Problem Investigation of Min-max Method for RSSI Based Indoor Localization

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***Abstract*—This paper evaluates the performance of min-max and trilateration methods for RSSI-based indoor localization by a real test. Our experiments have been carried out in a laboratory room in the Department of Electrical Engineering, Prince of Songkla University, Thailand. An LPC2103F microcontroller interfacing with a CC2500 radio transceiver which was developed by our research team is used as a wireless node. The experimental result from a given scenario demonstrates that the min-max method significantly gives the better performance than the trilateration method; an average estimated position is closer to a real target position, and an average error distance is smaller. For the RSSI-based min-max method, we also summarize its limitations as found during the experiment; our finding can be used as information for researchers to further develop the min-max method.**

Keywords—min-max method; trilateration method; experiment; indoor localization; received signal strength indicator (RSSI)

I. INTRODUCTION

Target localization is one of essential subjects in wireless communication networks because position information is useful for many applications, such as monitoring and control, building automation, health surveillance, target tracking, rescue, and etc. [1] - [4]. Therefore, one of the fundamental challenges in wireless communication networks is a node localization problem. In the research literature, there are many existing localization methods have been proposed. The min-max method and the trilateration method using received signal strength indicator (RSSI) information for position estimation are widely used because both methods are simplicity and low computational complexity [5], [6].

Based on the literature review, in [6], the experimental comparison of the RSSI-based indoor localization for wireless networks was presented. The authors conclude that the min-max method gives the better performance than the trilateration method when three reference nodes are used for position estimation. Note that to estimate a position of a target node, the min-max and the trilateration methods need to know the right positions of the reference nodes. This will be described in the paper. In addition, the authors also claim that the complexity of min-max operation is lower than the trilateration operation. From information as reported in [6], we can see that the comparison study of the min-max and the trilateration methods is not new. However, we also found that the study of the problem investigation of the RSSI-based min-max method is still not presented.

In this paper, the performance evaluation of the min-max method and the trilateration method is studied through the real test. Our experiments have been carried out in a laboratory room in the Department of Electrical Engineering, Faculty of Engineering, Prince of Songkla University, Thailand. For this test, we employ the LPC2103F microcontroller [7] with the CC2500 radio module [8] as the wireless node, which was developed by our research team. We note that although the comparison study of the min-max method and the trilateration method is not new, as mentioned before. However, we want to test this issue again due to the different setting of a test field as well as the different wireless node platform using in this work. The experimental result from a given scenario shows that the min-max method significantly provides the better performance than the trilateration method almost test locations in a test field. It estimates unknown target positions with small error distance. In addition, for the RSSI-based min-max method, we also report its limitations as found during the experiment. We believe that our findings are useful for researchers to further improve the performance of the min-max method.

The structure of this paper is as follows. Section II explains the concepts of the min-max and the trilateration methods. Section III describes the experimental setup. Section IV presents the experimental results and discussions. Finally, we conclude this paper in Section V.

II. MIN-MAX AND TRILATERATION METHODS

The concepts of how to estimate the position of a target node in the min-max and the trilateration methods are described as follows.

A. *Min-max Method*

In the min-max method, as shown in Fig. 1, the target node measures the RSSI values from three reference nodes, as placed at the position x_i and y_i (where i is the reference node number) and converts the measured RSSI values to the distance (i.e. d_i) based on the path-loss equation. Then, the target node draws a bounding box around each reference node. Where the position of the reference node is located at the center, and the length of the edge is equal to $2d_i$. Finally, the target node defines an intersection area as called a definition zone [9]. It is the area within x_{min}, x_{max}, y_{min} and y_{max} positions. These positions

