Distributed localization using normalized quad lateration in LoRa networks: application for tourist position estimation

Musayyanah[1], Prima Kristalina[2], Yosefine Triwidayastuti[1], Pauladie Susanto[1], Mochammad Zen Samsono Hadi[2]
[1]Department of Computer Engineering, Faculty of Technology and Informatics, Universitas Dinamika, Surabaya, Indonesia
[2]Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya (PENS), Surabaya, Indonesia

Article Info

Article history:

Received Jun 20, 2022
Revised Oct 15, 2022
Accepted Oct 24, 2022

Keywords:

LoRa
Mean square error
Normalization
Quadlateration
Received signal strength indicator
Tourist
Wireless sensor network

ABSTRACT

The tourism sector has been growing rapidly along with the decline of COVID-19. This sector should pay attention to safety and security, which is by tracking the position of tourists. In this work, we propose a tourist positioning tracking system. A node containing a microcontroller with LoRa wireless communication called unknown node (UN) is assembled as a wearable device. We use the received signal strength indicator (RSSI)-based localization technique with an additional normalization method to correct the error rate in position estimation. This method estimates the distance between the anchor node (AN) and UN to approximate the actual distance value. Three-dimensional position tracking (longitude, latitude, altitude) of five UN surrounded by four AN was performed using the quadlateration method. The estimation process was carried out by the UN whereas receiving information is transmitted from the four AN. The communication between AN and UN used a scheduling algorithm on all AN. The position estimation error of the five UNs was measured using mean square error (MSE) yields 20.73 m, 50.32 m, 32.92 m, 21.40 m, and 16.89 m respectively. The accuracy of the estimated distance obtained by the proposed normalization quadlateration method is increased up to 15.22%.

Corresponding Author:

Prima Kristalina
Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya (PENS)
Surabaya, Indonesia
Email: prima@pens.ac.id

1. INTRODUCTION

Advances in technology and wireless sensor network (WSN) have attracted the attention of many researchers because of their ease of application in many fields such as monitoring pollution conditions, forest fires, parking lots, tracking patients and livestock [1]-[3]. WSN is a wireless network infrastructure consisting of sensor nodes distributed in such area, energy-efficient, and can forward information to the base station [4]. The information carried by the signal on WSN infrastructure can travel long distances with various algorithms and methods according to their application. In this article, the existence of signal on WSN could be used to determine the position of tourists in the tourist areas.

Currently, the tourism industry in Indonesia is trying to develop tourism areas and prioritize the safety and security of visitors. It aims to expand job opportunities, improve human living standards, and increase regional income. In addition, the World Tourism Organization (UNWTO) stated that the tourism industry must pay attention to the safety and security of tourist visitors, especially in prohibited areas [5]. For example, areas with dangerous electrical installations, plant nurseries in urban farming areas, forest areas, and mountainous areas.

A study on tracking tourist positions has been carried out by [6] applying bluetooth low energy. However, the range of bluetooth communication is short, and it is not suitable to implement it in the large area. Instead, a long-distance communication system is needed. Meanwhile, conducted studies on position tracking utilizing global positioning system (GPS) technology with applications connected to the database server [7]-[9]. GPS technology utilizes large resources and is not suitable to be implemented with WSN. Therefore, smaller resources that can reach long distances are needed, such as long range (LoRa).

Tourist position tracking on WSN can be performed with localization. Localization determines the position of the node device based on information from other known node devices [10]. A node with an unknown position is called an unknown node or tourist node, while a node with a known position is called a reference node or anchor node. According to Chowdhury *et al.* [11], localization is divided into several parts, namely based on data processing method (distribution or centralization), transmission range (range free or range-based), node mobility (static or mobile), observation environment (outdoor or indoor), density nodes (sparse or dense), routing, and algorithms. The application of the localization category is based on the scenario used. In this article, localization is used based on data processing, namely distribution, and based on the observation environment, namely outdoor localization.

In general, position estimation in localization uses Trilateration and Multilateration. Trilateration estimates the position of a node (longitude and latitude) with three anchor nodes [12], [13]. If the position is detected in three dimensions, namely longitude, latitude, and altitude, then localization with Multilateration is used as in [14], [15]. The tourist area environment has uneven contours, so tracking is carried out in 3 dimensions called quadlateration, where quad represents the four reference nodes used. Quadlateration uses low computing power with many reference nodes [16]. Outdoor localization still requires GPS technology for position tracking. GPS is considered easier to implement and has an accuracy of up to five meters. However, GPS consumes a lot of energy, making it more expensive to use, especially for deployments with a larger number of nodes. Therefore in this article, GPS was only used on the anchor node [17].

