Implementation of RSSI-Based 3D Indoor Localization using Wireless Sensor Networks Based on ZigBee Standard

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ABSTRACT – Indoor localization as a part of the wireless node localization has its advantages to be applied in the real life. Complicated terrain and environments in an indoor environment become the proposed problems in this research. This paper proposes a simple and effective system for Wireless Sensor Networks-based 3D indoor localization based on ZigBee standard. A clean environment as the observed areaof 5 m × 5 m × 2 m is applied. The Min-Max algorithm as one of the techniques in the range-based localization is employed. The 8 reference nodes are deployed. The target node is stationary in the observed location. The expected estimated location error of the target should be less than the experiment areas, so that less than 2 m for our case. The results show that the estimated errors of all observed target locations are less than 2 m, which are satisfied our expectation. The proposed technique will be developed to improve the accuracy to support all applications for the future.

KEYWORDS -- Wireless sensor networks; 3D indoor localization; ZigBee; Min-Max algorithm

1. Introduction

The advancement of the wireless sensor node technology leads the rapid research in the wireless sensor networks (WSNs) applications. Node localization using WSNs-based techniques is a particular area in the wireless communication. The wireless node localization can be defined as verifying the location of a sensor node within the network with respect to reference nodes. The distance between sensor nodes can be estimated through their capabilities of parameters such as Received Signal Strength Indicator (RSSI), Time of Arrival(ToA), Time Difference of Arrival (TDoA) and Angle of Arrival (AoA). For the RSSI-based technique, it usually consists of the algorithms that estimate the locations with originally unknown location information.

Previous research in 2D indoor localization has been conducted by the authors in [1]. The system can be able to estimate position in 2D as the target in moving and stationary conditions. The sensing area in the system design is assumed to be flat enough and the node deployment is dense enough. On the other hand, the 3D system will have problem in the real applications as we know that it might has complicated terrain and environment, as well as large altitude differences [2]. By above observations, in this paper, the 3D node localization scheme for WSNs possessing new challenge is proposed.
In our scheme, the ZigBee technology is deployed. As the IEEE 802.15.4 standard for wireless communication, ZigBee has various advantages, i.e. cost-effective, low-power consumption, security, robustness, reliability and it can support low data rates. ZigBee has parameters which can be deployed as the estimation variable in order to find the location of the unknown sensor nodes. The useful parameters of this wireless standard for localization are RSSI and Link Quality Indicator (LQI) [3].

In this paper, an approach of the 3D node indoor localization using ZigBee-based WSNs is presented. The deployed experiment area is considered as a clean environment and has a size of 5m × 5m ×2m. In this 3D indoor localization system, the Min-Max algorithm as one of the range-based techniques is applied. The Min-Max algorithm is a representative of a 2D position derivation algorithm used in WSNs-based localization system, and it is considered to be extended for 3D applications. The observed area is a clean environment which defined as minimizing obstacles in the area of interest.

The remainder of this paper is organized as follows; Section 2, briefly explains used in this work the algorithm model. Section 3 shows the experiment system and setup. Section 4 presents the experiment result. Finally, conclusions are given in the Section 5.

2. Algorithm Model

2.1 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 (P_{ref}). The power at the receiving end is inversely proportional to the square of the 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 the distance can be determined as equation below [4],

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

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

2.2 Min-Max Algorithm

Savvideset. al, in [5] presents a simple method to acquire the position as a part of N-hop multilateration approach. This technique is commonly known as the Min-Max algorithm. In this subsection, the 2D Min-Max algorithm is presented for the simple explanation. The 3D Min-Max algorithm will be shown in Section 3. The basic idea of this technique is to form the rectangular or box area for each reference node using its position and estimated distance. The intersection between boxes is determined as the box of estimated target location. Fig. 1 illustrates the circle that is formed from distances between the target node and one reference node, where x_n, y_n is the coordinate of the reference node and d_n is the distance between the reference node and the target node from RSSI estimation

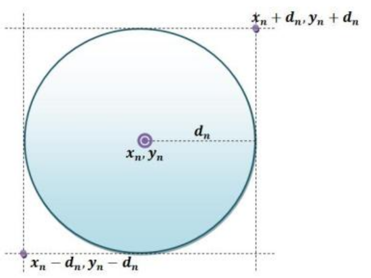

Figure 1. The illustration of the circle formed from the distance.

