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An enhanced trilateration algorithm for indoor RSSI based positioning system using zigbee protocol

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Abstract — The location information of the object based on wireless communication has a significant role in several Wireless Sensor Network (WSN) applications. Some applications require the appropriate details on the object's position. The advantages of Zigbee as part of Radio Frequency (RF) technology include inexpensive, broad scalability, sufficient availability, and suitability for Indoor Positioning System (IPS) topology. In this paper, we propose IPS using a Received Signal Strength Indicator (RSSI) based Zigbee protocol. The proposed approach is based on the enhancement of the Trilateration algorithm. The main concept of conventional trilateration is using the three strongest RSSI from the reference node. However, the instability from measured RSSI influenced its estimation result. Therefore, quadratic weighted is added to this proposed scheme as the enhanced trilateration algorithm. The estimated distance output from the conventional trilateration algorithm will be recalculated for the weighted value and multiplied by each reference node, producing a lower estimation error. The simulation result shows that using an enhanced trilateration algorithm can improve the accuracy level of estimated position up to 90.55% with mean square error (MSE) of 2.03 meters stacked up with only using conventional trilateration is attained high estimated error up to 4.31 meters.

Keywords – Conventional trilateration, enhanced trilateration, indoor positioning system, MSE, RSSI

I. Introduction

Precise accuracy of positioning systems has been a crucial requirement in various WSN application contexts such as mobile activity for human, animal, or package tracking, environment monitoring, vehicle navigation in industrial or military areas, and rescue missions when disaster or warfare conditions [1]. Nowadays, Global Positioning System (GPS) provides a reliable outdoor positioning system. However, GPS technology performance does not properly work for indoor environments, especially in-building locations, due to its signal limitation transmission [2]. Thereby, many researchers compete to improve schemes, methods, techniques, and algorithms for positioning systems, especially in indoor location areas.

There are several techniques that can be used for enabling Indoor Positioning System (IPS) such as: Received Signal Strength Indicator (RSSI) estimate distances by wireless signal transceiver measurement, Time of Arrival (TOA) calculate the distance by the time of wireless signal propagation measurement, Time Difference of Arrival (TDOA) estimate the distance by measuring the time difference of wireless signal transmission, then the Angle of Arrival (AOA) estimates the angle by measuring the same parameter as TDOA [3]. According to the measurement method and hardware, RSSI is the simplest implementation for IPS [4]. While, refers to the development technologies for supporting the IPS as well as infrared, ultrasonic, Wi-Fi, Radio-frequency Identification (RFID), Zigbee, and Ultra-wideband (UWB). Compared with the above technologies, Zigbee has been a more widely used RSSI-based positioning system because it has low power consumption, low costs, and high stability [5]. However, RSSI-based Zigbee for IPS can be influenced by multipath, reflection, and attenuation from the building environment which can be also influenced by the estimated position result [6]. Therefore, it is required an applicable algorithm with a lower error estimation position result.

The preferable positioning algorithms have been

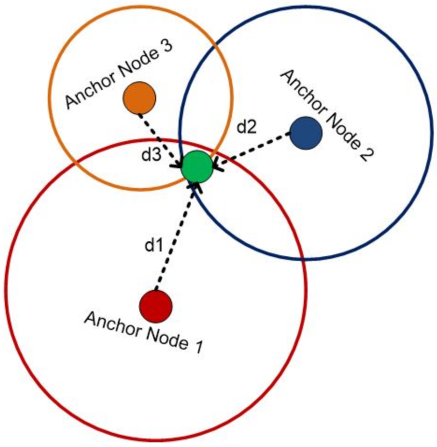

Fig. 1. Conventional trilateration algorithm illustration.

developed in IPS, which are proximity estimation, triangulation, trilateration, and pattern recognition or fingerprinting [7]. Due to the low cost and low computation complexity as the advantage of the positioning algorithm, trilateration is implemented in several positioning applications [8]–[10]. However, these algorithms require precise estimated distance calculation through the proper analysis of transmitter signals which can be directly influenced by the estimated position result [11]. Therefore, many researchers propose enhanced schemes for improving the estimated position result from the trilateration algorithm.