Outdoor localization requires a transmission medium capable of reaching long distances, such as in LoRa [18]. There are some techniques for localization using LoRa that have been performed before, namely received signal strength indicators (RSSI), Fingerprints, angle of arrival (AoA), and time difference of arrivals (TDoA). In AoA, TDoA and Fingerprint required advanced hardware specifications to achieve high accuracy [12]-[14]. Unlike the RSSI technique which does not require a lot of hardware and is only based on radio signal transmission, Fingerprints can predict the number of obstacles, but this technique requires a radio map that must be updated regularly [19]. The distance error on TDoA is reached 925 m so it takes time synchronization from the gateway to achieve high accuracy values [20]. The RSSI technique with linear least square (LLS) has been applied in [21], but LLS is considered unsuitable in high-noise or outdoor environments. In Savazzi *et al.* [22] RSSI was also used with 500m localization. Based on the results of previous studies, there is a need for innovations with additional methods to minimize position estimation errors.

This study will conduct a distributed localization in RSSI-based outdoor environment by adding the normalization process. Normalization is considered to reduce the level of position estimation error in outdoor localization, due to the utilization of actual distance deviation to an average the estimated distance parameter. The deviation is a constant or an identical value for each unknown node (UN) with anchor node (AN). The estimated position is calculated after the position data and RSSI from the AN is obtained. Then, the distances between UN and ANs are calculated to be estimated using normalization. The results of normalization are used to estimate the position of the unknown node. The estimation error is evaluated using the squared error (MSE). Localization begins when the tourist node receives information from the four reference nodes. The estimated position on the tourist node is calculated using an arduino due microcontroller with a 32-bit ARM processor, so that decimal data processing becomes more precise.

The contributions of this paper can be listed as follows:

a) This paper presents the formulation of quadlateration localization in detail with the addition of new method called normalization. The normalization method will assist the quadlateration localization to decrease the error rate in node position estimation.
b) This paper proposed an estimated node position system in distributed localization based on LoRa in the outdoor environment. LoRa is one of the low-power communication, which provides the long-distance communication. In Indonesia, LoRa works on the 920 Mhz frequency. This module is sufficient to utilize in outdoor environment without any repeater, so the loss of signal power from Transmitter to receiver could be decreased.
c) This paper utilizes arduino due for quadlateration computing to achieve the highly accurate localization. Furthermore, Arduino due has a 32-bit ARM processor that assists the process of calculating quadlateration from the GPS position data.
d) This paper presents the node circuit design and the inter-node scheduling algorithms. The AN circuit consists of due, GPS, and LoRa. Then, the communication of each UN with four ANs is managed by a scheduling algorithm that determines the time of transmitting packets from each AN.

This paper organized as follows. In section 1, introduction is presented. Section 2 explains the proposed methods starting from hardware design, node position scenarios, exponent path loss, normalization, scheduling algorithm, and quadlateration. Section 3 describes the results and discussion. Section 4 is the conclusion.

2. PROPOSED METHOD

This section describes the design of hardware representing a tourist node, positioning of AN and UN in tourism areas, measuring path loss exponents, normalization process, scheduling algorithms on distributed anchor nodes in tourist areas, estimating the position of visitor nodes with quadlateration, and calculating position estimation error with mean MSE. In MSE calculation compares actual position with garmin GPS readings.

2.1. Hardware design and node position scenarios

In this study, the hardware used was four anchor nodes and five unknown nodes. Each node had arduino due microcontroller and LoRa module. Meanwhile, the anchor node had a 6m Ublox Neo GPS component. This GPS is considered quite good at detecting longitude and latitude [23]. Arduino due has many serial connections for the input and output pins required by GPS and LoRa. Arduino due is also capable of storing and processing GPS data of more than 9 decimal digits to produce more precise position estimates. The wireless communication medium used to transmit GPS was LoRa data of the Hope RFM9x, an end device type at a frequency of 920 MHz with a dipole antenna. LoRa has a long-range, low power, and is suitable to be applied in outdoor environments [23]. The node layout and positioning scenario are shown in Figure 1. The node circuit was composed of Arduino Due to receiving the position of the node measured by the GPS module. The information about the node position and the signal strength was sent to the server by LoRA module. The layout of each component in the print circuit board is illustrated in Figure 1(a). Meanwhile, the map of the experiment location in the front yard of Al Akbar Surabaya Mosque is depicted in Figure 1(b).

(a) (b)

Figure 1. Node layout and positioning scenario with (a) the node circuit layout completed with arduino due, LoRA module, and GPS module and (b) the nodes positioning in front of Al Akbar Surabaya Mosque

Al Akbar Surabaya Mosque is one of the religious tourism areas in Surabaya City, Indonesia with an area of about 127x147 m^2. Around the mosque, there is a parking lot for cars and motorbikes as well as a special gazebo for visitors. The first anchor node (A1) was placed on the north balcony of the mosque, the second anchor node (A2) was placed in the car park area, the third anchor node (A3) was placed in the gazebo, and the fourth anchor node (A4) was placed on the south balcony of the mosque.

