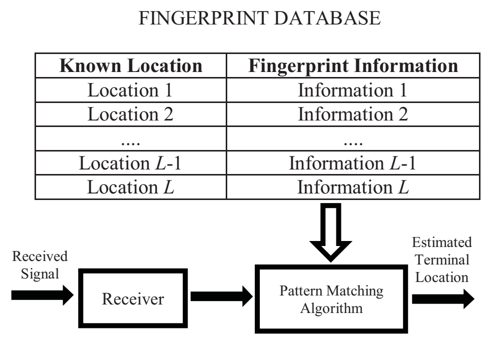

Figure 2. Location fingerprint technique

For simplicity, the fingerprint is defined as sets of measured RSSIs from all sensor nodes. Hence, let the number of sensor nodes that placed at fix locations as N, number of fingerprint locations as M and D_i as fingerprints at position $D_i (i = 1,2, \dots, M)$. Table I shows the illustration of fingerprint database for the experiment.

TABLE I. FINGERPRINT DATABASE

Fingerprint Location	Fingerprint Information
$F_1(x_1, y_1)$	$D_1 = \{rssi_{1,F_1}, rssi_{2,F_1}, \dots . rssi_{N,F_1}\}$
$F_2(x_2, y_2)$	$D_2 = \{rssi_{1,F_2}, rssi_{2,F_2}, \dots . rssi_{N,F_2}\}$
......	......
$F_M(x_M, y_M)$	$D_M = \{rssi_{1,F_M}, rssi_{2,F_M}, \dots . rssi_{N,F_M}\}$

When the target node is in the fingerprint area, it collects the RSSIs from all sensor nodes as

$$T = \{rssi_{1,T}, rssi_{2,T}, \dots . rssi_{N,T}\}.$$

Euclidean distance is used to find the location of target node by comparing it with the fingerprint database, D_i. D_i and T are two points in Euclidean N-space, then the distance is obtained by the equation

$$dist_i(x, y) = \sqrt{\sum_{n=1}^{N} \left(rssi_{n,T} - rssi_{n,D_i}\right)^2}. \quad (5)$$

III. EXPERIMENT SYSTEM AND SETUP

A. Experiment System

The authors reported the localization system based on ZigBee standard for the stationary target [8]. In this paper, we improve the system which is able to estimate the location of moving target. The ZigBee module, XBee-24ZB is used as reference nodes and target node. The ZigBee provides the RSSI parameter for experiments. The different amount of reference nodes is deployed for the experiments. There are 4 and 6 reference nodes. Fig. 2 depicts the illustration for experiment system. The 5m × 5m observed area is used as the experiments location for both maximum likelihood as range-based and location fingerprint techniques, respectively.

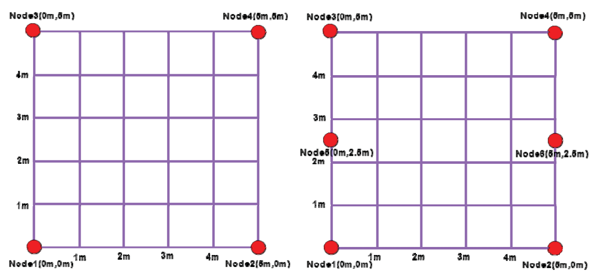

Figure 2. The illustration of experiment system using 4 reference nodes (left) and 6 reference nodes (right)

In this paper, the system estimate the location based on RSSI in the observed area. The target node is a wireless device which receives a packet from reference nodes, which each measures the received power. After receiving a packet, the target node measures RSSI and sends the results to the sink node. In this research, we use personal computer (PC) as sink node which graphical user interface (GUI) is already installed inside. The GUI for the experiment is shown in Fig. 3. The GUI is very useful for the users to see the location of the target node in the real time.

Figure 3. The GUI for The Experiment

As shown in Fig. 3, the GUI displays the appearance of the observed area. The 4 reference nodes are shown as the antenna signs which are located at the corners of the observed area. The target node is represented as the small robot with the letter that represents the location coordinate. Fig. 4 shows the corridor where the experiments are conducted.

