STM JOURNALS

International Journal of
Wireless Security and Networks

ISSN: 2584-0703
Volume 2, Issue 2, 2024
July–December
DOI (Journal): 10.37591/IJWSN

https://journals.stmjournals.com/ijwsn

Research IJWSN

Development and Implementation of Indoor Location-based Service in Museums Based on Bluetooth Low Energy Standard and Triangulation Algorithm

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Abstract

Location-based services (LBS) in indoor locations are for providing information needed by users, and this information can be provided to users based on a Geofence. The most important component of location-based service systems is the Global Positioning System (GPS), which does not have the ability to determine the location in an indoor location. In this research, LBS Android software was developed for museums with the possibility of providing multimedia information based on the Geofence concept. The visitor is first positioned by Indoor Positioning System (IPS) in this software, and multimedia information is presented to the visitor by being placed in the Geofence. To determine the user's location, Bluetooth Low Energy (BLE)-based transmitters were installed, and the Trilateration algorithm was used to develop a two-dimensional positioning system in an indoor location. The main input variables of this algorithm were the distance of the transmitters from the user and the X and Y coordinates related to the installation location of the transmitters. Received Signal Strength Indicator (RSSI) was used to obtain the distance between the visitor and the transmitters, and the coordinates of the transmitters were measured in terms of X and Y dimensions relative to the reference point. The positioning accuracy of the system was evaluated based on Root Mean Square (RMS) and apparent errors in the environment. The final apparent error is equal to 1.02975 and the apparent error range is (0.43–1.44) meters.

Keywords: Location-based services, museums, indoor positioning, triangulation, Bluetooth transmitters

INTRODUCTION

Location-based services (LBS), such as routing, location-based social networking (LSBN), and location-based information acquisition and tracking, are being used by many people around the world [1]. LBS are provided in different environments because people need to obtain the services needed for guidance. An application that provides different information to the user based on the user's location can be defined based on the user's location [10]. The most important component of LBS is determining the exact location of users to provide location services in the best possible manner [6].

Positioning technologies are generally based on outdoor and indoor positioning [6]. Positioning technologies in outdoor locations because of the ability of the Global Positioning System (GPS) to properly determine the positions of users [3]. However, in indoor locations, owing to the weakening of GPS signals when passing through the walls and roofs of buildings, the positioning accuracy is greatly reduced [8]. For this purpose and to solve this problem, over several years, various systems based on alternative technologies and standards were developed for indoor locations,

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Received Date: June 12, 2024
Accepted Date: June 24, 2024
Published Date: August 23, 2024

Citation: Aras Khosravi, Younes Seddighi, Parviz Zeaiean Firouzabadi. Development and Implementation of Indoor Location-based Service in Museums Based on Bluetooth Low Energy Standard and Triangulation Algorithm. International Journal of Wireless Security and Networks. 2024; 2(2): 1–9p.

including these technologies and standards used: Radio Frequency Identification (RFID), infrared waves, Bluetooth, Wireless Local Area Network (WLAN), image processing, sound waves, etc. [6]. In general, positioning in indoor locations faces more problems and is less accurate than positioning in outdoor locations [5].

In recent years, positioning and location-based service systems have been used in various fields such as sales centers, warehouses, museums, and parking [7]. Various studies have been conducted in this field. For example, Carrasco et al. (2018) [2] developed a location-based service system for positioning industrial machines and devices in industrial environments, and in their research to determine the location and receive information from each device. Industrial companies installed a low-energy Bluetooth transmitter on the devices, which was based on the signal strength received from them and received by the user's smartphone, and analyzed by the software developed by the researchers, the closest industrial device. This is specified by the user.

Unfortunately, few studies have been conducted on LBS in indoor locations in the tourism field. Most activities in this field are related to companies that implement these systems. They do not provide precise positioning accuracy and only provide relative numbers.

METHODOLOGY

The software implementation in this study was based on the Android operating system. The location service system used in this study includes three parts.