A novel enhanced trilateration algorithm has been proposed by [12] using an adaptive algorithm for improving the output from the trilateration algorithm and applying this method for medical implants in body localization. Pablo, *et al.* [13] have proposed indoor robot positioning using an enhanced trilateration algorithm formed by 3D trilateration and geometric modification calculation. While [14] has proposed high-precision RTT-based IPS using CNN algorithm-based RTT compensation distance network. Weighted centroid factors depend on the content of the beacon that has been applied to the three-dimensional centroid localization [15]. Each proposed algorithm has some advantages and disadvantages in several factors such as processing time, accuracy result, and suitability with the positioning scheme used.

This paper proposes an enhanced trilateration algorithm using quadratic weighted centroid for IPS based on RSSI Zigbee protocol transmission. We improve our previous work from [9] and use the observation area from [10]. The contribution of this paper is to propose an enhancement scheme for IPS that uses quadratic weighted static degree to improve the estimation from the trilateration algorithm. To apply the enhanced trilateration algorithm, RSSIs are transmitted by deploying 18 Anchor Nodes (ANs) which are equipped with Xbee S2 PRO module to the Unknown Node (UN) as the target node. The quadratic weighted static degree is calculated from the trilateration estimation result and then multiplied with the three strongest ANs coordinates. To evaluate the performance of the enhanced trilateration algorithm, this IPS will be simulated using RSSI measurement in a realistic scenario and also compared with previous work that used a conventional trilateration algorithm.

II. Research Method

This section discusses the conventional and enhanced trilateration algorithms.

A. Conventional Trilateration Algorithm

The trilateration algorithm is defined as a mathematical formulation where the green point as the target point is calculated using the distance from three intersected circles [13]. As shown in Fig. 1, ANs as the transmitter will transmit $RSSI$ to the UNs.

$RSSI$ can be measured as the distance ($d_i = d_1, d_2, d_3, \cdots, n$) between ANs to UN. The distances are derived from the Euclidean distance between the reference coordinate of each circle and its target coordinate which is formed by the intersections as shown in (1):

$$(x_{AN_i} - x_{UN})^2 - (y_{AN_1} - y_{UN})^2 = d_i^2 \qquad (1)$$

d_i as the reference from (1) will be subtracted with another d_n based on used numbers of distances as follows:

$$\begin{aligned} d_n^2 - d_i^2 =& \\ &=\{(x_{UN} - x_{AN_n})^2 + (y_{UN} - y_{AN_n})^2\} - \\ &\quad \{(x_{UN} - x_{AN_i})^2 + (y_{UN} - y_{AN_i})^2\} \end{aligned} \qquad (2)$$

$$\begin{aligned} d_n^2 - d_i^2 =& \\ &=2x_{UN}(x_{AN_i} - x_{AN_n}) + x_{AN_i}^2 - x_{AN_n}^2 + \\ &\quad 2y_{UN}(y_{AN_i} - y_{AN_n}) + y_{AN_i}^2 - y_{AN_n}^2 \end{aligned} \qquad (3)$$

AN_i ($i = 1, 2, 3, \cdots, n$) as the anchor node with coordinate point (x_i, y_i) and also d_i will estimate the UN position using trilateration formulas as shown in (4) and (5) [8]–[10], [13]:

$$x_{UN} = \frac{v_{AN_{n-i}}(y_{AN_n} - y_{AN_{n-i}}) - v_i(y_{AN_i} - y_{AN_{n-i}})}{(x_{AN_i} - x_{AN_{n-i}})(y_{AN_n} - y_{AN_{n-i}}) - (x_{AN_n} - x_{AN_{n-i}})(y_{AN_i} - y_{AN_{n-i}})} \qquad (4)$$

$$y_{UN} = \frac{v_{AN_{n-i}}(x_{AN_n} - x_{AN_{n-i}}) - v_i(x_{AN_i} - x_{AN_{n-i}})}{(y_{AN_i} - y_{AN_{n-i}})(x_{AN_n} - x_{AN_{n-i}}) - (y_{AN_n} - y_{AN_{n-i}})(x_{AN_i} - x_{AN_{n-i}})} \qquad (5)$$

