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Improved RSSI-based path-loss model for indoor positioning and navigation in LabVIEW using trilateration

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Abstract — Indoor positioning and navigation now contribute in many applications to track and direct people inside the building. The popular trilateration technique is utilized to detect user's position through three access point of Bluetooth low energy. However, received signal from Bluetooth has insignificancy due to the noise, multipath, fading or other radio propagation. A study of received signal characteristics in specific indoor locations must be considered to predict and improve the accuracy of estimation. In this case, the adjustment of raw received signal readings is essential. we extracted linear regression model by compare between raw and analytical value of received signal power. Then, utilizing the corrected received signal, finding the best suitable path loss exponent model is required in order to minimize position estimation error. The last step is applying the additional model and the chosen path-loss on LabVIEW as a mean to visualize position and navigation system. The result yield that the new model gives lower error on 2 out of 3 access points. The corresponding path loss exponent n = 2.1 is selected to comply with the indoor environment in this case. The lowest RMSE yields 1.24 and considered as a good level of accuracy. The Navigation system worked well providing route to the desired location in the Laboratory.

Keywords – Indoor positioning, LabVIEW, trilateration, bluetooth low energy

I. INTRODUCTION

Outdoor Positioning is widely used by users as a means of knowing the position and navigation to a destination. In outdoor conditions, the position is located by utilizing the Global Positioning System (GPS). GPS is capable of pinpoint user location based on the signal strength emitted by satellites. The signal is then captured by a GPS device or smartphone. However, in indoor conditions, GPS has a limit that the location inside the building cannot be detected precisely [1].

Finding a position indoors is just as important as outdoors. Especially if we are in a public building that has many rooms and space also has minimal guidance, such as Museum [2], Hospital or Mall. Indoor positioning also serves to monitor human movement inside the building [3]. It can track the whereabouts of Alzheimer's patients linked with application in the smartphone to notify the caregiver [4]. Furthermore, the position of specific objects or valuable items that liable can be localized with indoor positioning. For example, it is necessary to track the whereabouts importance healthcare equipment due to frequent used. Another example is to ascertain the existence of valuable objects in museums thus it will not get stolen.

In the literature, there are many techniques of indoor positioning has been discussed. Namely, angle of arrival (AoA), Time of Flight (ToF), Time Difference of Arrival (TDoA) and Received Signal Strength (RSS) [5], [6]. While the most widely used method is the trilateration which is also applied for positioning by GPS. Trilateration utilizes received power from three transmitters. The transmitters that are widely used are Wireless Fidelity (Wi-Fi), Zigbee [7], and Bluetooth Low Energy (BLE). The advantages using BLE for indoor navigation system are in the term of range, accuracy, privacy, and security [8].

Generally, the indoor positioning using trilateration is applied for the localization purpose. The other objective is for navigation in the museum [2], to help people with visually impaired in buildings [6], [9], [10], navigation with sensor independently [11] and a system navigation in smartphone called ViNav [12]. Navigation is very important to provide directions for users inside the building. Both localization and navigation had been discussed in literatures with various platform and programming software. However, there are no studies for indoor positioning and navigation system using LabVIEW software as a user interface.

Although RSSI is popular to determine location, according to many researches using RSSI show that the fluctuated value of RSSI may cause distance estimation error [13], [14]. The RSSI measurement is influenced by the complex noise present in the transmitter which cause BLE to transmit a varying signal power. Additionally, the effect of environment such as electromagnetic, multipath fading and other noises is an external causes of such problem [14].

To cope up with this problems, researchers have been study to filter the RSSI before hand with Kalman filter [15], [16], linier regression smothering [13], and an alogorithm with correction factor, correction exponent for each distance between transmitter and receiver [17].

Furthermore, the obstacle in indoor environment effect loss in power by multipath fading channel, interference or other presence of radio signal, temperature and any physical object surrounding the environment [18]. Considering the adjustment for RSSI value and the appropriate path loss exponent is the best option for these causes.

Studies with trilateration technique regarding RSSI improvement and path-loss were found in the literature. There is a Journal trilateration with estimated transmit power and path-loss exponential by a novel least-squares curve fitting (LSCF) [19]. In the Journal by Jo [20] developed a method to differentiate between Line-of-sight (LOS) and Non-line-of-sight (NLOS) to increase the accuracy and minimize the localization error in the trilateration technique until less than 1.5m. The similar research was conducted by Grzechca in [21] with the same trilateration technique and RSSI path-loss model and obtain average error 2.45 m. Thus, we aimed to find the better accuracy with additional RSSI calibration method.