2.2. Calculation of exponent path loss

The reference power and reference distance were obtained by measuring the power between the receiver and transmitter by the line of sight (LOS). The reference power of LoRa was measured several times with a certain distance variation until the receiver could not receive the signal information from the transmitter. Then, the path loss exponent (n) was calculated by (3). The path loss exponential (PLE) is derived from the log-normal shadowing in (1) [24], [25].

$$P_{RX} = P_{TX}\ G_{TX}\ G_{RX} \left[\frac{\lambda}{4\pi d}\right]^n \quad (1)$$

$$-P_{RX} = -P_{RX_0} + 10nlog\left[\frac{d}{d_0}\right]^n + x_\sigma \quad (2)$$

P_{RX} represents the power received at the receiver in watts, P_{TX} represents the power transmitted in watts, G_{TX} represents transmitter gain, G_{RX} represents receiver gain, λ represents wavelength, d represents the distance between the receiver and transmitter, n represents the path loss exponent, and x_σ represents the Gaussian random distributed variable with zero mean and standard deviation in dB.

$$n = \left(\frac{P_{RX0} - P_{RX}}{10Log\left(\frac{d}{d_0}\right)}\right) \quad (3)$$

With a reference distance of 10 m (d_0), the reference power (P_{RX0}) was -70.4 dB, where P_{RX} is the power received and d is the distance between the receiver and transmitter. The path loss exponent was measured 20 times according to the position of 4 anchor nodes and 5 unknown nodes. Each measurement was carried out for 30 minutes to obtain the power received (P_{RX}). After obtaining the path loss exponent from the observed environment, the distance between each anchor node and unknown node was calculated by the (4).

$$\hat{d} = d_0 10^{\left(\frac{P_{RX0} - P_{RX}}{10n}\right)} \quad (4)$$

2.3. Distance estimation with normalization

In localization, the distance parameter is very important in determining the position of a node. Therefore, there is a need for additional methods so that the distance value is close to the actual distance value. RSSI-based localization systems with three-dimensional position estimation produced large errors [20]-[22]. To minimize these errors, this study added the normalization method on distance estimation in (5).

$$d_{norm_{(i,j)}} = \left(d_{cal(i,j)} - \bar{\hat{d}}_{(i,j)}\right) + \hat{d}_{(i,j)} \quad (5)$$

d_{norm} represents the normalized distance, d_{cal} represents the actual distance, $\bar{\hat{d}}_{(i,j)}$ is the average estimated distance with *i* being the anchor node index, while *j* represents the unknown node index. $\left(d_{cal(i,j)} - \bar{\hat{d}}_{(i,j)}\right)$ is the difference between the actual distance and the average estimated distance. The distance between Anchor and unknown nodes in GPS was converted into meters as in (6). Variable C is a constant of 111.32 km. The GPS variable is the degree value of longitude and latitude, while position and altitude are already in meters.

$$Position(m) = GPS\ C\ 1000 \quad (6)$$

2.4. Scheduling algorithm

This study used two types of algorithms namely the scheduling algorithm and the position estimation algorithm. The scheduling algorithm for four anchor nodes must be able to send packets to five unknown nodes, so to avoid packet collisions, it is necessary to set the delivery time of packets from each anchor node. The algorithm was designed using the timing feature of the anchor node microcontroller. The packet sent by the anchor node consists of identity, longitude, latitude, and altitude. The arrangement of packets is shown in Figure 2. A packet has a data length of 51 bytes, *i* represents the anchor node index, Lon and Lat are the longitude and latitude of the anchor node, meanwhile, alt represents the altitude, and the number between 0-50 represents the bytes index.

0	1	2	3	4	5	6-20	21
A	i	;	X	i	=	Lon	;

22	23	24	25-37	38	39	40	41	42-50
Y	i	=	Lat	;	Z	i	=	Alt

Figure 2. Packet structure

The unknown node will receive packets from all anchor nodes sequentially starting from anchor 1, anchor 2, anchor 3, and anchor 4. Unknown node will estimate its position only if packets from all anchor nodes have been received. After the packet and RSSI are received, normalization is then carried out to then estimate the position using the quadlateration equation. Algorithm 1 represents the process of Anchor's node scheduling where each anchor node will create a packet to be sent to the UN in turn. Algorithm 2 represents the node position estimation process using RSSI data and calculates it by quadlateration localization technique. The algorithm of each process is shown in Figure 3.

Algorithm 1. Anchor's Node Scheduling

```
Set Anchor Number
Set Anchor ID
Set Scheduling Interval
Get System Milis
Get N = (Milis mod(Number x
   Interval)) / Interval
If N = ID then
   Create Packet
   Send Packet
```

Algorithm 2. Node Position Estimation

```
Get Packet
Identify packet's sender
According to its sender:
   Get RSSI
   Normalize d
   Save packet
If All Packets received then
   Compute QUAD Formula to get
      Position Estimation(xest,
      yest, zest)
       Clear all packets
```

Figure 3. The algorithm of node scheduling, and node position estimation

2.5. Position estimation with quadlateration

Quadlateration is a method for estimating three-dimensional positions. Many researchers use this method, with various types of localization techniques. In Podevijn *et al.* [20], this method is used for multidimensional position estimation with the time difference of arrival localization technique with a fairly large estimation error rate. The quadlateration method requires 4 anchor nodes as a reference for sending information to unknown nodes. Unknown node is the intersection of the four circle anchor node as illustrated in Figure 4.