1. Determining the user position in the indoor location.
2. Routing the user to reach the desired goal.
3. Getting multimedia information based on Geofence.

The different steps and functions of the software are shown in Figure 1, and the software development method is shown in Figure 2.

Development of Positioning System

Positioning systems in indoor locations include two components: the algorithm used to determine the position, and the technologies used. Because of the high error of positioning using GPS in indoor locations, we will need to develop an alternative system.

Determining the Coordinates of BLE Transmitters as Input to the Positioning Algorithm

In addition to the distance between the receiver and transmitters, the triangulation algorithm requires the coordinates of the location of the BLE installation. Therefore, the Universal Transverse Mercator (UTM) coordinate system was used according to the available tools to measure the implementation area based on the meter units. One of the aspects considered in this research is that the coordinates of all three transmitters should be considered as variables 1 to 3. A specific sender with a Media Access Control (MAC) address is randomly considered sender 1, and the inputs of the positioning algorithm related to variable 1 (X1, Y1) are determined based on the coordinates of sender 1. These principles have also been applied to other types of transmitters.

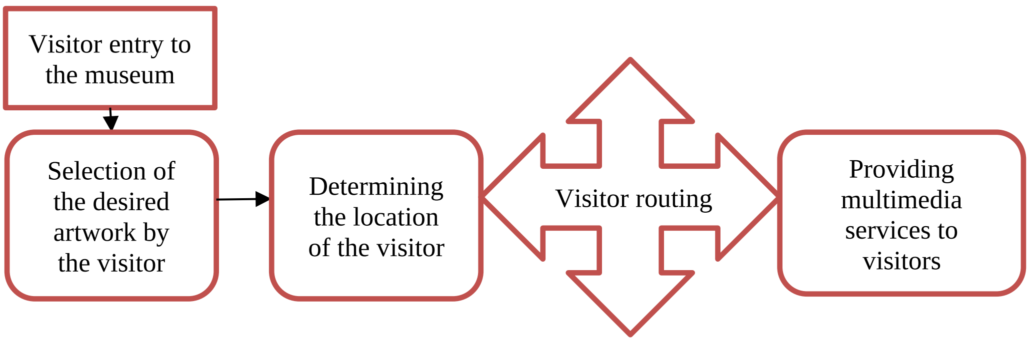

Figure 1. Various desired functions for LBS software.