This study conducted an empirical and analytical result aim to find the best fit RSSI values and path-loss exponential that results in minimum error. The suitable path-loss coefficient will be employed in LabVIEW to visualize position estimation as well as navigation for user. The contribution of this paper is summarized as follows,

i. We have experimented using three Bluetooth low energy modules that specially design for Internet of Things (IoT) inside indoor environment 17 × 8 m^2.

ii. We developed the optimum linear regression function for raw RSSI to minimalize distance estimation error with trilateration technique.

iii. We analyzed an empiric model for the best fit path-loss exponential for the indoor characteristic to minimize position estimation error.

iv. We built the user interface on LabVIEW to visualize position and navigation purpose.

II. RESEARCH METHODS

Indoor positioning and navigation system using LabVIEW were conducted in several step-by-steps. The first step was the literature review. The author was able to find out about the trilateration technique, how to do programming in LabVIEW and similar research conducted by other authors.

The second step was the arrangement of location and equipment setup for the experiment as well as. The third step was calibrating received signal strength Indicator (RSSI) from BLE. Then we employed the calibrated RSSI to find the suitable path-loss model in indoor positioning. The fourth step was to design and build the indoor positioning and navigation system in LabVIEW with Trilateration. LabVIEW was capable to display the position of the user. After the program had been finished, the test and simulation were run on LabVIEW. Finally, after getting the result, the author analyzed and discussed the result.

A. Location and Equipment Setup

The location used in this experiment is Telecommunication Laboratory in Electrical Engineering Department in Universitas Islam Indonesia. Fig. 1 shows the floor plan of the Laboratory that has 17 meters and 8 meters in length and width, respectively. It consists of an L-shaped main room and 4 small rooms. Each room is partitioned with a semi-permanent bulkhead made from plywood at the bottom and glass upon it. The area is gridded by a (1 m × 1 m) distance between the points, which will later be represented on the x on horizontally and y on vertically coordinates with a scale of 1: 100. It means that each 1x1 meter in the actual condition is assumed to be 1x1 cm in LabVIEW.

Bluetooth Low Energy is symbolized by three yellow circles with cross-red in Fig. 1. The location of BLE is spread across the room to ensure that it covers every point position within the Laboratory. The strength signal emitted from BLE will affect the reception of the receiver.

The equipment used in this study is listed in Table 1. Three BLE are needed to serve as access points (AP). The BLE used in data collection namely AP1 which located on the coordinate ($x = 1$, $y = 4$), AP2 which located on (*x = 8, y = 0*), and AP3 which located on (*x = 13, y = 6*). The access point as transmitter transmits a Received Signal Strength Indicator (RSSI) and captured by the smartphone as receiver. The application in the smartphone displayed the RSSI value from the BLE inside the room.

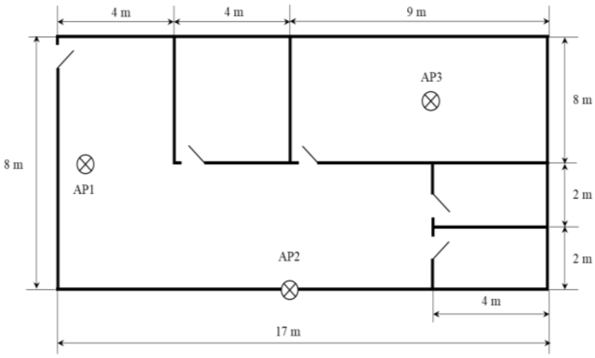

Fig. 1 The floor plan of the telecommunication laboratory

Table 1. The piece of equipment used in the research

No	Equipment	Quantity
1	BLE	3
2	Measurer	1
3	*Smartphone*	1
4	LabVIEW	1

B. Calibrated RSSI

The RSSI readings show fluctuations due to the noise which can affect the distance estimation. To minimalize the distance estimation error, we performed initial experiment for data acquisition in different distances from 1 – 20 meters away from the BLE without any obstacle in between transmitter and receiver. The measurement was done by using android applications. For each meter, we recorded 10 data, hence in total we have 200 data for each BLE.