$$V_i = \frac{(x^2_{AN_n} - x^2_{AN_{n-i}}) + (y^2_{AN_n} - y^2_{AN_{n-i}}) - (d^2_{AN} - d^2_{AN_{n-i}})}{2} \tag{6}$$

$$d_{quad1} = \frac{1}{dtri1} + \frac{1}{dtri2} \tag{7}$$

$$d_{quad2} = \frac{1}{dtri2} + \frac{1}{dtri3} \tag{8}$$

$$d_{quad3} = \frac{1}{dtri1} + \frac{1}{dtri3} \tag{9}$$

$$d_{quad4} = 2 \times \left(\frac{1}{dtri1} + \frac{1}{dtri2} + \frac{1}{dtri3}\right) \tag{10}$$

$$x_{etri} = \frac{(x_{AN_i} \times d_{quad1}) + (x_{AN_{i+1}} \times d_{quad2}) + (x_{AN_{i+2}} \times d_{quad3})}{d_{quad4}} \tag{11}$$

$$y_{etri} = \frac{(y_{AN_i} \times d_{quad1}) + (y_{AN_{i+1}} \times d_{quad2}) + (y_{AN_{i+2}} \times d_{quad3})}{d_{quad4}} \tag{12}$$

V_i $(1, 2, 3, \cdots, n)$ can be calculated using (6).

B. Enhanced Trilateration Algorithm

The enhanced trilateration algorithm is formed by adding the quadratic weighted algorithm to the trilateration estimated result. According to the trilateration result (x_{UN}, y_{UN}) it can be calculated the $dtri_{1,2,3,\cdots,n}$ to each AN reference point using Euclidean distance at (1). The main concept of quadratic weighted is adding a static degree to each AN node for determining the estimated position. The static degree is calculated using the estimated distance of the conventional trilateration algorithm as shown in (7), (8), (9), (10) [5].

$d_{quad(1,2,3)}$ as the static degree will be multiplied to AN coordinate point for determining the estimated position of enhanced trilateration algorithm (x_{etri}, y_{etri}) using (11) and (12) [5].

The result of the conventional and enhanced trilateration algorithm estimated position will be compared to the real position using Mean Square Error (MSE) in (13) [10].

$$MSE = \\ = \sqrt{(x_{estimated} - x_{real})^2 + (y_{estimated} - y_{real})^2} \tag{13}$$

III. Result

This section discusses the simulation parameter and the estimated position Result.

A. Simulation Parameter

In this paper, we simulated a realistic indoor environment of the 3rd floor of the PENS postgraduate building by enabling positioning-based RSSI using an enhanced trilateration algorithm. Inter-node communication is using Xbee-PRO (S2) module, while the calculation and simulation process is run at MATLAB software. There are 18 ANs as the RSSI transmitters which were placed on the wall at 1.5 m height and one UN as the target node which received RSSI from the AN at 0.9 m height. The UN is moving continuously based on its predefined route. The relevant simulation parameters of this system are written in Table 1.

Table 1. Simulation Parameters

Parameters	Value	Remarks
Operating frequency	2.4 GHz	Xbee-PRO (S2) module
Transmit power (EIRP)	17 dB	
Receiver sensitivity	-102 dBm	
Inter-anchor nodes distance	7 meters	Anchor nodes deployment
Inter-unknown node position	2 meters	Predefined Route

For supporting the simulation process of this system, there are two measurement phases: offline and offline phase. The offline measurement phase is used for determining specified path loss exponent (PLE) values at a certain distance. The PLE values of this paper are adopted from previous research [10]. It was grouped by area, and technique: cluster-based measurement and cluster-based linear regression calculation. The PLE value based on area and measurement technique grouping is subdivided into the Line of Sight (LOS) condition in the range of 0.89 to 1.76 while the Non-line of Sight (NLOS) condition is in the range of 2.1 to 5.09. Then, the PLE value using linear regression is 0.96 to 1.86 in the LOS condition and 2.14 to 4.98 in the NLOS condition.