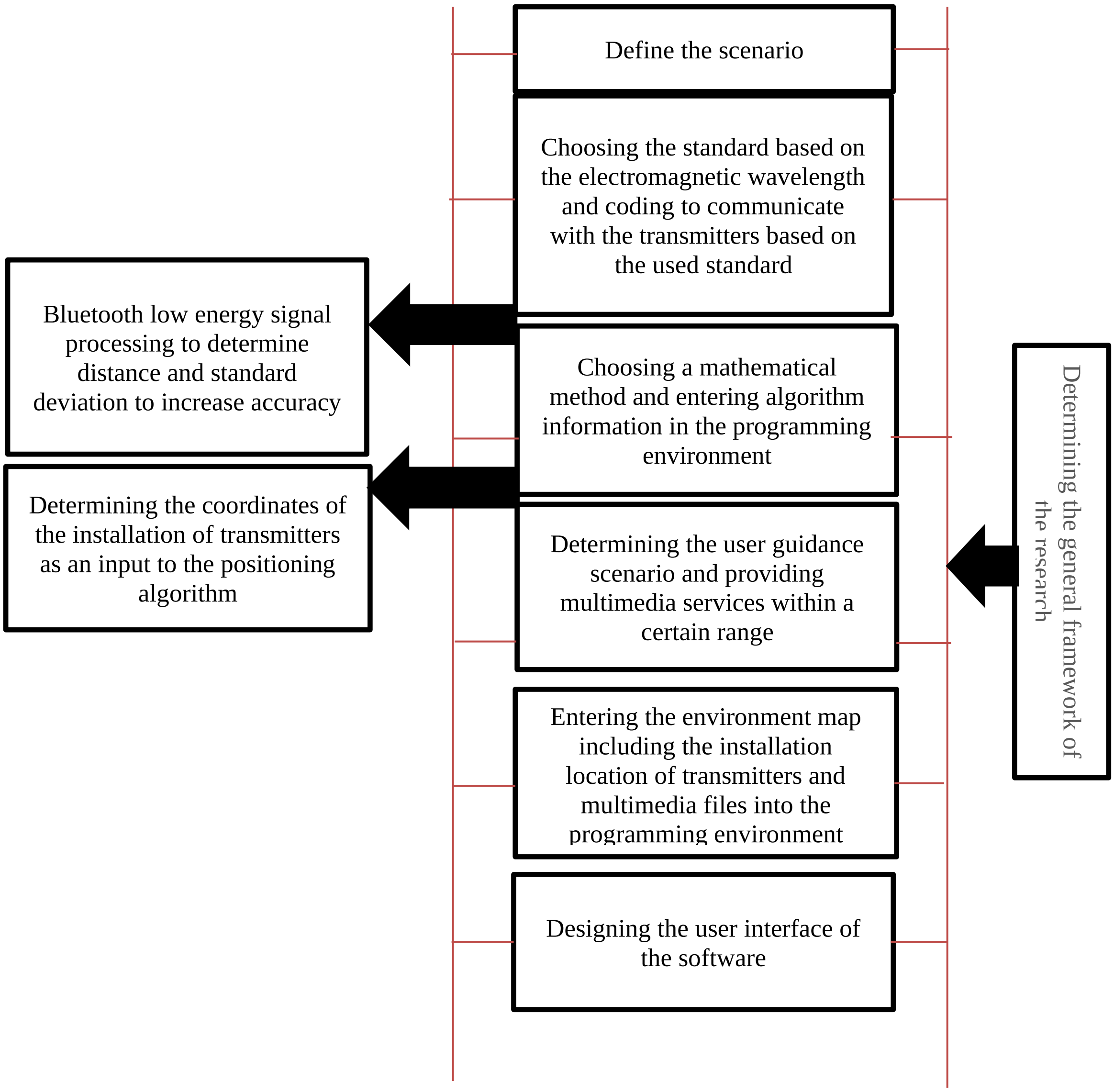

Figure 2. Steps related to the development of indoor location-based services software.

Finding the Distance Between the Receiver and Multiple Transmitters Based on RSSI Processing and Correction

One of the variables related to the distance determination algorithm is Xg, which must be calculated and entered into the algorithm. For this reason, at distances of 1 and 2.5 meters from each of the three transmitters in an interval of 60 s, 10 cases of received RSSI were recorded on average once every 6 s, and the standard deviation was calculated based on that.

Providing Multimedia Services Based on Geofence

The visitor positioning and guidance system has been developed in such a way that the visitor's location is determined after entering the environment and choosing one of the artists, and after guiding him to the selected artist's work, the photo and audio file related to the artist is selected within the range. This is a way to recognize a user's smartphone and provide information about it. After the user navigates the selected work, the developed application has the condition that if the user's mobile phone receives "RSSI" equal to -60 dB or more, the stored files related to the artist will be displayed. It contains a photo and audio file and plays it on the software installed on the user's smartphone. Considering that an RSSI equal to db60 can be received at a certain distance from the effect, the concept of geofencing and multimedia information for the software will be defined.

Functional Testing of the Location-based Service System

To test and evaluate the developed location-based service software, it was tested in two parts. The first part tests and evaluates the positioning accuracy, and the second part tests and evaluates the provision of multimedia services.

Positioning System Evaluation Test

In the triangulation algorithm, it is necessary to determine the distance of the user from the BLE transmitters based on the RSSI to determine the position. Because RSSI includes the rate of change that is effective in determining the distance and ultimately determining the position, the user's position will change several times in one minute. For this reason, we measured the positioning accuracy several times at randomly selected points in the environment. To test the two-point system in the implementation environment, we selected and specified the two-dimensional positions of these two points using metric measuring tools based on the reference point.