Figure 4. The indoor location for data collection

B. Experiment Setup

In order to verify the accuracy between range-based and fingerprint-based localization, the location of the target node is divided into two types, stationary and moving. Fig. 5 shows the target position for experiments. The 16 locations represented by a small circle along the diagonal line of the target node are used for validating the range-based and fingerprint-based localization techniques. Fig. 6 depicts the 36 database locations of sensor nodes as database information, represented as circles for fingerprint technique experiments.

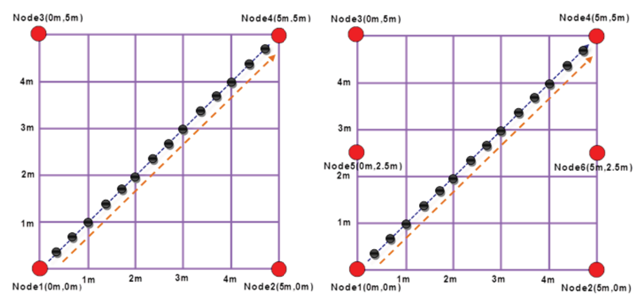

Figure 5. The left diagonal position of the target node for the experiments

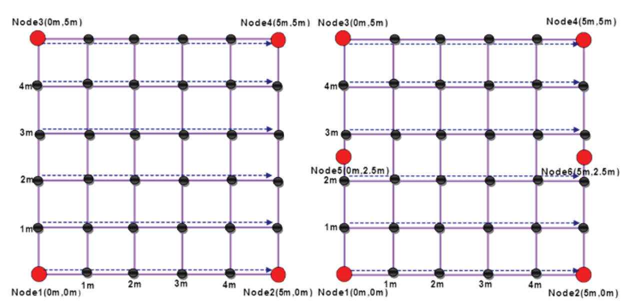

Figure 6. The 36 database locations for the fingerprint technique

IV. EXPERIMENT RESULT AND DISCUSSION

The objective of this paper is to compare the accuracy between the range-based and fingerprint-based localization techniques for the stationary and moving target. The effectiveness of the both techniques is verified by an indoor experiment and the estimated location errors are analyzed. The GUI is created to help the experiments in the visualization and for showing the estimated location.

A. Estimated Location Error for Range-based Technique

1. Stationary Target Node

For the stationary target node, we start placing the target node at (0 m, 0 m) and increase continuously on 0.33 m. For instance, the target node location for the diagonal left bottom to right up is change from (0 m, 0 m) and the experiment is continued until reach at (5 m, 5 m). Fig. 7 shows the estimated location error in meter of the range-based technique versus the position of the target node. It depicts the results for the 4 and 6 reference nodes, respectively.

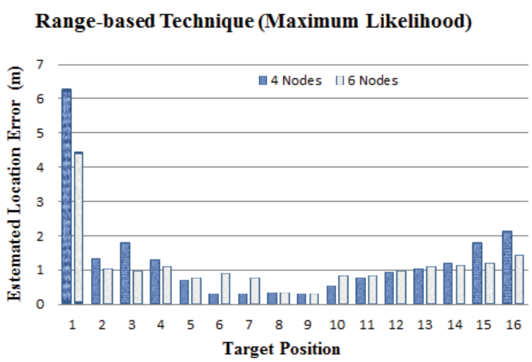

Figure 7. The estimated location error of range-based technique

Fig. 7 shows that the most of the estimated location errors is reduced as a function of the sets of reference nodes. The highest error is occurred in the 1st of the target position. From Fig. 7, we can see that the relatively high of the estimated location errors are in the target position where near or exactly in the position of the reference node. This result could be caused by the issue of diffractions at edges.

2. Moving Target Node

For the result of the moving target, we will show the result in the GUI appearance. For both algorithms, we use automatic robot which carries the target node and moves it alongside the diagonal line. Fig. 8 and Fig. 9 show the results for both sets of reference nodes for the maximum likelihood algorithm. According to the result of Fig.7, the set of 6 reference nodes gives the better result for estimating the location of target node. The GUI shows the distribution of the target node, represented as the small robot is spread along the diagonal line.