The idea is to select the minimum value in maximum values of x and y of boxes formed from reference nodes, and also to select the maximum value in minimum values of x and y of boxes formed from reference nodes.

$$x_{max} = \begin{bmatrix} x_{1max} = x_1 + d_1 \\ x_{2max} = x_2 + d_2 \\ \vdots \\ x_{nmax} = x_n + d_n \end{bmatrix} \quad (2)$$

$$y_{max} = \begin{bmatrix} y_{1max} = y_1 + d_1 \\ y_{2max} = y_2 + d_2 \\ \vdots \\ y_{nmax} = y_n + d_n \end{bmatrix} \quad (3)$$

$$x_{min} = \begin{bmatrix} x_{1min} = x_1 - d_1 \\ x_{2min} = x_2 - d_2 \\ \vdots \\ x_{nmin} = x_n - d_n \end{bmatrix} \quad (4)$$

$$y_{min} = \begin{bmatrix} y_{1min} = y_1 - d_1 \\ y_{2min} = y_2 - d_2 \\ \vdots \\ y_{nmin} = y_n - d_n \end{bmatrix} \quad (5)$$

From Equation (2) – (5), the chosen values are shown as

$$x_{min-max} = min(x_{max}) \quad (6)$$

$$x_{max-min} = max(x_{min}) \quad (7)$$

$$y_{min-max} = min(y_{max}) \quad (8)$$

$$y_{max-min} = max(y_{min}) \quad (9)$$

The location of the target node (x, y) is set to the center of this box.

$$x = (x_{min-max} + x_{max-min})/2 \quad (10)$$

$$y = (y_{min-max} + y_{max-min})/2 \quad (11)$$

Fig. 2 illustrates the Min-Max algorithm for the target node with the distance estimated from four reference nodes.

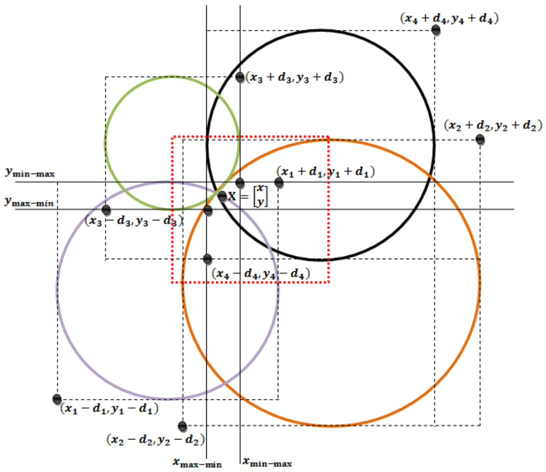

Figure 2. The illustration of Min-Max algorithm using 4 reference nodes.

Above explanation is for the case of the 2D indoor localization. In our case, the z-axis is added. The additional equation will be shown as

$$z_{max} = \begin{bmatrix} z_{1max} = z_1 + d_1 \\ z_{2max} = z_2 + d_2 \\ \vdots \\ z_{nmax} = z_n + d_n \end{bmatrix} \quad (12)$$

$$z_{min} = \begin{bmatrix} z_{1min} = z_1 - d_1 \\ z_{2min} = z_2 - d_2 \\ \vdots \\ z_{nmin} = z_n - d_n \end{bmatrix} \quad (13)$$

From Equation (12) and (13), the chosen values are shown as

$$z_{max-min} = max(z_{min}) \quad (14)$$

$$z_{max-min} = max(z_{min}) \quad (15)$$

The location of the target node in z-axis is:

$$z = (z_{min-max} + z_{max-min})/2 \quad (16)$$

3. Experiment System and Setup

In this paper, the Min-Max algorithm is applied as the range-based localization technique. The node distance is acquired by measuring of RSSI without any additional node hardware design. Fig. 3 shows the illustration of measurement system in the 2D experiment.