It is a general propagation path-loss models to calculate received power RSSI using logarithmic distance path-loss model or find the distance measurement. The equation expressed in (1) is also stated as a one slope model equation for finding received power [14], [22]. Raw RSSI readings were compared to the analytical RSSI which compute from (1). Where R_{an} [dBm] is the analytical RSSI, R_0 [dBm] is RSSI at one meter distance from transmitter, d is the real distance, and n is path-loss exponent. Since there was no obstacle between the transmitter and the receiver, the condition is assumed to LOS [20], [23], thus in the calibration process we used path-loss exponential $n = 2$.

$$R_{an} = R_0 + 10n \cdot \log{(d)} \quad (1)$$

Afterwards, we determined the model for corrected RSSI with linear regression by comparing raw RSSI reading and analytical RSSI. The same method had been proposed in [13]. A linier regression model in (2) has been fitted to the acquired data. The regression model helps us to correct the raw RSSI readings, thus, yielding the corrected RSSI value, R_c, which then use it in LabVIEW.

$$R_{raw} = a + b \cdot R_c \quad (2)$$

C. Path-Loss

While transmitting in indoor environment, RSSI readings from BLE suffer loss in power due to the multipath, fading and other phenomena [Sandoval]. According to the paper, the power loss may affect the performance of estimating distance if we still consider the condition of free space. To cope with that, we need to find the suitable path-loss exponential n for NLOS in indoor environment to minimize distance estimation and position estimation error.

Determining path-loss exponent, paper in [22], Li uses Least-Square of the acquisition data to find the appropriate path-loss. While in our case, we applied empirical model based on the experiment with data tests at several reference points, to find which path-loss exponent gives the minimum localization error.

We conduct experiments by acquiring the data test from three access points in seven locations. For each coordinate, ten data of raw RSSI of each access point had been recorded. First, we took average value of raw RSSI for each location, then by using (2) the corrected RSSI for each AP is obtained. The second step was to obtain the estimated positions using trilateration with parameter n. We compared value n range between $2 \le n \le 3$ for obstructed environment in factories [24] and chose the optimized path-loss exponent based on minimum localization error on reference points.

D. Trilateration

After we had found the suitable path-loss value, we determined the estimated position by using Trilateration. Trilateration is a technique to determine the position of an object based on the simultaneous distance measurement from three access points or BLE [7], [19]–[21]. Trilateration uses the concept of trigonometry. If the object moves, its position can still be observed and calculated. Trilateration is calculated by utilizing three RSSI value, which have been corrected. Equation (3) shows how to obtain the estimated coordinate position (x', y') from the coordinate of the access point and the distance between the access point and user (d_i). Coordinate of access point denoted by (x_i, y_i), where $i = 1, 2, 3$ is the index of the access point which is known.

$$(x' - x_i)^2 + (y' - y_i)^2 = {d_i}^2 \quad (3)$$

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The distance d_i need to be calculated prior the trilateration technique by using (1) with the corrected received power, R_c. The distance can be imagined as a radius of the circle which has the center in the access point. The three circles from each access point will intersect at a point of estimated position.

The analytical study aims to find accuracies from different values of path-loss. Based on positionings error, accuracy evaluation is defined as the Eucledian distance between the real coordinate (*x, y*) and the estimated coordinates of the user's position (*x', y'*). The equation of eucledian distance, *ED*, can be found in (4). Then the whole accuracy is determined by root-mean-square-error (RMSE) in (5).

$$ED = \sqrt{(x - x')^2 + (y - y')^2} \quad (4)$$

$$RMSE = \sqrt{\frac{1}{M}\sum_{m=1}^{M}(x'_m - x_m)^2 + (y'_m - y_m)^2} \quad (5)$$

E. Programming in LabVIEW

The design of the user interface in LabVIEW is based on the floor plan in Fig.1 and trilateration techniqur in (3). There are two main programs, firstly is to determine the user's position, and secondly is to navigate the user to the desired room. The flowchart diagram of the two main programs indoor positioning and navigation system is displayed in Fig. 2 and 3, respectively.