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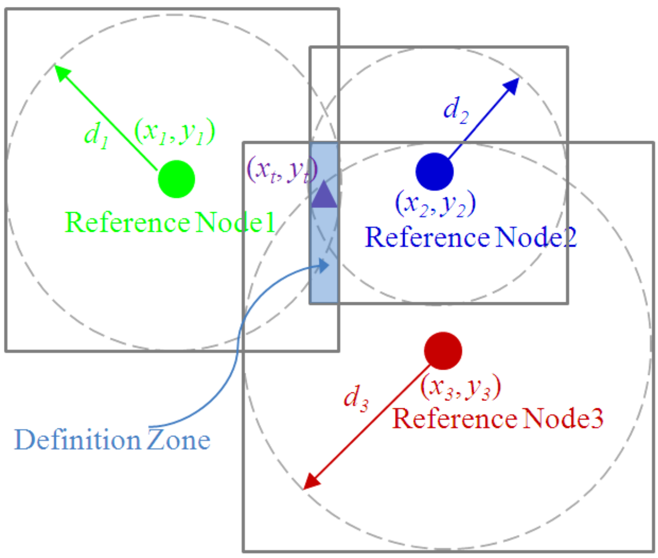

Fig. 1. Min-max method

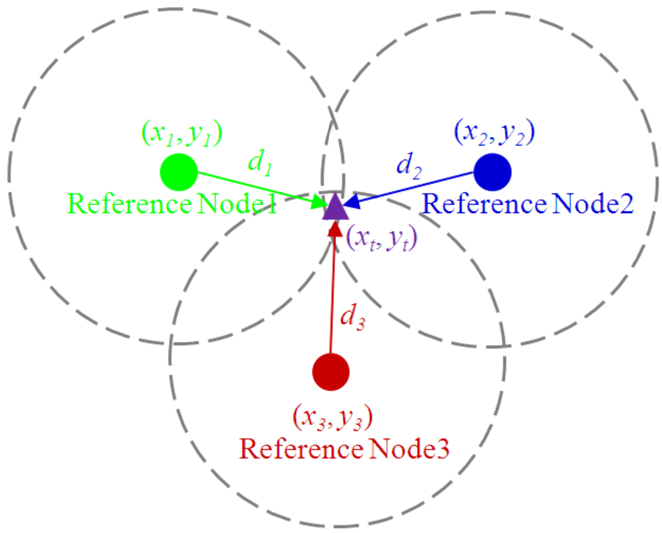

Fig. 2. Trilateration method

can be expressed by (1) – (4). The center of the definition zone is assumed as an estimated target node position (i.e. x_t, y_t), as written by (5) and (6). Note that the area among three reference nodes is called the internal zone as defined by the work in [9].

$$x_{min} = max(x_1 - d_1, x_2 - d_2, x_3 - d_3) \quad (1)$$

$$x_{max} = min(x_1 + d_1, x_2 + d_2, x_3 + d_3) \quad (2)$$

$$y_{min} = max(y_1 - d_1, y_2 - d_2, y_3 - d_3) \quad (3)$$

$$y_{max} = min(y_1 + d_1, y_2 + d_2, y_3 + d_3) \quad (4)$$

$$x_t = \frac{(x_{min} + x_{max})}{2} \quad (5)$$

$$y_t = \frac{(y_{min} + y_{max})}{2} \quad (6)$$

B. Trilateration Method

In the trilateration method, as shown in Fig. 2, the target node measures the RSSI values from three reference nodes, and converts the measured RSSI values to d_i based on the path-loss equation. Then, the target node draws a circle around each reference node. Where the radius of the circle is equal to distance d_i, and the position of the reference node is located at the center. Finally, the target node calculates the intersection of the three circles by using (7) to (9). The intersection point is assumed as an estimated target node position.