Figure 3. The illustration of measurement system.

For our 3D experiment setup, 8 reference nodes are deployed. The placement of reference nodes is based on the latitude or height difference in the 3D case. Here, each set of 4 nodes is placed on the floor and on the holder at 2 m height. In the experiment, the Xbee-24ZB module is used both as reference nodes and the target node, respectively. the Xbee-24ZB module is the ZigBee module with the operating frequency of 2.4 GHz. Fig. 4 shows the hardware of the Xbee-24ZB module used in this work.

Figure 4. Xbee-24ZB as the reference nodes and the target node.

3.1 Experiment System

The basic idea behind RSSI is the configured transmission power at the transmitting device (TX) directly affecting the receiving power at the receiving device (RX) [6]. The reference nodes receive the request message, and then send intensity signal values to the unknown sensor node or target node. The unknown sensor node will collect the data (RSSI) from reference nodes and forward it to the PC for estimating the location of the target node. Fig. 5 shows the experiment system.

Figure 5. The real measurement system and setup.

The distances between the reference nodes and the target node can be calculated from RSSI values. Then the location of the target node can be further estimated according to those distances as explained in section 2.1. Fig. 5 shows the real measurement system and set up for our research. The node holder consists of an adjustable long pipe and a small box placed at one end of the pipe used to carry the node. The reference nodes are deployed in the 5 m × 5 m × 2 m observed area.

3.2 Experiment Setup

The Min-Max algorithm is applied as the algorithm for this 3D indoor localization. Section 2.2 explains about the Min-Max algorithm for 2D, but here the z-axis is added as the latitude differences. So, in the same manner of Equation (10) and (11) and it is added z-axis as in Equation (16).

From here, the 9 target positions are randomly deployed in the experiment system. The design is proposed to divide the area of 5 m × 5 m × 2 m into 5 levels. Fig. 6 illustrates the 5 levels of the experiment setup.

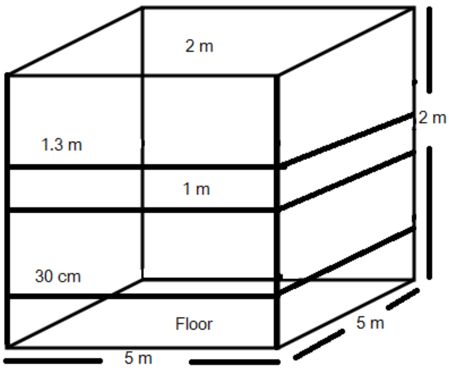

Figure 6. The illustration of experiment setup.

The 9 positions of the target node are randomly selected in the experiment setup. There are 2 target positions, on the floor, 0.3 m, 1 m, and 1.3 m, 1 target position is placed on the 2 m level exactly at center of the box. The complete explanation about the target position will be explained in the Section 4.

4. Result and Discussion

The objective of this paper is to validate the accuracy of Min-Max algorithm in 3D indoor localization. The effectiveness of the both techniques is verified by an indoor experiment and the estimated location errors are analyzed.

4.1 Target Position

In this paper, 9 target positions are analyzed. In Section 3.2, the 5 levels of the 5 m × 5 m × 2 m area is proposed. Table 1 shows the 9 target positions.

Table 1. The target positions for evaluation.