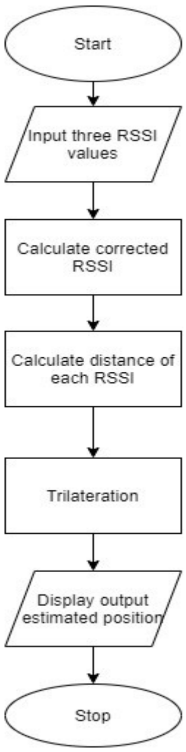


Fig. 2. Flowchart of the Indoor Positioning in Labview

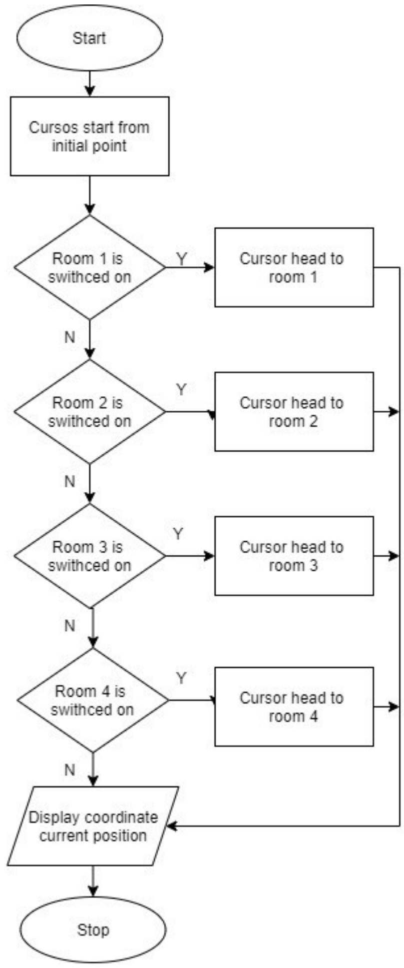


Fig. 3. Flowchart of the navigation system in Labview

Indoor positioning system requests three RSSI value from access points. It will be the main input. Then the program will be calculated the estimated position using trilateration and display the estimated coordinates in the floor plan created by LabVIEW. The navigation system created in LabVIEW has a command to select which room to be addressed. For instance, if the user wants to go to the classroom, then the selected room will be turned on and the navigation will show the route from the entrance to the classroom. The entrance on the left top of the floor plan will be the initial point for the navigation.

The simulation test in the indoor positioning system in LabVIEW generates the estimated coordinate of the user's position. At this stage, data collection from the three BLEs was carried out by positioning the user at seven location points. Then with the help of an application from a smartphone, the user records the RSSI data from the three BLE. This data collection process is carried out in a condition where there are no people. The position of BLE and the user's smartphone is at the same height, so it is assumed that the trilateration technique is only in two dimensional by considering the *x* and *y* coordinates.

III. RESULTS

A. Calibration results

Based on the calibration results, the RSSI values obtained from repeated data collection over one metre distance are -68.66 dBm, -68.5 dBm and -68.3 dBm from AP1, AP2 and AP3 respectively. These data are served as a reference R_0 for finding the analytical distance from user and each access point.

The collected data from 1 – 20 meters for each BLE is shown in table 2. For average RSSI value, we have recorded ten RSSI samples for each meter. The first thing we did is finding the linier regression from (2) by determine coefficients a and b for each access point. Equations (6-8) show the relation between R_{raw} and R_c.

$$R_{raw1} = 1.051 \cdot R_{c1} + 5.61 \quad (6)$$

$$R_{raw2} = 1.049 \cdot R_{c2} + 4.88 \quad (7)$$

$$R_{raw3} = 1.058 \cdot R_{c3} + 5.33 \quad (8)$$

To verify these equations, we compared between the distance obtained from raw RSSI readings (d_{raw}) and distance obtained from corrected RSSI (d_c). Figure (3a-c) show the comparison distance for each access point. The distance is computed from (1) by using raw RSSI readings and corrected RSSI.

Table 2. Raw RSSI readings from three BLE

Real distance (meter)	R_{raw1} [dBm]	R_{raw2} [dBm]	R_{raw3} [dBm]
1	-68.6	-68.5	-68.3
2	-73.7	-73.3	-72
3	-77.4	-77.2	-76.5
4	-80	-79.4	-79.3
5	-81.6	-81.4	-81.6
6	-80	-81	-82.9
7	-82.6	-85.2	-84.2
8	-86.2	-86	-87.3
9	-87.1	-89.1	-88
10	-88.9	-88.6	-89.5
11	-88.2	-89.8	-89.6
12	-89.4	-90	-90
13	-90.1	-90.5	-90.3
14	-90.6	-90.9	-90.9
15	-91	-91.4	-91.7
16	-91.7	-91.9	-92.3
17	-92.6	-92.8	-92.7
18	-93	-93.1	-93.1
19	-93.5	-93.1	-93.6
20	-94	-94	-93.9

