A Weighted Geometric Dilution of Precision-Based Method for Indoor Positioning System

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Abstract—The weaknesses of ranging techniques on using RSS in indoor localization are fluctuating the RSS values. This situation will affect to the accuracy of distance measurement between anchor and target node. The accuracy in node position is not only influenced by accurate distance measurements, but also the geometric effects between anchors and targets. In this paper, we present a localization technique by using weighted geometric dilution of precision (WGDOP). We design an anchor set to estimate a target. The initial estimation was estimated by using trilateration and geometric dilution of precision (GDOP) then we implemented WGDOP as the weight for the estimation of several anchor sets offered. We evaluate the performance of WGDOP, this technique can increase the accuracy by 40% than without used weight in this system.

Index Terms—Geometric dilution of precision, ranging techniques, RSS

I. Introduction

The study in Wireless Sensor Network (WSN) becomes popular because there are many applications which has been developed in WSN system. WSN uses a sensor node which is placed both in indoor or outdoor. The sensors have an ability to sense a parameter with the limit source to communication [1], [2].

Application of WSN can be classified into two categories, monitoring and tracking. In WSN, it is important to know the location from sensor node of them. Localization is a process to determine the position of sensors by using a specific algorithm, because the data and information are ineffective if we don't know the geographic position of them [3], [4]. Localization can be implemented in outdoor and indoor, e.g. GPS for outdoor localization. But the usage of GPS in an indoor area will not be optimal because the signal can not be trought in the building. Therefore, the study of indoor localization has been deployed using Zigbee, Wi-Fi, BLE, RFID, etc. There are many research in BLE for indoor localization, because BLE is cheap and it has a low power consumption [5].

One of technic in indoor localization is ranging technic. The ranging techniques are time difference of arrival (TDOA), received signal strength (RSS), time of arrival (TOA), and angle of arrival (AOA) [6]. In indoor localization, it is important to know the position of anchor nodes to estimates unknown nodes which is unknown of their position. The simplest technic is by determining the distance between the anchor and the unknown. In this case, distance measurement can be a problem if it does not approach the original distance. The distance is used for estimating the location of objects by a certain algorithm like trilateration.

Trilateration needs at least 3 distance measurements between anchor and target that calculates the intersection of 3 circles to detect the position of target. Researcher [7] did experiment in trilateration algorithm, and the result showed that the error position in this algorithm is influenced by obstacles in indoor area. So, it caused an error in distance especially in distance estimation using RSS. We can use a Log Normal Shadowing (LNS) equation to estimate the distance. This equation is influenced by the exponential path loss in indoor [7], [8].

Because there was a fluctuation of RSS caused by obstacles, some studies in [9]-[11] did the experiment by filtering the RSS using Kalman Filter to get more accurate distance measurement. Path loss in indoor area depends on the character of the building, we can get the path loss by the experiment. The study in [12] designed a path loss model based on hybrid method between particle swam optimization (PSO) and polynomial exponential (PE). They used PSO method to select the optimum path loss coefficient which is generate by the PE method. The study in [13] showed that path loss in indoor area would be different in one area to another. To get more accurate distance, she clusters the area and did the experiment to get the path loss of each cluster area. So, the LNS equation still has a weakness if we use one path loss in all indoor area without cluster it first and make the path loss model. The study in [14], [15] did not use a LNS equation to estimate the distance. They used linear regression to get the distance estimation. He said that the error distance can be reduced significantly.

Beside the distance estimation, we need a good geometry between the anchor and target to improve the accuration in positioning [16]. GDOP method can represent the effect of geometry between measurement error and estimation error to the anchor. The study in [16] tried to investigate the GDOP of base station placement and to get the best fit for real application. The result showed when he took the base station more, and the accuracy was improved. The study in [17], [18] tried to consider the geometri effect by choosing the minimum

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GDOP in anchor selection. GDOP shows the accuracy of position estimation so that a small GDOP value shows high accuracy. However, not every error shows the same varians so it needed a weight value in GDOP matriks to reduce the noise of mesurement which had been done in [2], [19]-[20].

In this paper, we try to get the estimation by using a weighted matrix WGOP to improve the data accuration, The calculation of distance estimation is using linear regression equation by modeling the distance function. Performance of the proposed algorithm will be simulated by using MATLAB and calculate the MSE between the estimation and real position.

The rest of paper is organized as follows. In section II, we summarize the theory of GDOP and our proposed method. In section III, we describe the algorithm of our system such as distance estimation, position estimation using trilateration-GDOP, and our proposed WGDOP. The result and discussion present in section IV. Finally, in section V, we conclude our work and add a future work of this research.

II. Theory

A. Geometric Dilution of Precision (GDOP)

GDOP is defined as a ratio of MSE position to MSE distance. When an anchor is placed to a larger angle with each other, an error position can be minimized. Fig. 1 ilustrates the scheme of GDOP.