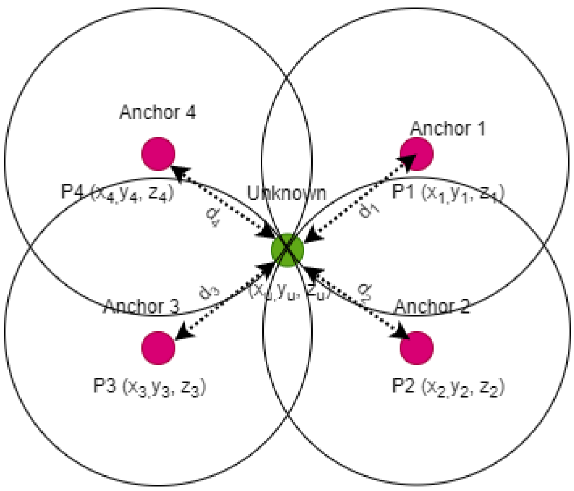

Figure 4. Localization with quadlateration

Quadlateration is calculated starting by finding the distance between the anchor node and unknown node as in (7).

$$d_i = \sqrt{(x_u - x_i)^2 + (y_u - y_i)^2 + (z_u - z_i)^2} \quad (7)$$

In (7) is a distance formula as many as the number of anchor nodes to be eliminated by linear algebra and convert into a matrix as in (8). Each matrix variable is defined in (8)-(11).

$$X = B^{-1}A \quad (8)$$

$$\boldsymbol{X} = \begin{bmatrix} x_u \\ y_u \\ z_u \end{bmatrix} \quad (9)$$

$$\boldsymbol{B} = \begin{bmatrix} 2(x_1 - x_2) & 2(y_1 - y_2) & 2(z_1 - z_2) \\ 2(x_2 - x_3) & 2(y_2 - y_3) & 2(z_2 - z_3) \\ 2(x_2 - x_4) & 2(y_2 - y_4) & 2(z_2 - z_4) \end{bmatrix} \quad (10)$$

$$\boldsymbol{A} = \begin{bmatrix} (x_1^2 - x_2^2) + (y_1^2 - y_2^2) + (z_1^2 - z_2^2) + (d_2^2 - d_1^2) \\ (x_2^2 - x_3^2) + (y_2^2 - y_3^2) + (z_2^2 - z_3^2) + (d_3^2 - d_2^2) \\ (x_2^2 - x_4^2) + (y_2^2 - y_4^2) + (z_2^2 - z_4^2) + (d_4^2 - d_2^2) \end{bmatrix} \quad (11)$$

X is a 3x1 matrix representing the estimated position of the unknown node, B is a 3x3 matrix representing the position of the anchor node, and A is a 3x1 matrix representing the position and distance between the anchor node and the unknown node. The unknown node position was calculated using MSE as in (12). MSE calculates the difference between actual positions $(x_r\ y_r, z_r)$ and estimated positions$(x_u\ y_u, z_u)$. Low MSE value indicates an accurate localization method [26], [27].

$$\text{MSE} = \sqrt{(x_r - x_u)^2 + (y_r - y_u)^2 + (z_r - z_u)^2} \quad (12)$$

The proposed system is divided into two stages, as depicted in Figure 5. The first stage is to determine the PLE and estimate the distance between anchor and unknown node as shown in Figure 5(a). The PLE was calculated using (3) followed by the normalization method of the measured distance. The normalization of position estimation was computed in the second stage, by implementing the normalized distance and the anchor position, as shown in Figure 5(b).

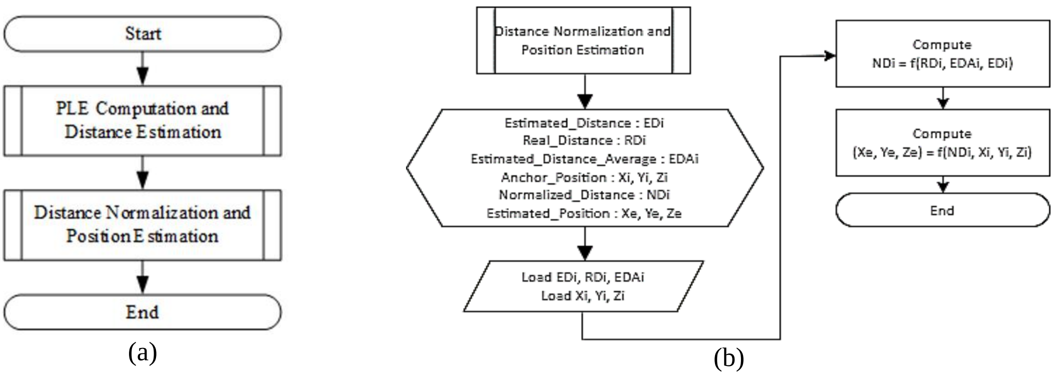

Figure 5. The flowchart of the proposed system with (a) the first stage and (b) the second stage