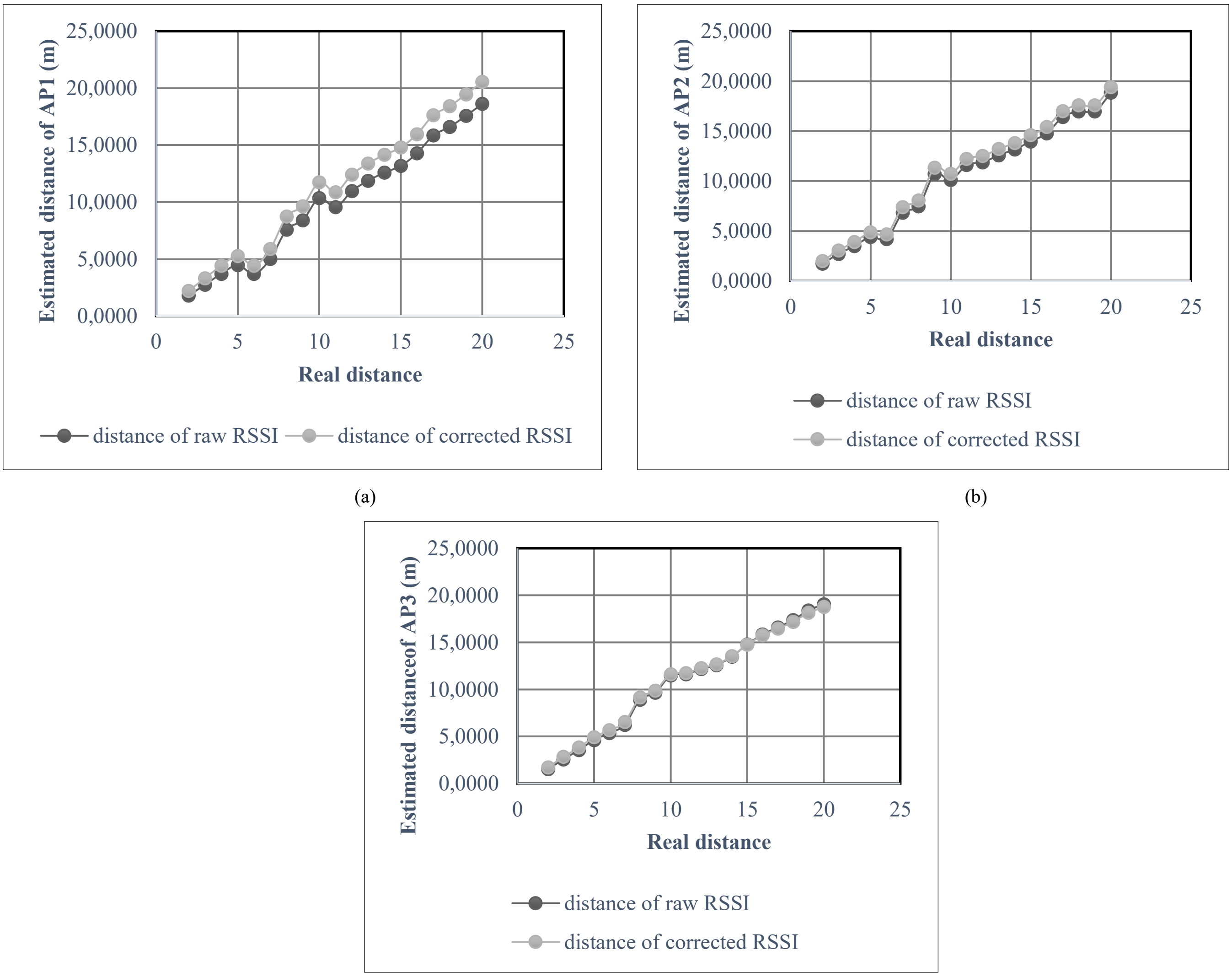
While the error distance is acquired by finding the difference between each distance and the real one. The error distances for each access point are presented in Table 3. Both of error distance of raw readings and corrected RSSI are ed_{raw} and ed_c, respectively. We can see that two out of three corrected RSSI shows lower error distance. The lowest error is 0.522 m and the highest error is 0.5444 m. Although in AP3 the error corrected distance has slightly higher than the error raw distance, but from Fig (3c), we can see that the raw distance and corrected distance yield almost the same result..