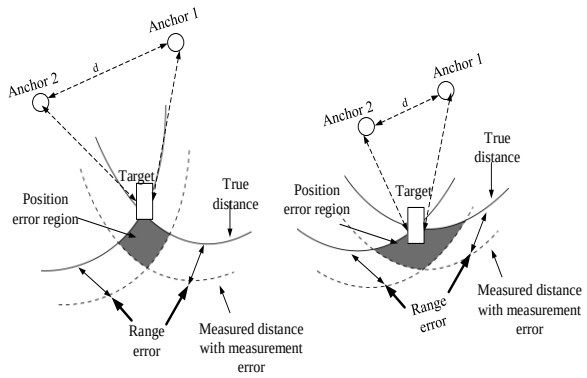


Fig. 1. Ilustration of Algorithm GDOP

The black area is a range of error position. When the angle is small, we can see that the error range becomes bigger. So that the geometry factor has a significant influence in positioning [21]. The accuracy can be known by searching the smallest GDOP value. GDOP is defined as in (1).

$$GDOP = \sqrt{tr[(H^T H)^{-1}]} \tag{1}$$

In (1), the H matrix is an important component in calculating the GDOP. H matrix is defined in (2).

$$H = \begin{bmatrix} e_{11} & e_{12} & 1 \\ e_{21} & e_{22} & 1 \\ \vdots & \vdots & \vdots \\ e_{n1} & e_{n2} & 1 \end{bmatrix}, e_{i1} = \frac{\hat{x} - X_i}{\hat{r}_i}, e_{i2} = \frac{\hat{y} - Y_i}{\hat{r}_i} \tag{2}$$

where $(\hat{x}, \hat{y})$ is position of target which estimates by using trilateration and (X_i, Y_i) is position of anchor nodes. Pseudo range between anchor i and estimation is defined as $\hat{r}_i$ that shows in (3). e_{i1}, e_{i2} are unit vector from anchor i to target.

$$\hat{r}_i = \sqrt{(\hat{\boldsymbol{x}} - \boldsymbol{X_i})^2 + (\hat{\boldsymbol{y}} - \boldsymbol{Y_i})^2} \tag{3}$$

B. Weighted GDOP

GDOP is commonly used in satellite systems to express distance errors in affecting estimates of target locations [8]-[9]. Because of the error varians are different although in same measurement, we propose a weighted matrix name W to replace the variance of error. W is defined as in (4). So that we calculate the GDOP value as in (5).

$$W_{ij} = \begin{bmatrix} W_{1j} & 0 & 0 \\ 0 & W_{2j} & 0 \\ 0 & 0 & W_{3j} \end{bmatrix} \tag{4}$$

$$WGDOP = \sqrt{tr(H^T W H)^{-1}} \tag{5}$$

III. Methodology

A. Distance Model Based on Regression Model

Simple linier regression modeling is an equation model that describes the relationship of one predictor variable (X) with one response variable (Y) which is described in a straight line. Mathematically, simple linear regression is stated by (6) [22].

$$\boldsymbol{Y} = a\,\boldsymbol{X} + b \tag{6}$$

$$a = \frac{\sum_{n=1}^{20} y_n - b\sum_{n=1}^{20} x_n}{N}$$

$$b = \frac{N(\sum_{n=1}^{20} x_n y_n) - \sum_{n=1}^{20} x_n \sum_{n=1}^{20} y_n}{N\ \sum_{n=1}^{20} x_n{}^2 - (\sum_{n=1}^{20} x_n)^2} \tag{7}$$

where Y is a regression line, a is a gradient, b is a regression constanta, and X is an independent variable. We can use (7) to calculate the values of a and b where N is the amount of data.

We use the linear regression model as in equation (6) to determine the distance between the target and the anchor. The illustration of the estimated results is shown in Fig. 2, where the straight line Y is the estimated distance between the target and the anchor and we need RSS as the predictor variable (X). Before we did the distance modeling, we did the initial measurements according to Fig. 3 where the target is a transmitter while the anchor is the receiver. The transmitter and receiver devices are shown in Fig. 4, the transmitter device is a beacon card meanwhile the receiver device is an ESP32 module.

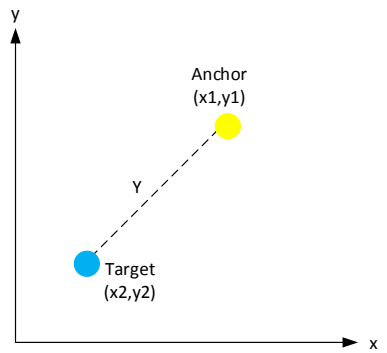


Fig. 2. Distance between anchor and target

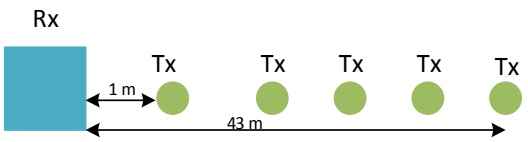
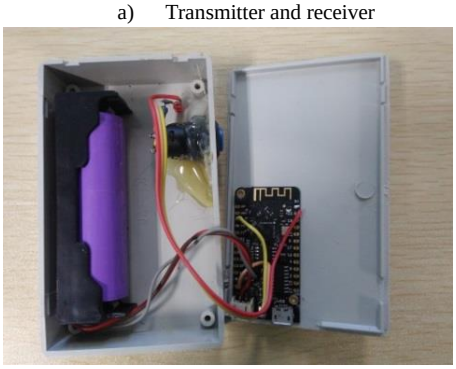