No.	Name	Coordinate (*x* ,*y*, *z*)
1.	Target 1 (T1)	(2.5, 2.5, 0)
2.	Target 2 (T2)	(1, 2.5, 0)
3.	Target 3 (T3)	(2.5, 1, 0.3)
4.	Target 4 (T4)	(1, 4, 0.3)
5.	Target 5 (T5)	(2.5, 4, 1)
6.	Target 6 (T6)	(4, 2, 1)
7.	Target 7 (T7)	(2, 3, 1.3)
8.	Target 8 (T8)	(3, 1, 1.3)
9.	Target 9 (T9)	(2.5, 2.5, 2)

According to Equation (1), A and n values are obtained by experiment using 1 m distance. A and n values are used for acquiring the distance between each reference node and the target node. From the experiment, we obtain the value of A is -36.53 and n value is 1.35.

The detail of how we get the A and n values are shown in Fig. 7 and Fig. 8.

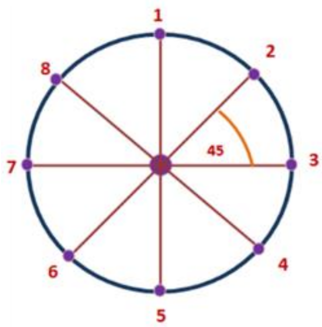

Figure 7. The illustration to find (A) value

The A value is obtained by placing the transmitter and receiver in the 1 meter distance and uses the circle as shown in Fig. 7. Fig. 7 shows the value A in 2D case. For our case, the A value is measured with the 1 meter distance using the ball-form similar in Fig. 7. The A value is obtained from average of RSSI in 1 meter at each azimuth and elevation by increasing 45 degrees to round (ball-form). After we know the A value, we will find the n by measuring the RSSI (at 1 to 5 meters).

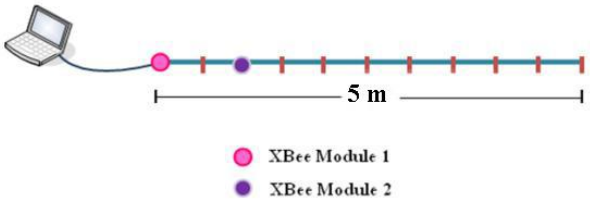

Figure 8. The illustration to find (n) value.

The n value is obtained by comparing the RSSI values from real measurement (1 m to 5 m) with the calculated RSSI by using Equation (1). As mentioned previously, we get the A value from procedure in Fig. 7. By using Equation (1) and we change the value of d from 1 m to 5 m. From there, we assume the n value is in range from 1 and 5. The next step, we observe the minimum error by using the root mean square error (RMSE). The RMSE equation is show below

$$RMSE = \sqrt{\frac{\Sigma(Measured\ RSSI - Calculated\ RSSI)^2}{Number\ of\ RSSI}} \quad (17)$$

From Equation (17), the number of RSSI that we used is 10. As mentioned before, the RSSI value is obtained from 1 m to 5 m using the 0.5 m separation (10 times). After we get the minimum value of RMSE, this value refers to n value; in our case n value is 1.35.

Table 2 shows the estimated coordinates from 9 target position. The experiment is conducted 10 times to get the average data of RSSI from 8 reference nodes. From comparison between Table 1 and Table 2, we can observe that the error is relatively high in some target positions. There are a lot of factors that affect the results, such as battery power of the nodes, the diffraction of edges, refraction by media with different propagation velocity and reflection in metallic objects [7].

Table 2. The estimated target positions.

No.	Name	Coordinate (*x* ,*y*, *z*)
1.	Target 1 (T1)	(2.86, 2.13, 1.36)
2.	Target 2 (T2)	(2.5, 2.26, 1.21)
3.	Target 3 (T3)	(2.26, 2.74, 0.45)
4.	Target 4 (T4)	(0.35, 2.87, 0.46)
5.	Target 5 (T5)	(1.83, 3.36, 1.23)
6.	Target 6 (T6)	(3.95, 1.64, 1.43)
7.	Target 7 (T7)	(2.89, 3.66, 1.39)
8.	Target 8 (T8)	(2.72, 2.27, 1.73)
9.	Target 9 (T9)	(1.67, 3.33, 2.0)

4.2 Estimated Error

In this research, we start placing the target node on the floor and the next upper levels as illustrated in Fig. 6. For instance, the first position of the target node is at (2.5 m, 2.5 m, 0 m) and the experiment is continued until the top level (2 m) at (2.5 m, 2.5 m, 2 m). Fig. 9 depicts the estimated location error in meter of the Min-Max algorithm versus the position of the target node.