The estimated distance between the AN and the UN can be calculated according to the PLE value. The estimated distance (d) will be used for estimated position calculation at the enhanced trilateration algorithm. Then, the online measurement phase is the measured RSSI transmission from the AN to the UN. The measured RSSI will be converted to the estimated distance using (14).

$$d = 10^{\frac{P_0 - RSSI_{ij}}{10 \times PLE}} \tag{14}$$

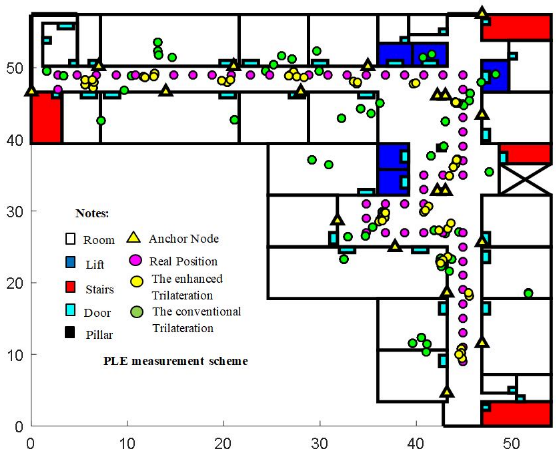

Fig. 2. Estimated position result using un-cluster PLE measurement technique.

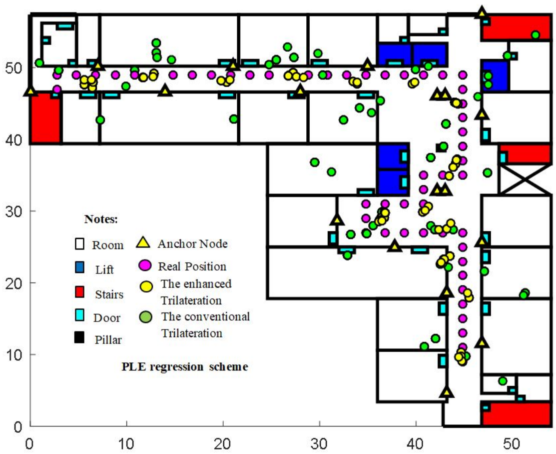

Fig. 3. Estimated position result using un-cluster PLE linear regression technique.

P_0 is the measured RSSI at the reference point (usually 1 m from the AN position). The un-interference RSSI measurement in the 1 m position was conducted at the anechoic chamber as the offline measurement phase also. Meanwhile, $RSSI_{ij}$ is the measured $RSSI$ at a predefined route position of the UN movement. Estimated distance from (14) will be processed to determine the estimated position of an UN using conventional trilateration as in (1), (2), (3), (4), (5), (6) and enhanced trilateration as in (7), (8), (9), (10), (11), (12).

B. Estimated Position Result

This paper aims to improve the accuracy result from our previous work at [10] using an enhanced trilateration algorithm. Four scenarios will be analyzed in this paper. They are using a cluster-based scheme and without using a cluster-based scheme. In those, each scheme will be split into PLE measurement-based and PLE regression-based.

As shown in Fig. 2 and Fig. 3, the estimated position results of a UN using conventional trilateration are far

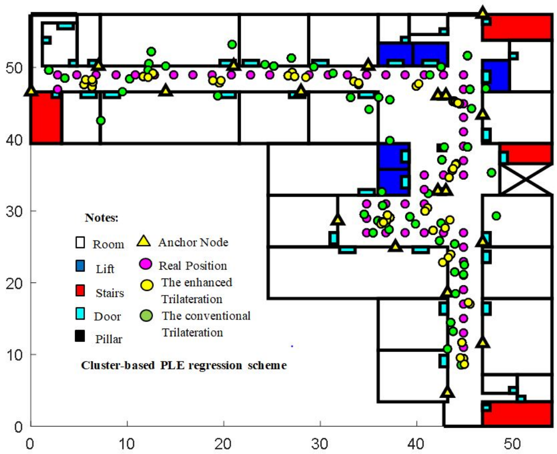

Fig. 4. Estimated position result using cluster PLE linear regression technique.