Fig. 3. Distance measurement based on RSSI

The goal of initial measurement is to obtain the RSS data at a certain distance so that the values of a and b can be determined. The data from initial measurements are used as a reference between the original distance to signal strength. The initial measurement was done by the transmitter device move backward at a certain distance until 43 meters which we get the average of RSS in every distance ($\overline{rss}$).

a) Transmitter and receiver



b) ESP 32 module as receiver

Fig. 4. The device in our system

Based on intial measurement in Fig. 3, we can calculate the a and b coefficient based on (9) and we got the a is -57,08 and b is -0,9096. So that the distance model would be as in (8).

$$\widetilde{d_{ji}} = -57{,}08 + (-0{,}9096\ x\ \overline{rss}) \tag{8}$$

where $\widetilde{d_{ji}}$ is distance measured and $\overline{rss}$ is an average of signal streght between anchor i and target j. We did a fitting distance by using linear regression based on measurement and it is shown in Fig. 5.

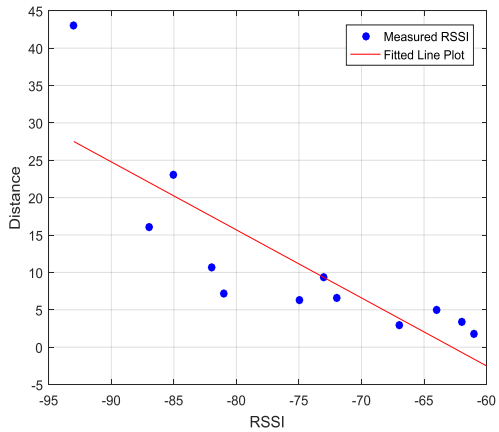


Fig. 5. Fitting distance based on linear regression

B. Combination of Anchor Set

The set anchor combination is proposed because the target can not be estimated by the closest anchor but by a mathematical combination as in (9), which m is number of anchors that read signal strength of target and s is the requirement anchor.

$$C_s^m = \frac{m!}{(m-s)!s!} \tag{9}$$

In our cases, we need 3 anchors in every set because we use a trilateration to estimate the position. So that there will be several choices of position estimates to improve the accuracy of its position which has been done in research [2]. The final estimate is obtained by taking the centroid from some of the proposed combinations.

C. Combined Method of Trilaterateration and GDOP

In our previous study [7], we did a combination method of trilateration and GDOP. In every combination anchor, we do a 20 measurement of every 3 anchors so that we get 20 estimations from trilateration algorithm. To choose the estimation which has a small error, we tried to use GDOP method. The smallest GDOP shows the best estimation that has a small error. GDOP is calculated based on (1). Our proposed method is shown in Algorithm 1.

Algorithm 1 : Positioning based on minimum GDOP

1.**Initialization** : set anchor (C_i) where i=1...,T, n=1...,20 where n is number of measurement

2.**Iteration** : Estimate the position using trilateration for every set anchor (X_n,Y_n).

3.**Minimum of GDOP** : Check the value of GDOP for multiply position estimation.

4.**Estimate location** : Check the index of n which is related

to step 3.
5.**Output** : $(\widehat{X_i}, \widehat{Y_i})$, the position estimation of target for every anchor set.

D. Weighted GDOP

This weighted method is implemented in a combination of set anchors. In the matrix W at (4), we need a trilateration centroid value of 20 estimated positions without combining the GDOP method, the distance between the anchor and the estimation of trilateration centroids (b_{ji}), and the distance between the anchor and the estimated trilateration-GDOP combination (r_{ji}). So that the contents of the diagonal W are as in (11).

$$Ed_{ji} = \sqrt{(\widetilde{d_{ji}} - r_{ji})^2 + (\widetilde{d_{ji}} - b_{ji})^2} \quad (10)$$

$$W_{ji} = (r_{ji} - b_{ji})/Ed_{ji} \quad (11)$$

where Ed_{jI} is an MSE (mean square error) between measured distance and distance from anchor to estimated position both in centroid trilateration and combined trilateration-GDOP. The size of matrix is 3x3 because the maximal anchor number that we use is 3 for trilateration algorithm. Next the W matrix is used to calculate the WGDOP value using (5).

We calculate the final location estimate using the WGDOP inverse as the weight of each initial estimate and combine it as in the pseudocode shown in Algorithm 2.