3. RESULTS AND DISCUSSION

This section shows the MSE value from the position estimation results and compares the estimated distance without and with normalization. Three-dimensional poition estimation from unknown node using quadlateration used distance that must be normalized first. The actual position of the 5 unknown nodes is presented in Table 1 and the estimated position is shown in Tables 2-6.

Table 1. The actual positions of unknown node

Node	Xr (m)	Yr (m)	Zr(m)
Unknown 1	547551.35	816751.93	13.50
Unknown 2	547555.47	816712.10	16.06
Unknown 3	547566.38	816702.84	14.70
Unknown 4	547558.48	816762.68	14.89
Unknown 5	547537.22	816760.40	12.78

Table 2. The estimated positions of unknown 1

Xu (m)	Yu (m)	Zu(m)	MSE (m)
547551.47	816759.58	12.06	7.78
547561.56	816761.86	17.05	14.67
547552.77	816757.15	27.39	14.91
547565.37	816756.45	26.16	19.42
547547.38	816730.64	12.67	21.68
547570.97	816759.56	5.61	22.48
547551.45	816757.03	-10.98	25.01
547554.61	816749.40	39.36	26.18
547526.80	816756.57	5.10	26.36
547533.11	816752.35	-8.85	28.85
MSE Average			20.73

Table 3. The estimated positions of unknown 2

Xu (m)	Yu (m)	Zu(m)	MSE (m)
547536.85	816748.80	-5.44	46.43
547544.14	816749.42	42.56	47.16
547532.11	816753.19	15.33	47.27
547547.13	816758.20	1.35	49.11
547540.37	816747.95	47.13	49.78
547545.49	816755.57	40.38	50.80
547537.87	816756.29	-4.06	51.65
547529.79	816756.62	1.84	53.33
547551.71	816765.07	10.72	53.37
547542.19	816761.94	-0.84	54.28
MSE Average			50.32

The position estimation was performed 30 times by calculating the average MSE. The average MSE for unknown 1 was 20.73 m, unknown 2 was 50.32 m, unknown 3 was 32.92 m, unknown 4 was 21.40 m, and unknown 5 was 16.89 m. The position estimation on localization is close to accurate if the error ≤ 10% of the observation area [4]. MSE estimation ranged from 16.89 m to 50.32 m or ≤ 10% of the observation area of 1867 m^2. Thus, this localization system can be considered accurate in determining the estimated position of a node**.**

The novelty of this study is the application of normalization for distance estimation. Normalization is the process of obtaining a certain distance value so that the value is close to the actual distance value. The actual distance between unknown node 1 and anchor node 1 is 73.75 m, denoted by $\widehat{d_1}$, with anchor node 2 or $\widehat{d_2}$ of 35.46, with anchor node 3 or $\widehat{d_3}$ of 54.61 m, and anchor node 4 or $\widehat{d_4}$ of 92.26 m. Table 7 shows the results of distance estimation before and after the normalization process.

Table 4. The estimated positions of unknown 3

Xu (m)	Yu (m)	Zu(m)	MSE (m)
547553.66	816701.86	4.83	16.13
547569.18	816716.98	1.73	19.39
547590.10	816702.36	17.17	23.85
547549.81	816690.23	2.36	24.21
547560.47	816706.40	40.35	26.57
547571.49	816714.65	37.94	26.57
547583.09	816728.95	48.31	45.73
547573.85	816747.71	20.14	45.81
547579.27	816703.84	63.03	50.03
547572.51	816748.69	35.88	50.88
MSE Average			32.92

Table 5. The estimated positions of unknown 4

Xu (m)	Yu (m)	Zu(m)	MSE (m)
547575.54	816745.57	13.57	24.20
547540.59	816745.06	-4.65	31.82
547546.48	816750.74	7.95	18.30
547552.31	816748.87	37.90	27.54
547542.34	816743.28	9.45	25.82
547551.40	816761.29	1.38	15.32
547542.04	816749.05	2.63	24.62
547533.92	816744.91	10.29	30.66
547549.14	816752.03	17.96	14.50
547559.57	816763.15	14.46	1.27
MSE Average			21.40

Table 7 shows the result of position estimation unknown node with normalization and without normalization. It could be shown that normalization overcomes better results in estimating distances in RSSI-based localization. The experiment was carried out 30 times where the estimated distance depended on the RSSI value received by the unknown node. However, the RSSI value was influenced by the experimental environmental conditions causing scattering. Scattering is an event caused by the presence of an object whose size is greater than or equal to the signal wavelength. This scattering usually occurs due to the presence of trees and tall buildings. Therefore, using normalization, the scattering data could be minimized.