$$(x_t - x_1)^2 + (y_t - y_1)^2 = d_1^2 \quad (7)$$

$$(x_t - x_2)^2 + (y_t - y_2)^2 = d_2^2 \quad (8)$$

$$(x_t - x_3)^2 + (y_t - y_3)^2 = d_3^2 \quad (9)$$

III. EXPERIMENTAL SETUP

The details of our experiments are described as follows. The experiments have been carried out in a laboratory room in the Department of Electrical Engineering, Faculty of Engineering, Prince of Songkla University, Thailand, as shown in Fig. 3. There are several obstacles, such as chairs, tables, book cabinets and some electrical machines in this test field. The dimension of the test filed is equal to 4.54 m × 7.40 m. In our experimental scenario, as shown in Fig. 4, we utilize three reference nodes to estimate the position of the target node. These three reference nodes are located at the positions (x = 0 m, y = 6.20 m), (x = 0 m, y = 0 m), and (x = 3.60 m, y = 6.20 m), respectively. There are five different target nodes to be estimated their positions. These positions are at real position 1 (i.e. x = 1.10 m, y = 5.50 m), real position 2 (i.e. x = 2.56 m, y = 5.50 m), real position 3 (i.e. x = 3.64 m, y = 3.10 m), real position 4 (i.e. x = 2.04 m, y = 2.50 m) and real position 5 (i.e. x = 0.30 m, y = 1.90 m). All nodes are placed above the floor 1 m. We use the LPC2103F microcontroller with the CC2500 RF transceiver as the wireless node for this experiment, which is shown in Fig. 3.

There are two steps in the localization process. Firstly, we use one transmitter node and one receiver node to collect the RSSI data at five different distances; 1 m, 2 m, 3 m, 4 m, and 5 m, respectively. For each distance, the receiver collects 10,000 RSSI data samples. These dataset are utilized for finding the path-loss equation, which describes the relationship between the RSSI value and the distance of the test field. We use this path-loss equation to convert the measured RSSI value to the distance value. It is shown in (10). Where a parameter A is an average received power at the distance 1 m from the transmitter, η is the path loss exponent, and d_0 is a reference distance. In this experiment, the parameters A = - 41.818, η = 3.615 and d_0 = 1 m. Secondly, the test target node as described above collects 1,000 RSSI data samples from each reference node. Theses measured RSSI data are transferred to a computer as a base station via a wireless communication for estimating the target position. The measured RSSI data are converted to the distance by using (10) as described before. Finally, the min-max method and the trilateration method are applied for estimating the target node position.

$$RSSI(dBm) = A - \left[10 \times \eta \times log_{10}\left(\frac{d}{d_0}\right)\right] \tag{10}$$

An average estimated position (*AEP*) and an average error distance (*AED*) are chosen as the performance metrics for evaluation the performance of the min-max and the trilateration methods. These performance metrics are defined in (11) and (12), respectively. Where N is the number of RSSI data samples. x_i and y_i are the estimated position x and the estimated position y. x_{real} and y_{real} are the real position x and the real position y. x_{est} and y_{est} are the average estimated position x and the average estimated position y. The 95% confidence interval (C.I.) is also provided for each average result.

$$AEP = \left(\frac{1}{N}\sum_{i=1}^{N} x_i, \frac{1}{N}\sum_{i=1}^{N} y_i\right) \tag{11}$$