Algorithm 2 : Positioning based on Weighted GDOP

1.**Initialization** : set anchor (C_i) where i=1...,T, n=1...,20 where n is number of measurement
2.**Iteration** : Estimate the position using trilateration for every set anchor (X_n,Y_n).
3.**Minimum of GDOP** : Check the value of GDOP for multiply position estimation.
4.**Estimate location** : Check the index of n which is related to step 3.
5.**Temporary Location** : $(\widehat{X_i}, \widehat{Y_i})$, the position estimation of target for every set anchor.
6. **Weight of temporary location** : Check the W value using (11)
7. **Estimate Final location** : $\sum_{i=1}^{T} \frac{(\widehat{X_i}, \widehat{Y_i})}{W(C_i)} / \sum_{i=1}^{T} \frac{1}{W(C_i)}$
8.**Output** : (X_w, Y_w)

IV. Performance Evaluation

A. Experimental Setup

In this study we did the experiment in the Pascasarjana PENS at 4th floor building in appendix 1, and the map of building is shown in Fig. 6. We did the experiment in hall area where it is divided into 3 areas, hall A, hall B and hall C. We spread out 7 anchors in hall A, 2 anchors in hall B, and 2 anchors in hall C. The anchor node was mounted at a 2 meters height and the target was placed at a 1 meter height, it is shown in Fig. 7. The anchor node distribution was shown in a green triangle in Fig. 6. The location was divided into grids with 60 cm away each other. The test location only in the hall. Table I shows the simulation parameters used in this experiment.

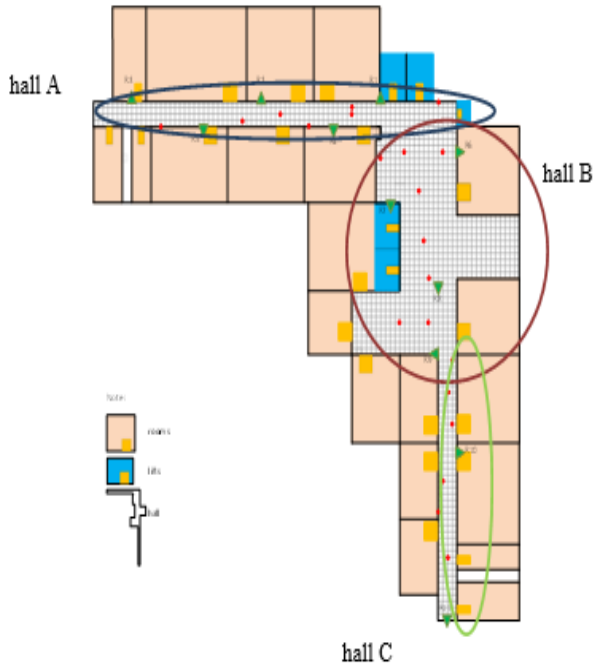


Fig. 6. The observation area

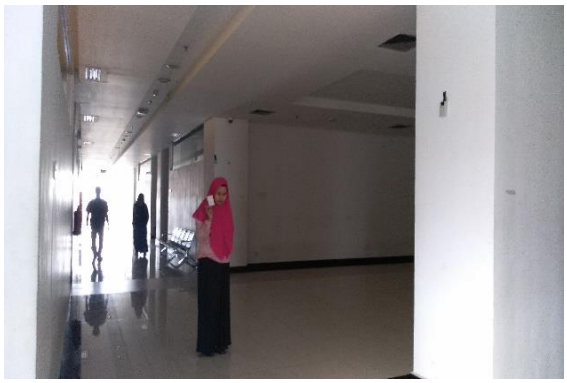


Fig. 7. Placement of anchor and target in hall B

TABLE I: SIMULATION PARAMETER

No	Parameter	Remark
1.	Number of anchor nodes	11
2.	Number of target nodes	1
3.	Size of area observation	7.2 m x 11.4 m
4.	Power transmit	-59 dBm
5.	Path loss environment	1,35

B. Evaluation of Distance Measurement

The signal strength characteristics of the distance have a normal log model, but in this study the distance measured was limited only 50 meters. So that we expected that the characteristics of signal strength vs distance are linier. For that reason, we use linear regression modeling to get distance estimation, and evaluate the results of estimation based on regression modeling with original distance at the initial measurement in Fig. 3.

We assume that when the distance gets farther away, the RSS value gets weaker. Fig. 8 shows a comparison of distance estimation results. The blue line is the result of initial measurement in the observation area, meanwhile the red line is estimated distance by using linier regression. At a certain distance such as at a distance of 16 meters the RSS value is -87 dBm while at a distance of 23 meters, the RSS value is -85 dBm. The phenomena occurs due to several factors such as multipath and fading effects so that the received signal strength is not linear as expected.