B. Path-Loss Exponential Result

We determined the suitable path-loss exponential based on data test from seven coordinates. Table 4 shows the Eucledian distance (ED) or position estimation error for each path-loss exponent values. The minimum RMSE is obtained by path-loss exponent $n = 2.1$ which is 1.24. This result proves more accurate than the study in [21] with the same purpose and trilateration technique with average error 2.45 m. Comparing the result obtained from the study of the enhance algorithm with LOS and NLOS consideration in [20], it has average error less than 1.24 m, and it considers as a good result of accuracy

Table 3. The comparison of error distance between the distance of raw RSSI and corrected RSSI.

Real Distance (meter)	Error distance of AP1		Error distance of AP2		Error distance of AP3	
	ed_{raw1}	ed_{c1}	ed_{raw2}	ed_{c2}	ed_{raw3}	ed_{c3}
1	0	0	0	0	0	0
2	0.201	0.219	0.262	0.002	0.469	0.270
3	0.246	0.330	0.277	0.071	0.430	0.177
4	0.285	0.428	0.492	0.090	0.452	0.171
5	0.533	0.277	0.584	0.130	0.376	0.082
6	2.285	1.572	1.783	1.340	0.630	0.334
7	1.988	1.112	0.161	0.389	0.763	0.474
8	0.414	0.738	0.501	0.068	0.913	1.145
9	0.586	0.645	1.715	2.337	0.661	0.869
10	0.351	1.749	0.116	0.732	1.482	1.619
11	1.450	0.119	0.614	1.242	0.614	0.746
12	1.035	0.411	0.115	0.514	0.162	0.268
13	1.115	0.401	0.411	0.220	0.411	0.325
14	1.411	0.156	0.817	0.187	0.510	0.470
15	1.817	0.209	1.036	0.407	0.209	0.239
16	1.711	0.029	1.209	0.584	0.151	0.243
17	1.151	0.627	0.594	0.016	0.404	0.542
18	1.404	0.418	1.018	0.414	0.622	0.810
19	1.421	0.456	2.018	1.414	0.592	0.848
20	1.379	0.552	1.164	0.588	0.945	1.246
Average error distance	**1.039**	**0.522**	**0.744**	**0.537**	**0.540**	**0.544**



(a) (b)

(c)

Fig. 3. Comparison between distance of raw RSSI and corrected RSSI from AP1 (a); AP2 (b); and AP3 (c).

Table 4. Accuracy of data test for each path loss-esponent

Data test	Real Coordinate Position		Eucledian Distance of each path-loss exponent (*n*)										
	x	**y**	**2**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**	**3**
1	9	6	1.93	1.54	1.37	1.34	1.39	1.46	1.53	1.60	1.66	1.71	1.76
2	6	6	0.99	0.89	0.83	0.79	0.78	0.77	0.77	0.77	0.78	0.78	0.78
3	15	3	1.41	1.24	2.88	4.10	5.00	5.67	6.19	6.60	6.92	7.17	7.38
4	1.5	3	1.90	2.64	3.29	3.80	4.19	4.50	4.74	4.94	5.09	5.22	5.33
5	4.5	3	1.71	2.14	2.45	2.69	2.87	3.02	3.13	3.23	3.30	3.37	3.42
6	7.5	3	0.37	0.88	1.27	1.57	1.80	1.99	2.14	2.26	2.37	2.45	2.52
7	10.5	3	3.19	1.42	0.15	0.80	1.51	0.00	2.47	2.81	3.08	3.30	3.48
	RMSE		**1.28**	**1.24**	**1.32**	**1.47**	**1.58**	**1.58**	**1.73**	**1.78**	**1.82**	**1.85**	**1.88**

Another Comparison of localizations error between the empirical model and Path-loss Interpolation in [22] is our model has lower RMSE than the Least-square model has minimum RMSE 2.57. Research in the same area, indoor localization with the same method using Zigbee, has RMSE 1.54 [7]. Ours is better and it was considered as fairly good level of accuracy.

Table 5 shows the estimated location with the chosen path-loss exponent $n = 2.1$. Based on the table. we get the lowest ED are 0.88 obtained from real coordinate position ($x = 7.5; y = 3$) and 0.89 obtained from real coordinate position ($x = 6; y = 6$). Both of coordinates located around the center of the room. It receives a good trade-off of RSSI from each access point. Thus, results minimum of distance estimation error. It implies that the data test has the best accuracy as well as the closest position to the real one.