$$AED = \sqrt{(x_{real} - x_{est})^2 + (y_{real} - y_{est})^2} \tag{12}$$

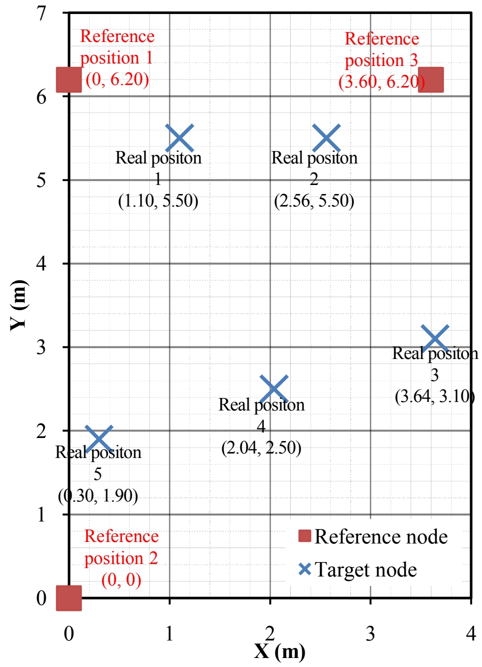

Fig. 4. Experimental scenario

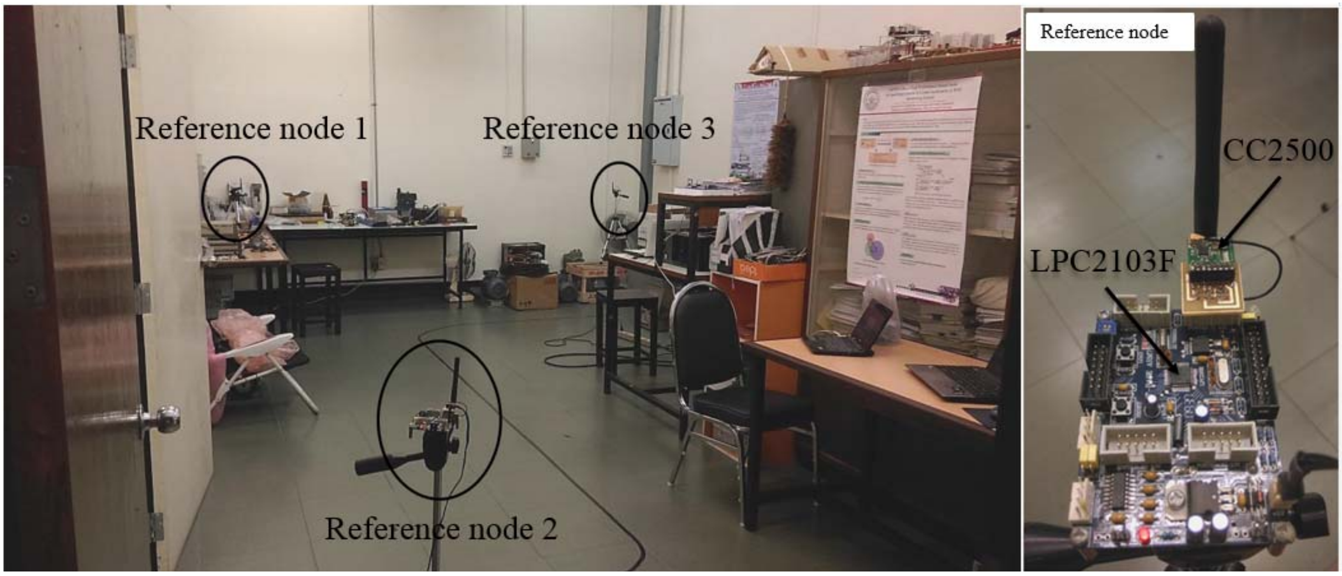

Fig. 3. Test field and wireless node used in our experiment

IV. Experimental Results and Discussions

The error distance calculated from each RSSI sample number by the min-max method and the trilateration method is shown in Fig. 5 (a-e). The experimental results guarantee that the min-max method provides the better performance than the trilateration method almost test locations in our test field. The average value of the estimated position and the average error distance at each test position by both methods are summarized in Table 1. The average results also confirm that the min-max method gives the best performance. In addition, in the min-max method, it provides small error distance when the test targets are placed in the internal zone; at real position 1 (x = 1.10 m, y = 5.50 m), at real position 2 (x = 2.56 m, y = 5.50 m), and real position 5 (x = 0.30 m, y = 1.90 m). As mentioned in Section II before, the internal zone is the area within three reference nodes [9]. On the other hand, when the test target is placed outside this zone, the error distance increases, like the case of the real position 3 (x = 3.64 m, y = 3.10 m). These findings are agree with the results as studied in [9]. In [9], the authors summarize that the min-max method can produce a high position error if the target node is located outside the internal zone.

In this experiment, we found the limitations of the RSSI-based min-max method, which are summarized here.