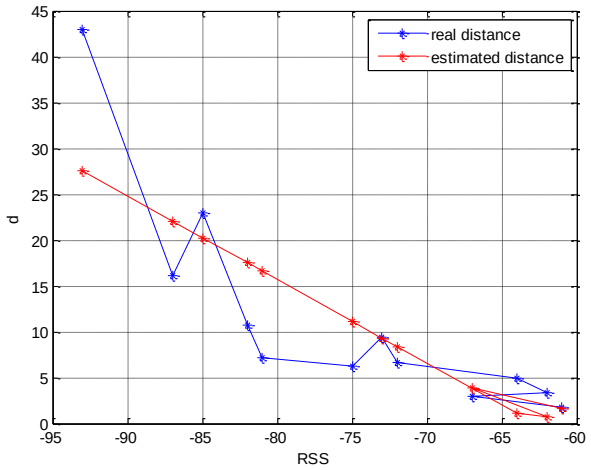


Fig. 8. The estimated distance in meter

Furthermore, by using the linear regression equation, we estimate the distance based on the RSS input value. When the RSS value is between -61 dBm to -67 dBm, the distance estimation still has fluctuating values, while for RSS values exceeding -67 dBm, the estimated distance value becomes linear. Although distance vs RSS has become linear, there are errors between estimates and real values. The error is 49%. Because the distance is not accurate, it can cause the enhancement of error position.

C. *Evaluation of Preliminary Centroid Trilatration Based on Number of Measurement*

When we did the experiment, the amount of signal strength received in each measurement is different in each test so that we make an observations on the effect of the number of measurements on the estimated error using the centroid trilateration method. The maximum number of measurements is 20 measurements for each anchor at each test location. The results of the centroid trilateration are the average of the n measurements. We divided the observation into n measurements, there are 5,10,15,10, and 20. For each test, we calculate the average value of its estimated position and the estimated error of its original position.

Fig. 9 shows the test results, we observe that when the number of measurements is n = 5, the probability of errors in estimating their position is 0.24. In the trilateration centroid method, it still has disadvantages because there is an estimated position in the n measurement which has large error so that when the average value is calculated, the error value is also large. When the number of measurements (n) is increased, the position error of the centroid trilateration also increasing the error of position estimation. So this trilateration centroid method still has weaknesses. Then the position estimation process is added by the GDOP method to improve its accuracy.

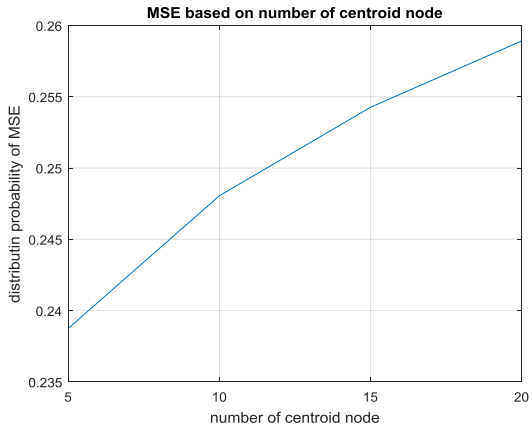


Fig. 9. MSE of preliminary centroid trilateration

D. *Evaluation of Increasing in Number of Visiting Location*

The number of test locations visited by the target determines the error of the system so that in this experiment, we evaluate the number of test site visits to the error in estimating their position. In this test we compared 2 methods, namely the centroid trilateration method and the trilateration-GDOP combination method with 20 test locations visited.

In the trilateration- GDOP method, we use an anchor set that reads the strongest target signal. First we have to sort the anchor that reads the strongest RSS. Next, we take the 3 RSS as a reference in choosing a reader to calculate the trilateration method. Each of our location points has 20 measurements so that 20 estimated position will be produced by trilateration. We try to take the centroid value and choose the estimate position using the GDOP method according to (2).

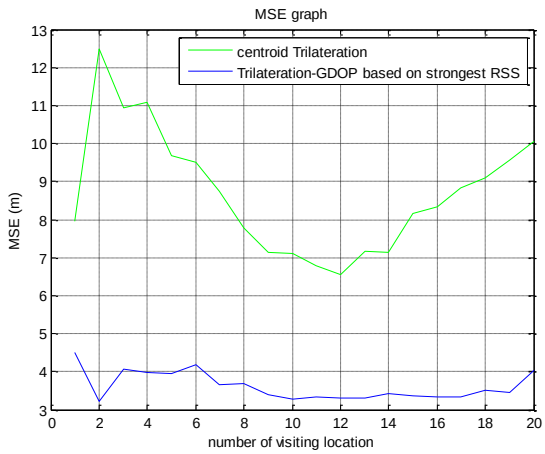


Fig. 10. MSE graph of trilateration-GDOP and centroid-trilateration

In Fig. 10, the x axis is the number of nodes visited by the target while the y axis is the estimated error in meters. The green line is the result of the centroid-trilateration method while the blue line is the result of the trilateration method and GDOP. The centroid trilateration in location visit 6 to 14 has decreased error, because location is quite large and has minimal obstacle so that multipath and fading effects can be minimized. But at the next location, there is still an increase in errors. The biggest errors occurs when the target visit in the second location, the error is up to 13 meters. Trilateration Centroid has a fairly large error value, because the estimation results show an average value of several estimates which the probably estimate positions have large errors so that it influence the average of error. We observe that estimates by using the combined GDOP method can reduce estimation errors up to 60% better than centroid trilateration. So that from 20 possible estimates, position estimation is chosen which has a good geometry of the three anchors. There are many obstacles at that location such as in locations 6 to 14, but there is a possibility in n measurement which the result close to the real position.