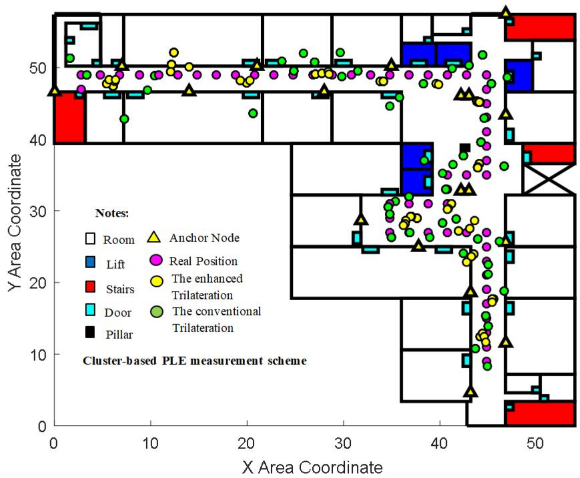

Fig. 5. Estimated position result using cluster PLE linear measurement technique.

away from the real position. While using the enhanced trilateration are come closer to the real position but gathered at the center area from its AN position. According to the PLE regression and PLE measurement, the estimated results are almost the same with some positions deviating slightly.

Likewise, with the use of cluster-based PLE value in measurement and regression technique in Fig. 4 and Fig. 5, the estimated position results are better in using enhanced trilateration than using conventional trilateration. Using cluster-based PLE value is more precise than using un-cluster-based PLE value. Cluster-based PLE value can describe environment conditions specifically which can make accurate results in the estimated distance as well as the estimated position.

IV. Discussion

Two parameters of performance will be analyzed in this paper. Those are MSE performance analysis and accurate performance analysis. Each performance is compared by using conventional and enhanced trilateration algorithms. This proposed algorithm is applied in four scenarios: un-cluster-based PLE

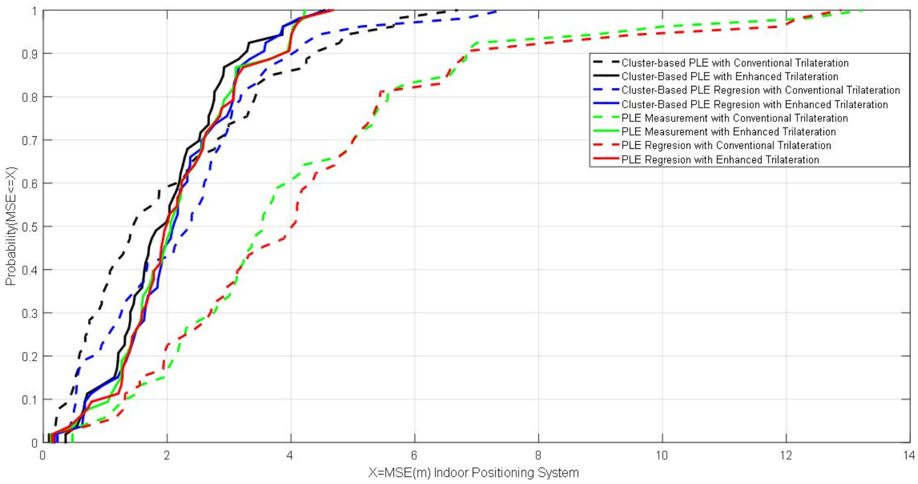

Fig. 6. CDF graph of estimated error position (MSE) from UN.