- The min-max method estimates the target position at the center of the definition zone, as shown in Fig. 1 and (5) - (6). This can cause the estimation error if the real target does not locate at the center of the zone. From an average result at the real position 4 (x = 2.04 m, y = 2.50 m) as illustrated in Fig. 6, the unknown target locates on the lower right corner of the definition zone, but the min-max method estimates its position at the center of the zone. The works in [9] and [10] also report this limitation.
- The definition zone as determined by the min-max method does not cover the real target position, as shown in Fig. 7, an average result at the real position 3 (x = 3.64 m, y = 3.10 m). This shows that the weighted bounding box localization algorithms proposed in [9] and [10] may not work efficiently.
- The min-max method produces a high position error if the target node is located outside the internal zone, as described before, like the case of the real position 3 (x = 3.64 m, y = 3.10 m).
- The estimation error increases if the target node does not receive the measured RSSI data from one of the reference nodes. The consecutive RSSI packet drops at the target node can increase the estimation error.

Why the RSSI-based min-max method has the limitations as described above is explained here. Firstly, the min-max method estimates the target position using the RSSI data as converting to the distance. However, the measured RSSI data is fluctuating over time due to multi-path fading, radio interference, and noise effects, especially in an indoor environment. As a result, the signal fluctuation can produce the error during converting the RSSI value to the distance, and creating the bounding box. This can lead to increase in the estimation error. Secondly, when the target node locates outside the internal zone, the min-max method produces higher position error because the definition zone created by the min-max method is bigger. Thirdly, the effect of RSSI packet drop at the target node can increase the estimation error; using small numbers of RSSI data to estimate the target position is not accurate.

V. Conclusions

In this paper, the performance evaluation of the min-max and the trilateration methods for RSSI-based indoor localization is studied. The experimental result indicates that the min-max method significantly performs better than the trilateration method. It estimates the unknown target position with small error distance. For the min-max method, we also investigate its limitations as found during the experiment; this finding can be used as information for improving the performance of the min-max method.