Based on data in Fig. 10, we make a probability of error for 2 methods. We divided the data into some classes. Every class has a range error in meter. In trilateration-GDOP method, we devided class into 5, they are 2.8 m – 3.1 m, 3.2 m – 3.5 m, 3.6 m- 3.9 m, 4 m – 4.3 m, and 4.4 m – 4.7 m. Meanwhile in centroid trilateration method, we devided the class into 6 classes. They are 5,5 m – 6,5 m, 6.6 m – 7.6 m, 7.7 m – 8.7 m, 8.8 m- 9,8 m, 9.9 m – 10.9 m, and 11 m – 12 m. The probability of error is shown in Fig. 11. The x axis is a range error in meter and the y axis is the probability. In the trilateration-GDOP method, the most error occurs in range 3,2 m – 3,5 m. In centroid trilateration, the most error is appear in range 7,7 m – 8,7 m.

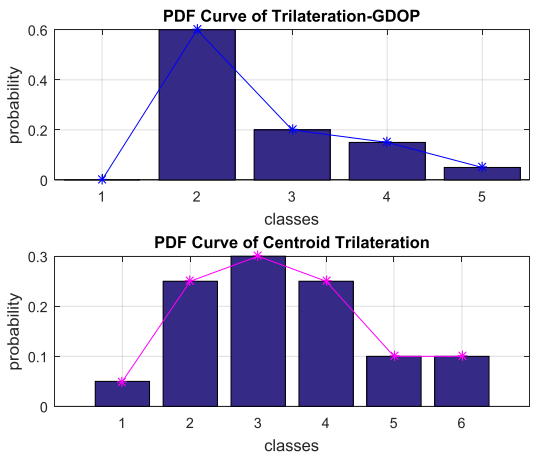


Fig. 11. PDF of error for trilateration-GDOP vs centroid trilateration

E. Evaluation of Combination Set Anchor using Trilateration-GDOP

When we use the trilateration-GDOP method, the estimation error can be reduced but the condition only uses the anchor set which reads the strongest signal. We assume that other anchor combinations can affect accuracy in position estimation. So we investigated the possible set of anchors that can estimate targets using (9). Each estimated result in all combinations will be averaged. This test is based on algorithm 1, and the results are shown in Fig. 12. The x axis is the number of points visited while the y axis is MSE in meters. The blue line is the method based on strongest RSS meanwhile the magenta line is the method based on combining set anchor using (9).

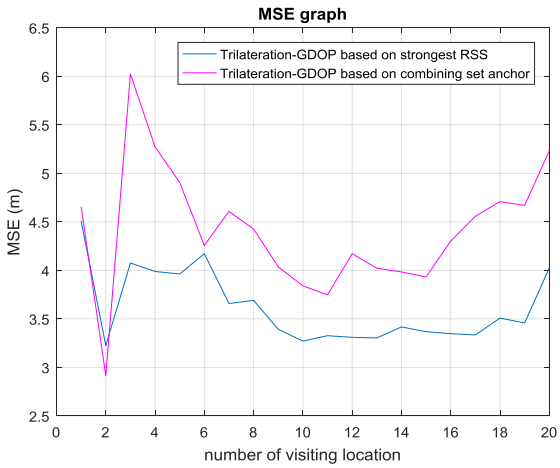


Fig. 12. MSE graph of Combination Set Anchor using Trilateration-GDOP

The blue line shows a lower error compared to centroid-trilateration in the strongest anchor RSS set. When target visits in the second location, The errors decreases up to 3 meters. The results of a set anchor combination can make large errors in several locations, due to geometric effects, and obstacles. So that the signal strength which is read by some anchors has an impairment. But when it compared with the strongest RSS combination method, the average estimation error is greater.

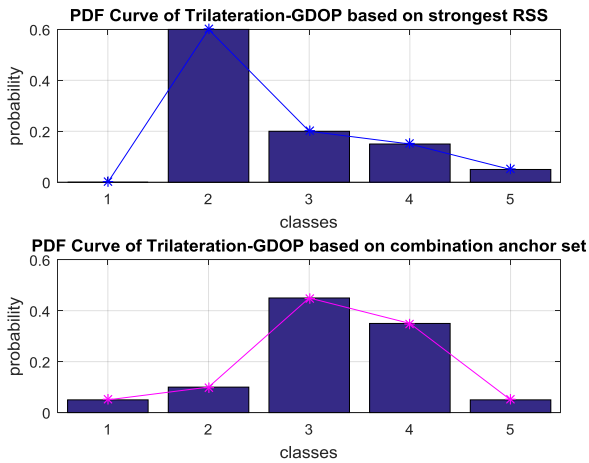


Fig. 13. PDF of error for trilateration-GDOP based on strongest RSS vs combination of anchor set