The highest ED is 2.64 obtained from real coordinate position ($x = 1.5; y = 3$). It is located on the far left of the room. The position is close to AP1, the RSSI of AP1 is well received. While the coordinate is far from AP3. thus the RSSI of AP3 is poor received. This contributes to the highest distance estimation error. Hence. It implies that the data test has the worst accuracy as well as the farthest position to the real one.

Table 5. Estimated position of path-loss exponent $n = 2.1$

Data test	Real Position		Estimated position with corrected RSSI	
	x	y	x'	y'
1	9	6	8.7	4.5
2	6	6	6.6	5.4
3	15	3	13.8	3.1
4	1.5	3	2.9	5.3
5	4.5	3	5.9	4.6
6	7.5	3	7.4	3.9
7	10.5	3	11.6	2.1

C. User Interface and Navigation System using LabVIEW

The results of programming in Labview for navigation are shown in Fig. 5. The main screen displays the floor plan and the user is symbolized by "+" sign on the screen. On the right side. there is a panel that has the information about the X and Y coordinates. as well as the RSSI value of the three BLE. The switch for each room is available and it is indicated by Room 1. Room 2. Room 3. and Room 4. The Start and Stop button work for running and stopping the navigation system. The panel on the top of the main display contains information about the user's current position.

The simulation is done by turn on the switch of the room to be addressed. Then the user sign indicated by a "+" will take step-by-step and provide navigation to the room. Once it reaches the destination. the program will close. However. it could not display a line indicating the route.

Figure 4 shows the initial position of the user. where it is located at the entrance on the upper right side. While Fig. 5 shows the position after had arrived in room 2.

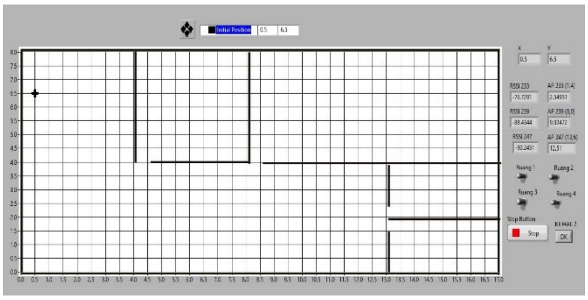


Fig. 4. Display of initial point in the navigation system

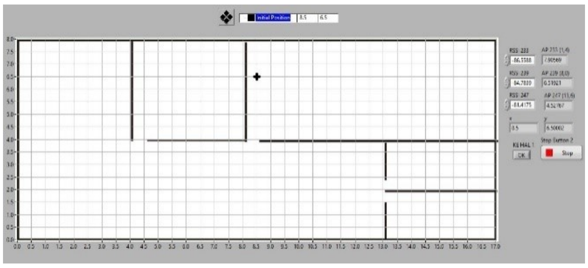


Fig. 5. Display of reached destination in the navigation system

IV. DISCUSSION

According to the table 3. the errors occur greater in between 4 – 10 meters. It is a common problem that RSSI has a disadvantage due to its fluctuated signal strength received by smartphone. Though the environment has been considered LOS and exhibit free-space properties. but the effect of connectors and antenna can caused the error [13].

In the case of our Laboratory is a NLOS environment. Based on our experiments. the path loss exponent $n = 2.1$ is the suitable value for Bluetooth which has frequency 2.45 GHz. The difference in the value of the Eucledian distance can be caused by the existence of semi-permanent wall as room dividers in the laboratory. RSSI signal undergoes reflection. refraction. diffraction. or scattering. Thus. the signal power received by the smartphone experiences attenuation and is no longer as powerful as when it is transmitted.

In the navigation system. LabVIEW can provide route recommendations by running the user's cursor to the destination. but the drawback is that the route is not shown by a line.

V. CONCLUSSION

The study of this research conclude that the regression function of corrected RSSI can optimally reduce the error from distance estimation. The combination of corrected RSSI and the chosen path loss exponent yield the good amount of accuracy. Moreover. with the additional processing of RSSI. LabVIEW is a feasible program to display user interface for indoor positioning and navigation. Although it needs more development in the navigation process to display the route. the navigation system show guidance for the user. This research also proves that the trilateration technique alone can provide the coordinates of the user's position quite well. We recommend applying more than one method to combine with trilateration to acquire better result.

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