Table 6. The estimated positions of unknown 5

Xu (m)	Yu (m)	Zu(m)	MSE (m)
547537.78	816762.81	3.06	10.03
547529.47	816756.37	3.67	12.61
547530.31	816751.68	19.97	13.25
547525.24	816758.61	23.25	16.01
547528.18	816759.95	-0.69	16.23
547526.06	816757.46	24.33	16.33
547522.53	816753.63	16.06	16.50
547555.92	816764.38	4.00	21.04
547552.76	816771.55	1.43	22.24
547521.50	816745.54	0.73	24.75
MSE Average			16.89

Table 7. The estimated distance with and without normalization in meters

$\widehat{d_1}$	$d_{norm(1,1)}$	$\widehat{d_2}$	$d_{norm(2,1)}$
28.90	71.30	31.94	33.68
31.94	74.34	21.40	23.14
28.90	71.30	28.90	30.64
35.30	77.70	35.30	37.05
21.40	63.80	47.67	49.42
43.13	85.53	26.15	27.89
28.90	71.30	23.65	25.40
17.52	59.91	31.94	33.68
31.94	74.34	58.24	59.98
28.90	71.30	47.67	49.42

According to the graph in Figure 6, the proposed normalization method provides preferable accuracy for outdoor localization. Moreover, the average error of distance estimation in the outdoor environment is approximately 44.17% [21], and the proposed normalization method yields an average error of 15.22%. Therefore, normalization contributes to the accuracy of about 28.95%.

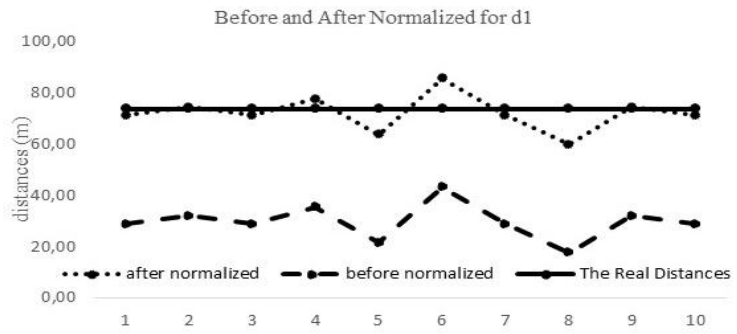

Figure 6. Effect of normalization on distance estimation

4. CONCLUSION

A distributed localization with quadlateration for three-dimensional position estimation has been proposed. By implementing the normalization method, the error accuracy of distance estimation will be decreased significantly. Based on the analysis, the position estimation results were more accurate with an average of 20.73 m, 50.32 m, for UN 1; 50.32 m for UN 2; 32.92 m for UN 3; 21.40 m for UN 4, and 16.99 m for UN 5. Without implementing the normalization method, the error of distance estimation was 44.17%, and after adding the normalization method, the error was decrease up to 15.22%. Hereinafter, the accuracy of positioning is increased up to 28.95%.

The other method to improve the accuracy of error estimation in localization technique is employing machine learning on distance estimation, for example using fuzzy logic. This method leads to the provide the selection process on variations of possible errors using the membership function. In addition, to reduce hardware costs and power consumption of a node, it is possible to use a method without GPS for the localization process.

ACKNOWLEDGEMENTS

This study was funded by the Director of Research and Community Service with letter number B/117/E3/RA.00/2020 under the Research Scheme of Inter-University Cooperation from the Indonesian Ministry of Education and Culture with a contract number 004/ST-PPM/KPJ/VII/2021.

REFERENCES

[1] A. Sudarsono, P. Kristalina, M. U. H. Al Rasyid, and R. Hermawan, "An implementation of secure data sensor transmission in wireless sensor network for monitoring environmental health," *Proceeding - 2015 Int. Conf. Comput. Control. Informatics Its Appl. Emerg. Trends Era Internet Things, IC3INA 2015*, 2016, pp. 93–98, doi: 10.1109/IC3INA.2015.7377753.

[2] O. Dieng, C. Pham, and O. Thiare, "Outdoor localization and distance estimation based on dynamic rssi measurements in LoRa networks: Application to cattle rustling prevention," *Int. Conf. Wirel. Mob. Comput. Netw. Commun.*, vol. 2019-Octob, pp. 1–6, 2019, doi: 10.1109/WiMOB.2019.8923542.

[3] T. Antoine-santoni, A. Aiello, J.-S. Gualtieri, and F.-M. Manicacci, "AMBLoRa: a wireless tracking and sensor system using long range communication to monitor animal behavior," *In the Seventh International Conference on Smart Cities, Systems, Devices and Technologies*, no. July, pp. 35–40, 2018.