Based on data in Fig. 12, we make a probability of error for 2 methods. We divided the data into some classes. Every class has a range error in meter. Both in

two methods, we devided class into 5. The classes in strongest RSS set anchor are 2.8 m – 3.1 m, 3.2 m – 3.5 m, 3.6 m- 3.9 m, 4 m – 4.3 m, and 4.4 m – 4.7 m.. The classes in combination anchor set are 2,5 m – 3,1 m, 3,2 m – 3,8 m, 3,9 m- 4,5 m, 4,6 m – 5,2 m, and 5,3 m – 6,9 m. The probability of error is shown in Fig. 13. The x asis is a range error in meter and the y axis is the probability. In combination anchor set, the most error occur in range 3,9 m- 4,5 m. The probability of combining set anchor method is greater than a method by using strongest RSS anchor set. The proposed combination of anchor still produces a large position estimation error so that this method is further improved using weighting additions on the GDOP matrix, and the results are used to weight the previous estimates position.

F. Evaluation of Weighted GDOP for Combnation Set Anchor

Based on algorithm 2, we evaluate the performance of the weighting given for each estimate using GDOP. This weighting aims to reduce noise between the measurement distance and the estimation of the target. We take the estimated sample at the point x = 22, y = 7 (15th visit location), the average error is at 4 meters. At that point, the set of anchors that are formed is as many as 3 (C = 3), each set of anchors has an estimated position and will be given a weighting value based on (10). Furthermore, the last estimate is calculated as in algorithm 2 which use an average inverse $\frac{1}{W(C_i)}$ for each position estimate in all combinations of anchor sets.

The estimation results will be calculated the MSE value and shown in Fig. 14, the performance results of the WGDOP for the set anchor combination scenario. The x axis represents the number of locations visited by the target while the y axis is the estimated error in meters.

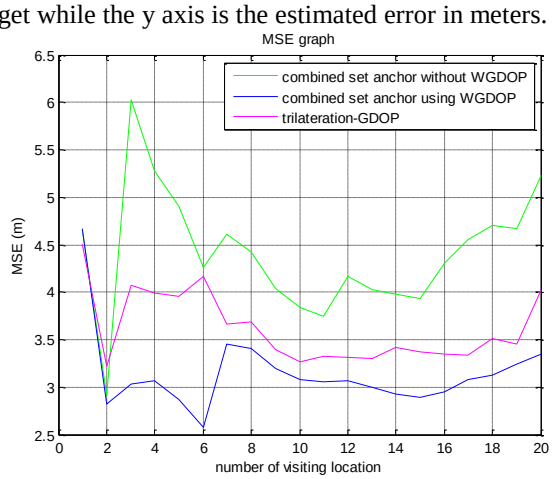


Fig. 14. MSE graph of WGDOP method

The blue line is the result of a combination method without weighted while the magenta line is the result of a combination method using weighted. At the first location, the work of weight is still not optimal. But when the target moves to 2nd location to 20th location, errors of estimation by using weighted are smaller than without weighted. The biggest error is 4,7 meters. By using the W matrix from (6), the weighted value can reduce the estimation error and increase its accuracy by 40% better than the method without weight. If we compared to the trilateration-GDOP, the weighted in combining set anchor has a lower error.

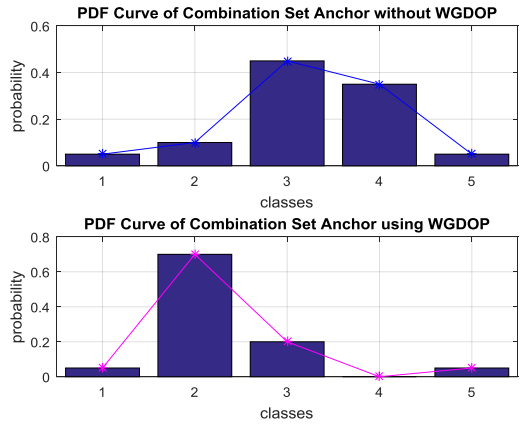


Fig. 15. PDF of error for combination anchor without WGDOP vs using WGDOP

Then we make a probability of error for 2 methods. We divided the data into some classes. Every class has a range error in meter. Both in two methods, we devided class into 5. The classes in method without WGDOP are 2,5 m – 3,1 m, 3,2 m – 3,8 m, 3,9 m- 4,5 m, 4,6 m – 5,2 m, and 5,3 m – 6,9 m. The classes in method using WGDOP are 2,2 m – 2,6 m, 2,7 m – 3,1 m, 3,2 m - 3,6 m, 3,7 m – 4,1 m, and 4,2 m – 4,6 m. The probability of error is shown in Fig.15. The x axis is a range error in meter and the y axis is the probability. In WGDOP method, the most error occurs in range 2,7 m – 3,1 m. The probability is lower than probability without GDOP.

G. Summarize of Four Methods Proposed

In this section, we summarize the proposed method for estimating the position in our system. Fig. 16 shows the results of the plot between the anchor and the real position meanwhile Fig. 17 shows the summarize of position estimation by using 4 methods.