From Fig. 9, we can observe that the highest error occurs in the position number 3. In this position, the error reaches 1.74 m for the y-axis. If we see the trend of error in 3 axes, the error mostly comes from positions number 1, 2, 3, 4, and 8. As we know from Table 1, these positions are located in the 0 m, 0.3 m, and 1.3 m for z-axis. This error may be occurred because of the different high or latitude between the target node and reference nodes.

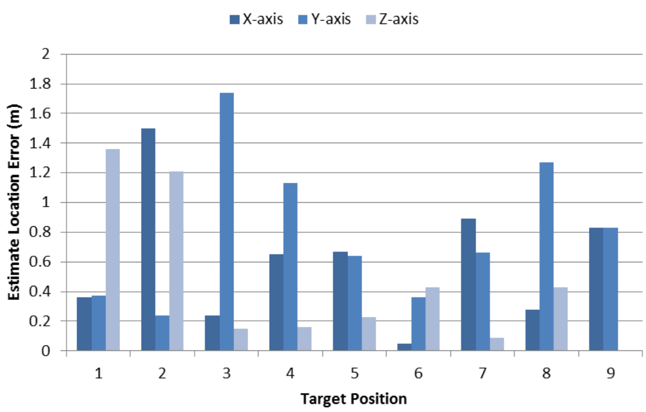

Figure 9. The estimated location error of the Min-Max algorithm in 3D.

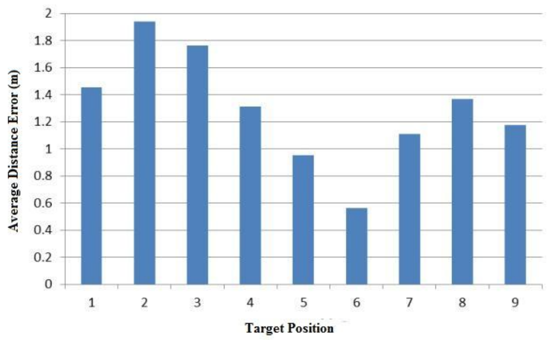

Figure 10. The error distance of Min-Max algorithm in 3D.

Fig. 10 performs the distance between coordinates of real target position and estimated target position. As we observe from Fig. 10, the error does not reach more than 2 m. This is acceptable result since our expectation or our measurement setup is 2 m length. This graph is obtained by this following Norm equation [8]:

$$error = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2} \quad (15)$$

where (x, y, z) is the real coordinates of target node and (x', y', z') is the estimated coordinates of target node. As explained previously, reference nodes are placed in the 0 m and 2 m. The relatively high error also could be a result of wave propagation between transmitter (the target node) and the receiver (the reference node) since the deployment of 8 reference nodes in the observation area.

5. Conclusion

This paper proposes the method to apply the Min-Max algorithm as the range-based localization in 3D indoor scenario. The 8 reference nodes are deployed. The target node is placed into 5 levels of the 5 m × 5 m × 2 m area. We expect the estimated error of the target location should be less than the experiment areas, i.e., less than 2 m in this case. The results show that the estimated errors of all observed target locations are less than 2 m, which are satisfied our expectation. However, some applications require higher accuracy and 2 m error may be considered the huge error for those applications. Therefore, for the future work, we plan to develop this proposed technique to improve the accuracy which is applicable to all applications in the real life. We have a plan to calibrate the power in the transmitter before transmit the data and after get the data. It is used for maintaining the power from battery that has equal values. Therefore, the limitation of RSSI error will be achieved. Moreover, we will consider about the formula of RSSI in the indoor environment. We observe that the RSSI formula that we used should be added by the parameter such as the shadowing of antenna and the furniture propagation.

6. Acknowledgement

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