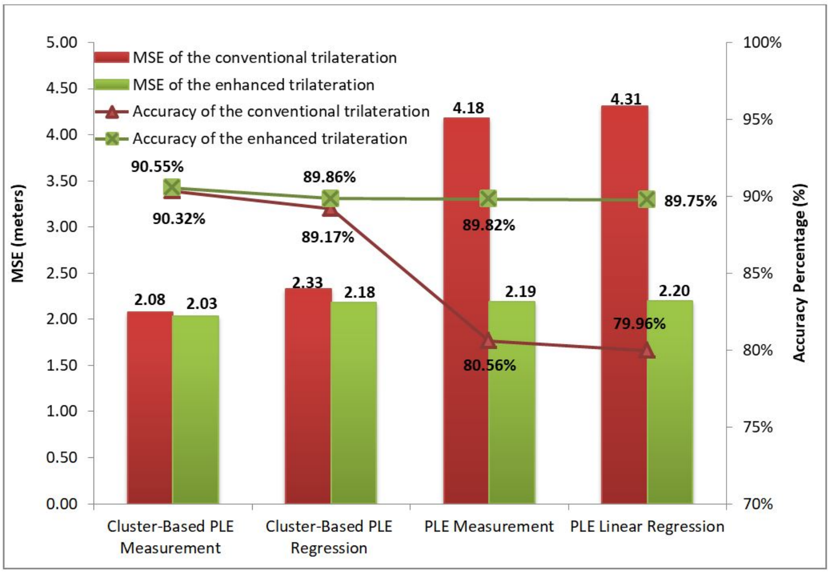

Fig. 7. Pareto chart comparison of MSE and accuracy average system .

measurement, un-cluster-based PLE regression, cluster-based PLE measurement, and cluster-based PLE linear regression.

A. MSE Performance Analysis

The estimated error position (MSE) of a UN is analyzed using Cumulative Distribution Function (CDF) in overall data, as illustrated in Fig. 6 Using this CDF approach can find out the smallest or the largest MSE value based on the cumulative probability for each scheme. The best performance as the smallest MSE value distribution is shown by cluster-based PLE measurement value that used an enhanced trilateration algorithm. It has a CDF range of 0.6 up to 0.95, even though a CDF range of 0 up to 0.59 MSE value is larger than cluster-based PLE measurement using a conventional trilateration algorithm.

However, compared to the range of MSE value using the enhanced trilateration algorithm achieves 0.18 m up to 4.62 m while using conventional trilateration has a higher range of MSE value up to 7.41 m. According to the result, the worst scenario is using un-cluster-based PLE linear regression, while the worst algorithm is using conventional trilateration. It proves that using an enhanced trilateration algorithm can improve the MSE of each scenario. Using enhanced trilateration has an MSE value of fewer than 6 meters, but using conventional trilateration still has an MSE value of up to 13 m.

B. Accuracy Performance Analysis

The accuracy performance is analyzed along with the average MSE system of each scheme. The accuracy performance is inversely proportional to the MSE result, as shown in Fig. 7. In the form of a Pareto chart, the percentage of accuracy and the average value of MSE for each scheme are displayed. The results show that each scenario with an enhanced trilateration algorithm has a reduction MSE average. Before using the enhanced trilateration algorithm, the cluster-based PLE measurement achieved MSE 2.08 m while after using the enhanced trilateration it achieved 2.03 m. It also affects the accuracy performance from 90.32% when using conventional trilateration to 90.55% in the enhanced trilateration algorithm. This improvement is followed by the other scenarios, especially when using un-cluster scenarios that have an improvement of up to 50% in the MSE average system.

Therefore, it can be proved that using the enhanced trilateration algorithm is more effective in decreasing the estimated error (MSE), rather than the conventional trilateration algorithm. The reason is that in enhanced trilateration some weighted factors using a quadratic algorithm are added. Adding a weighted value to the estimated distance from the conventional trilateration result can reduce the estimated position result, especially at the center position of all the ANs.

V. CONCLUSION

In this paper, we propose an enhanced trilateration algorithm for an indoor positioning system. This algorithm was implemented in the cluster and un-cluster-based PLE value. Inter nodes communications are equipped by Zigbee protocol. The estimated position of the UN is compared between conventional trilateration and enhanced trilateration. The comparative analysis shows that the enhanced trilateration algorithm decreases MSE estimated error up to two times better than using the conventional trilateration algorithm.

In future work, we can apply this algorithm for indoor to outdoor positioning systems to know the performance of this proposed algorithm.

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