After determining the two desired points for testing in the environment, the position was measured ten times for each test point. The final accuracy of the system was determined by considering the error at both test points based on the mean square error (RMSE). In addition, to determine the error range, the lowest and highest RMS errors recorded for both test points in the two dimensions, X and Y, were considered.

RESULTS

The measurements related to the fixed values and the value measured by the software for test point 1 are listed in Table 1, and the amount of RMS error measured for point 1 is shown in Table 2. The measurements related to the fixed values and the value measured by the software for test point 2 are listed in Table 3, and the amount of RMS error measured for point 2 is equal to that in Table 4. For each table, the RMS error was obtained, and finally, the RMS error obtained for two points was averaged and considered as the final error. The ranges of the maximum and minimum errors in two dimensions X and Y at test points 1 and 2 were determined based on the minimum and maximum RMS errors recorded, which are listed in Table 5.

As shown in Table 2, the amount of positioning error in two dimensions, which is marked in yellow, is the result of the difference between the actual value of the coordinates of the experimental point and the value of the coordinates obtained by the software (the difference of values in each of the dimensions for RMS error calculation is used).

Regarding Tables 2 and 4, it is necessary to mention these two points:

The first test position has a greater distance from the BLE transmitters than the second test position and considering that we investigated the amount of RSSI changes at two distances of 1 meter and 2.5 meters, it was found that the rate of RSSI changes with increasing distance from the number of transmitters increases and based on the fact that distance is the most important input variable in the triangulation algorithm. In addition, to obtain the distance in this study, we used the signal reduction logarithm. Because the stability of the RSSI decreases with increasing distance, it should be expected that the greater the distance from the transmitters, the more the positioning error will increase. In both tables, the amount of recorded error is higher in the Y dimension compared to the X dimension, which can be attributed to the longer length of the Y dimension compared to the X dimension in the environment where the system is implemented.

According to the measurement of the RMS error and apparent error of the system, the amount of error and the functioning of the system are appropriate, as shown in Figures 3 and 4. In this research, the system was implemented in a two-dimensional space, and to reduce the error, it was necessary to have more transmitters to receive stronger signals instead of weak signals and reduce the error; because of the lack of these transmitters in the laboratory, it was not possible to use more BLE, as shown in Table 6 [9].

ISSN: 2584-0703

Table 1. Positioning measurements in the first test position to determine the apparent error.

Measured position for point 1 based on measuring tools (x_{i1}, y_{i1}) (Base on meter)	The measured position for point 2 based on the triangulation algorithm in the software (x_{j1}, y_{j1}) (Base on meter)	The amount of positioning error in two dimensions x and y based on the subtraction of the two corresponding dimensions of the coordinates (Based on meter)	Order of positioning
(2.1, 4.86)	(2.05, 3.33)	(0.05, 1.53)	1
(2.1, 4.86(	(0.79, 1.24)	(1.33, 3.62)	2
(2.1, 4.86)	(1.52, 1.92)	(0.58, 2.92)	3
(2.1, 4.86)	(1.82, 387)	(0.28, 0.99)	4
(2.1, 4.86)	(1.39, 2.42)	(0.71, 2.44)	5
(2.1, 4.86)	(1.52, 1.92)	(0.58, 2.94)	6
(2.1, 4.86)	(2.77, 2.86)	(0.67, 2)	7
(2.1, 4.86)	(2.33, 1.78)	(0.23, 3.08)	8
(2.1, 4.86)	(3.02, 3.03)	(0.98, 1.83)	9
(2.1, 4.86)	(2.06, 1.44)	(0.04, 3.42)	10

Table 2. Calculation of RMS error for two dimensions x, y at the first test point.

RMS error value for X_1	RMS error value for Y_1
RMS= $\sqrt{\frac{[(0.05)^2+\cdots+(0.04)^2]}{10}}$ = 0.669985	RMS= $\sqrt{\frac{[(1.53)^2+\cdots+(3.42)^2}{10}}$ = 2.6
The amount of RMS error based on the average error in X_1 and Y_1	$\mathbf{0.669 + 2.6/_2 = 1.634}$

Table 3. Positioning measurements in the second experimental position.