[4] S. Sharma and A. Kaur, "Survey on wireless sensor network, its applications and issues," *J. Phys. Conf. Ser.*, vol. 1969, no. 1, 2021, doi: 10.1088/1742-6596/1969/1/012042.

[5] J. F. Rusdi *et al.*, "A tourist tracking model by tourist bureau," *J. Phys. Conf. Ser.*, vol. 1807, no. 1, 2021, doi: 10.1088/1742-6596/1807/1/012010.

[6] F. Gonçalves, A. L. Martins, J. C. Ferreira, E. Marques, M. Andrade, and L. Mota, "Tourism guidance tracking and safety platform," *Lect. Notes Inst. Comput. Sci. Soc. Telecommun. Eng. LNICST*, vol. 310 LNICST, no. April, pp. 162–171, 2020, doi: 10.1007/978-3-030-38822-5_11.

[7] P. Beldar, P. Bansode, R. Mane, and S. Gaikwad, "Traveler Guide using GPS Related papers Traveler Guide using GPS," *Int. J. Comput. Sci. Mob. Comput.*, vol. 3, no. 2, pp. 406–409, 2014.

[8] I Ketut Gede Sudiartha, "Monitoring and Tracking Group Traveler Application Using GPS Technology," *Int. J. Adv. Trends Comput. Sci. Eng.*, vol. 10, no. 1, pp. 168–174, 2021, doi: 10.30534/ijatcse/2021/231012021.

[9] B. McKercher, N. Shoval, E. Ng, and A. Birenboim, "First and repeat visitor behaviour: GPS tracking and GIS analysis in hong kong," *Tour. Geogr.*, vol. 14, no. 1, pp. 147–161, 2012, doi: 10.1080/14616688.2011.598542.

[10] K.-H. Lam, C.-C. Cheung, and W.-C. Lee, "New RSSI-Based LoRa localization algorithms for very noisy outdoor environment," *In 2018 IEEE 42nd Annual Computer Software and Applications Conference (COMPSAC)*, vol. 2, pp. 794-799. IEEE, 2018, doi: 10.1109/COMPSAC.2018.10340.

[11] T. J. S. Chowdhury, C. Elkin, V. Devabhaktuni, D. B. Rawat, and J. Oluoch, "Advances on localization techniques for wireless sensor networks: A survey," *Comput. Networks*, vol. 110, pp. 284–305, 2016, doi: 10.1016/j.comnet.2016.10.006.

[12] A. R. Destiarti, P. Kristalina, and A. Sudarsono, "Mobile cooperative tracking with RSSI ranging in EKF algorithm for indoor wireless sensor network," *2016 Int. Conf. Knowl. Creat. Intell. Comput. KCIC 2016*, no. November, 2017, pp. 60–66, doi: 10.1109/KCIC.2016.7883626.

[13] M. E. Rusli, M. Ali, N. Jamil, and M. M. Din, "An improved indoor positioning algorithm based on RSSI-trilateration technique for internet of things (IOT)," *Proc. - 6th Int. Conf. Comput. Commun. Eng. Innov. Technol. to Serve Humanit. ICCCE 2016*, pp. 12–77, 2016, doi: 10.1109/ICCCE.2016.28.

[14] A. El Aalaoui and A. Hajraoui, "Energy efficiency of organized cluster election method in wireless sensor networks," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 18, no. 1, pp. 218–226, 2019, doi: 10.11591/ijeecs.v18.i1.pp218-226.

[15] Y. Zhang and Y. I. Wu, "Multiple sources localization by the WSN using the directions-of-arrivals classified by the genetic algorithm," *IEEE A*, vol. 7, pp. 173626–173635, 2019, doi: 10.1109/ACCESS.2019.2956825.

[16] B. Anderson, "An algebraic solution to the spectral factorization problem," *IEEE Trans. Automat. Contr.*, vol. AC-12, no. 4, pp. 410–414, 1967, doi: 10.1109/TAC.1967.1098646.

[17] A. R. Destiarti, P. Kristalina, and A. Sudarsono, "Hybrid Filter Scheme for Optimizing Indoor Mobile Cooperative Tracking System," *TELKOMNIKA Telecommun. Comput. Electron. Control*, vol. 16, no. 6, pp. 2536~2548, Dec. 2018, doi: 10.12928/telkomnika.v16i6.10162.

[18] J. Danebjer and V. Halldórsson, "A hybrid approach to GPS-Free geolocation over LoRa," pp. 1–64, 2018, Accessed: Sep. 08, 2022. [Online]. Available: https://lup.lub.lu.se/student-papers/search/publication/8962876

[19] M. Anjum, M. A. Khan, S. Ali Hassan, A. Mahmood, and M. Gidlund, "Analysis of RSSI fingerprinting in LoRa networks," *2019 15th Int. Wirel. Commun. Mob. Comput. Conf. IWCMC 2019*, pp. 1178–1183, 2019, doi: 10.1109/IWCMC.2019.8766468.