Figure 8. Result of Moving Target for 4 Reference Nodes in GUI using range-based technique

Figure 9. Result of Moving Target for 6 Reference Nodes in GUI using range-based technique

B. Estimated Location Error for Fingerprint Technique

1. Stationary Target Node

The fingerprint information for the experiment is a collection of the RSSI data which is obtained by placing the nodes in the 36 database locations as shown in Fig. 6. As mentioned previously, the main idea of this technique is to compare the target data with the database. Fig. 10 depicts estimated location errors in meter of the fingerprint technique versus the position of the target node.

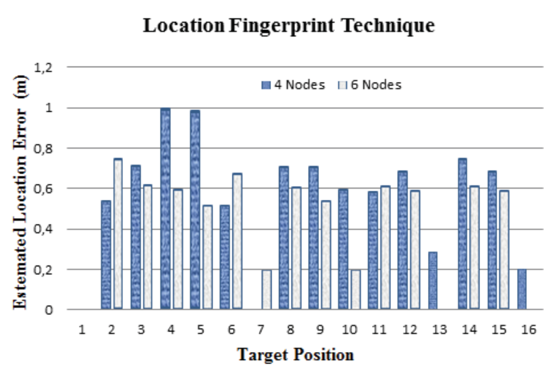

Figure 10. The estimated location error of fingerprint technique

Fig. 10 depicts that the estimated location errors in fingerprint technique relatively smaller than the range-based error. From Fig. 10, we can see that the highest error is occurred in the 4th and 5th of target position. Technically speaking, the sets of the reference node can significantly reduce the estimated location error. As in range-based, the fingerprint technique gives better result when there are 6 nodes as the sets of the references nodes.

2. Moving Target Node

Fig. 11 and Fig. 12 show the result for both sets of reference nodes for location fingerprint algorithms. According to the result of Fig. 10, the set of 6 reference nodes gives the better result for estimating the location of the target node. The GUI shows the distribution of the target node, represented as the small robot is spread along the diagonal line.

Figure 11. Result of Moving Target for 4 Reference Nodes in GUI using fingerprint-based technique

Figure 12. . Result of Moving Target for 6 Reference Nodes in GUI using fingerprint-based technique

C. The Average Error Between Range-based and Location Fingerprint Techniques for the Stationary Target

The different amount of reference nodes is used as space diversity, it affects to the accuracy of the localization system. For the average estimated error, we only use the data from the result of stationary target measurement. From Table 2, we can see that the location fingerprint gives the better result for the experiment in the left diagonal position testing.

As we can see, the error from both techniques is acceptable, since the error is 1.31 m in the range based using 4 reference nodes and 1.12 m for using 6 reference nodes. For the location fingerprint, the average estimated error reach 0.56 m for 4 reference nodes and 0.44 for 6 reference nodes. We can see from Table 2, the additional amount of reference nodes gives better result for both techniques, respectively. From this result, we can get a conclusion that for the diagonal position of the target node, fingerprint technique gives the better accuracy.

TABLE II. THE AVERAGE ERROR TABLE FOR STATIONARY TARGET

Localization Technique	Estimated Location Error (m)	
	4 Nodes	6 Nodes
Maximum Likelihood	1.31	1.12
Location Fingerprint	0.56	0.44

V. CONCLUSION

This paper proposes the method for comparing the range-based and location fingerprint techniques in indoor scenario. The target node is moved along the left diagonal position. The results show the average error reached less than 1.2 m in the range-based technique and less than 0.5 m in the location fingerprint technique. From the result of the estimated locations error, the location fingerprint technique gives the better accuracy than the range-based localization. Since the target node is moving, the error can be triggered by many factors, such as the accuracy of RSSI measurement in the devices, also the power and electromagnetic effects during the experiment. The result of both stationary and moving targets, show that the simple but effective system is obtained. The GUI for the experiments shows the estimated location for both techniques effectively in real time. This result gives the explanation that the proposed method can be applied in the real application.

VI. ACKNOWLEDGMENT

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