Measured position for point 2 based on measuring tools (x_{i2}, y_{i2}) (in meters)	The position measured based on the triangulation algorithm Based on meter)	The amount of positioning error in two dimensions x and y based on the coordinates obtained from positioning (x_{i2}-x_{j2}, y_{i2}-y_{j2}) (in meters)	Order of positioning
1.33, 2.1	1.33, 1.96	0, 0.14	1
1.33, 2.1	1.92, 2.41	0.59, 0.31	2
1.33, 2.1	1.01, 4.03	0.32, 1.97	3
1.33, 2.1	1.64, 1.93	0.31,017	4
1.33, 2.1	1.34, 2.61	0.01, 0.51	5
1.33, 2.1	149, 2.76	0.16, 0.66	6
1.33, 2.1	0.84, 4.29	0.49, 2.19	7
1.33, 2.1	1.95, 1.95	0.62, 0.15	8
1.33, 2.1	1.19, 1.06	0.14, 1.04	9
1.33, 2.1	0.97, 1.28	0.36, 0.82	10

Table 4. Calculation of RMSE for two dimensions X and Y at the second test point.

RMS error value for X_2	RMS error value for Y_2
RMS= $\sqrt{\frac{[(0)^2+\cdots+(0.36)^2]}{\square\square}}$ = 0.36687872	RMS= $\sqrt{\frac{[(0.14)^2+\cdots+(0.82)^2]}{10}}$ =1.0626899
The amount of RMS error based on the average in two dimensions X_2 and Y_2	$\mathbf{0.714} = (\mathbf{1.062 + 0.366}) \ / \ \mathbf{2}$

Table 5. Determining the amount of system error based on two test points 1 and 2 in terms of RMS error and error interval (Based on meter).

The amount of RMS error at test point 1	1.634
The amount of RMS error at test point 2	0.714
Final RMS error based on the average of two test points 1 and 2	= 1.174 $1.634 + 0.714/_2$
RMS error range based on two test points 1 and 2 for the X dimension	(0.36687872 - 0.669985)
RMS error range based on two test points 1 and 2 for Y dimension	(2.6 – 1.0626899)

Table 6. Determining the apparent error rate of the system based on two test points 1 and 2 in terms of the percentage of the number of occurrences and the error interval (in meters).

The amount of apparent error in determining the position in test point 1 based on the average error in x_1, y_1 correspondingly (based on meter) $(xn + yn/2)$	The amount of apparent error in determining the position of P in x_2, y_2 correspondingly (based on meter) $(xn + yn/2)$	The amount of final apparent error resulting from averaging the error in two test points 1 and 2 (Based on meter)	Position registration event sequence
0.79	0.07	0.43	1
2.47	0.45	1.46	2
1.75	1.45	1.4475	3
0.635	0.24	0.4375	4
1.575	0.26	0.9175	5
1.76	0.41	1.085	6
1.335	1.34	1.3375	7
1.665	0.385	1.025	8
1.405	0.59	0.9975	9
1.73	0.59	1.16	10
The final apparent error resulting from the averaging of all apparent errors		1.02975	
Apparent error margin		0.43-1.46	