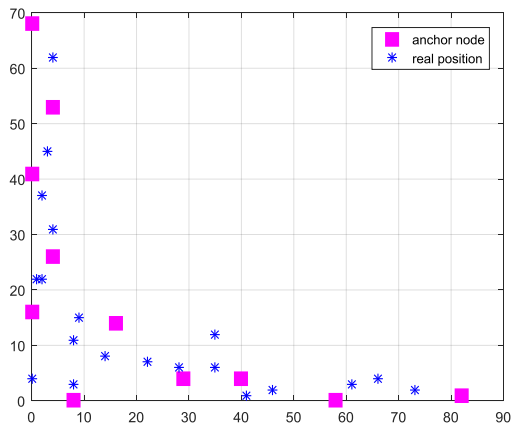


Fig. 16. Plot of deployment node

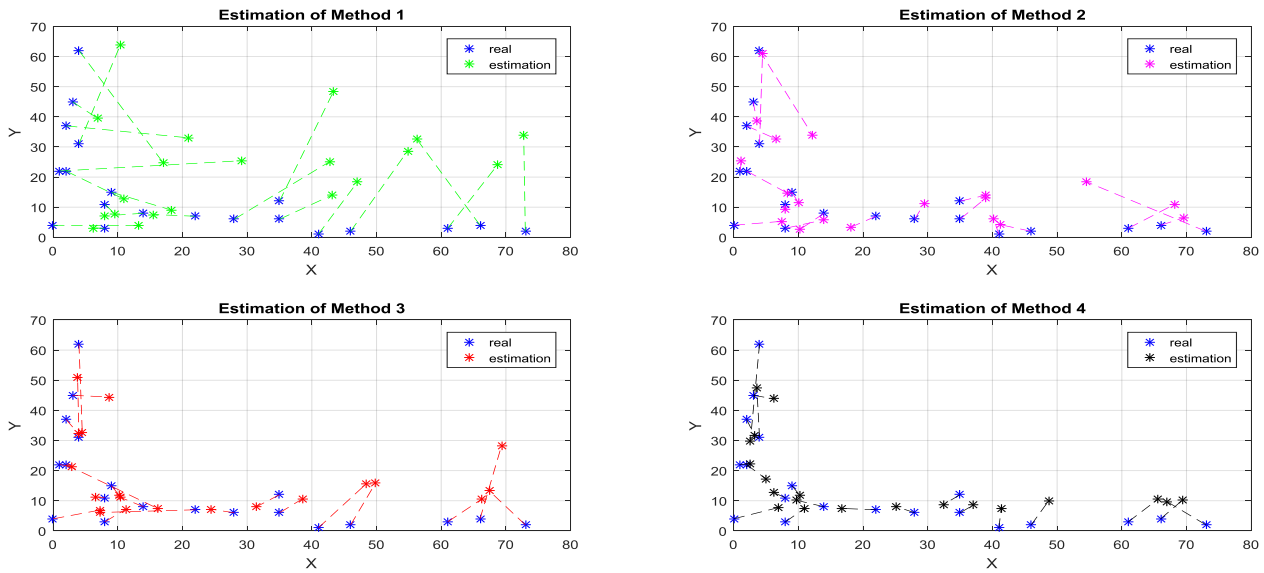


Fig. 17. Estimation of 4 methods

We show the distance between the real position and the estimated position. The method 1 is centroid tilateration, the method 2 is trilateration-GDOP using 3 strongest RSS which did in previous study [23], the method 3 is trilateration-GDOP based on combining set anchor, and the method 4 is weighted-GDOP for combining set anchor.

In Fig. 17, it can be seen that the method 4 close to the real position because it has the smallest distance from real position to the estimated position. So that on this system, the W matrix can increase the accuracy of its position in combining set anchor cases. The test results from the four methods are summarized in Table II.

TABLE II: SUMMARY OF PROPOSED METHOD

No	Method	Average of MSE (m)
1	Centroid trilateration	10
2.	Trilateraion GDOP using 3 strongest RSS	4
3.	Trilateration GDOP based on combining set anchor	5.3
4.	Weighted GDOP for combining set anchor	3

V. CONCLUSION

In the centroid trilateration method, when the amount of data for the centroid is added, the estimated error also increases by 8%. So that improvement techniques are needed such as GDOP to select estimates that have the best geometry on the anchor. The GDOP technique is able to reduce errors by 59% compared to the trilateration centroid technique. We also evaluated that the performance of the estimates in all combinations still gets errors compared to the strongest RSS anchor combination. So we add weight to the combination anchor set By adding weight, the average error estimate can be reduced by 40% compared to before. And when compared with the trilateration-GDOP method for the strongest set of anchor RSS, the result is an increase in accuracy of 17%. So that the WGDOP method can improve accuracy in target positioning techniques.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Prima and Afifah made design for the localization algorithms. Amang designed the communication between transmitter to receiver. All author responsible for writing the paper and had approved the final manuscript.

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