[20] N. Podevijn *et al.*, "TDoA-based outdoor positioning with tracking algorithm in a public LoRa network," *Wirel. Commun. Mob. Comput.*, vol. 2018, 2018, doi: 10.1155/2018/1864209.

[21] K.-H. Lam, C.-C. Cheung, and W.-C. Lee, "RSSI-Based LoRa localization systems for large-scale indoor and outdoor environments," *IEEE Trans. Veh. Technol.*, vol. 68, no. 12, 2019, doi: 10.1109/TVT.2019.2940272.

[22] P. Savazzi, E. Goldoni, and L. Favalli, "A wiener based RSSI localization algorithm exploitng in LoRA network," *IEEE Sens. J.*, vol. 19, no. 24, 2019, doi: 10.1109/JSEN.2019.2936764.

[23] G. C. Tawde, "Scalability in LoRaWAN gauri chandrashekhar tawde," in *Thesis, Deflt: TU Delft Electrical Engineering, Mathematics and Computer Science*, 2018.

[24] S. K. Gharghan, R. Nordin, A. M. Jawad, H. M. Jawad, and M. Ismail, "Adaptive neural fuzzy inference system for accurate localization of wireless sensor network in outdoor and indoor cycling applications," *IEEE Access*, vol. 6, pp. 38475–38489, 2018, doi: 10.1109/ACCESS.2018.2853996.

[25] A. R. Destiarti, P. Kristalina, and A. Sudarsono, "Cluster-based PLE areas for mobile cooperative localization in indoor wireless sensor network," *Proc. 2016 8th Int. Conf. Inf. Technol. Electr. Eng. Empower. Technol. Better Futur. ICITEE 2016*, 2017, doi: 10.1109/ICITEED.2016.7863241.

[26] C. Science and S. H. Thimmaiah, "A range based localization error minimization technique for wireless sensor network," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 7, no. 2, pp. 395–403, 2017, doi: 10.11591/ijeecs.v7.i2.pp395-403.

[27] M. Laaouafy, F. Lakrami, O. Labouidya, and N. Elkamoun, "An experimental evaluation of localization methods used in wireless sensor networks," vol. 25, no. 3, pp. 1518–1528, 2022, doi: 10.11591/ijeecs.v25.i3.pp1518-1528.

BIOGRAPHIES OF AUTHORS

Musayyanah obtained a bachelor's degree in telecommunications engineering Politeknik Elektronika Surabaya (PENS). She also obtained a Master of Engineering degree in 2015 from Institut Teknologi Sepuluh Nopember. Currently, she is a lecturer in the Department of Computer Engineering, Faculty of Information and Technology (FTI), Universitas Dinamika, Surabaya Indonesia researching wireless sensor networks and the internet of things. She has only some article indexed G-scholar has 15 citations with h-index of 2. She can be contacted at email: musayyanah@dinamika.ac.id.

Prima Kristalina is a lecturer and researcher in the Department of Electrical Engineering at Politeknik Elektronika Negeri Surabaya, in Surabaya, Indonesia. She is a reviewer of international reputable journals and conferences. Her research topic is related to Object Tracking and Positioning in Wireless Sensor Networks. She is active in publishing some journal articles and intellectual property rights. Her publications have reached 187 citations by 159 documents, and Scopus h-index 9. She can be contacted at email: prima@pens.ac.id.

Yosefine Triwidyastuti obtained bachelor's and master's degrees in engineering at Institut Teknologi Sepuluh Nopember. Currently, she is a lecturer in the Department of Computer Engineering, Faculty of Information and Technology (FTI), Universitas Dinamika, Surabaya Indonesia. She conducts research on wireless sensor network, automation and internet of things. She has several National and International publications. Publication on G-scholar with 59 citations and h-index of 3. She can be contacted at email: yosefine@dinamika.ac.id.

Pauladie Susanto obtained bachelor's degree at Universitas Dinamika. He obtained master's degree at Institut Teknologi Sepuluh Nopember. Currently, he is a lecturer in the Department of Computer Engineering, Faculty of Information and Technology (FTI), Universitas Dinamika, Surabaya Indonesia. He conducts research on wireless sensor network, automation and internet of things. He has several National and International publications. He has one scope-indexed publication with 9 citations. G-scholar publications of 35 citations with h-index of 3. He can be contacted at email: pauladie@dinamika.ac.id.

Mohammad Zen Samsono Hadi is a lecturer and researcher in the Department of Electrical Engineering at PENS (Politeknik Elektronika Negeri Surabaya) Surabaya, Indonesia. His research relates to the Wireless Sensor Network, and Internet of Things. He has many publications indexed on Scopus, Sinta and G-Scholar. He has 27 citations by 22 documents with Scopus h index of 3. He has 54 citations with an h-index of 4 on Google Scholar. He can be contacted at email: zenhadi@pens.ac.id.