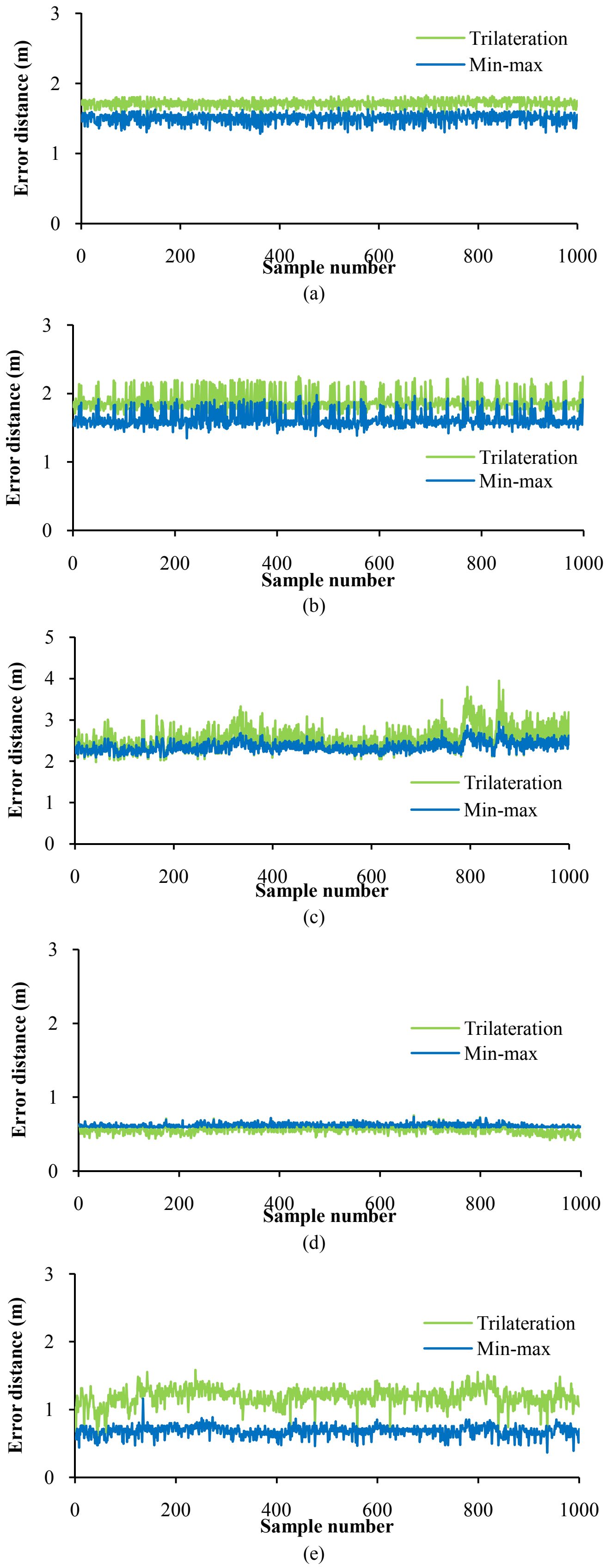

Fig. 5. The error distance by the min-max and the trilateration methods; (a) at real position 1, (b) at real position 2, (c) at real position 3, (d) at real position 4, and (e) at real position 5

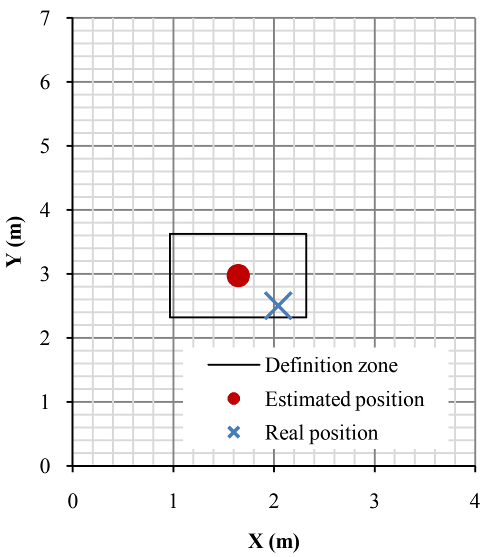

Fig. 6. The real target does not locate at the center of the definition zone; an average result at the test point (x = 2.04 m, y = 2.50 m)

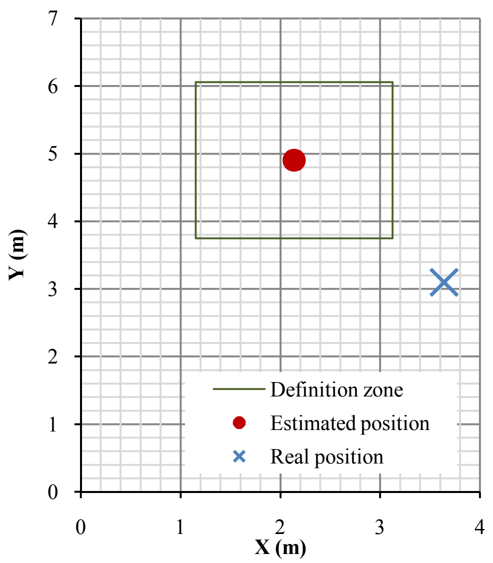

Fig. 7. The definition zone does not cover the real target position; an average result at the test point (x = 3.64 m, y = 3.10 m)

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Table 1 The average estimated position and the average error distance by the Min-max and the trilateration methods at each test location

Real position		**Min-max method**				**Trilateration method**			
		Average estimated position		Average error distance (m)	95% C.I.	Average estimated position		Average error distance (m)	95% C.I.
x (m)	y (m)	x (m)	y (m)			x (m)	y (m)		
1.100	5.500	1.525	4.055	1.506	0.004	1.538	3.838	1.718	0.003
2.560	5.500	2.116	3.940	1.621	0.007	2.213	3.642	1.889	0.007
3.640	3.100	2.135	4.903	2.350	0.007	2.320	5.279	2.553	0.017
2.040	2.500	1.642	2.974	0.620	0.001	1.765	2.994	0.567	0.003
0.300	1.900	0.812	2.347	0.682	0.004	1.333	2.472	1.187	0.008