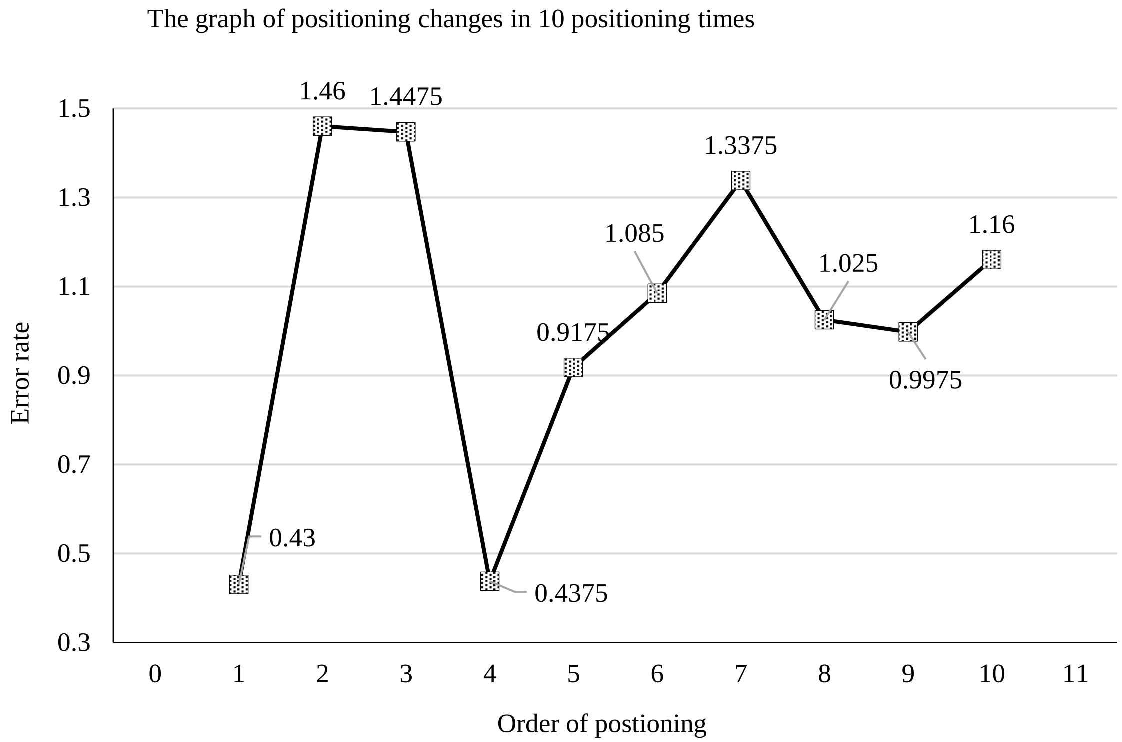

Figure 3. Linear diagram of changes in apparent position error in 10 measurements.

Testing and Evaluating the Provision of Multimedia Services

To test the effectiveness of the multimedia service program, it was necessary to test all three Bluetooth transmitters [4]. For this purpose, we tested the BLE transmitters related to Rumi (Figure 5), Mehdi Akhwan Sales (Figure 6), and Kamal-ul-Molk (Figure 7) based on receiving RSSI equal to -60db and receiving the photo and audio files of the artists.

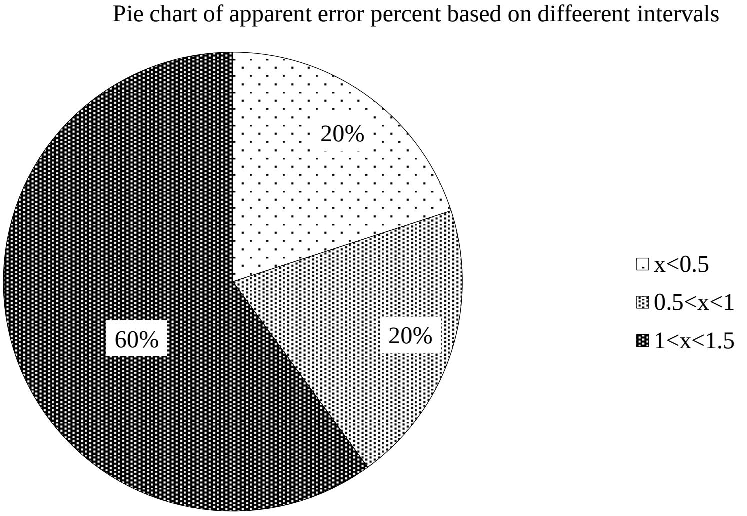

Figure 4. The percentage of apparent positioning error in three specified intervals.

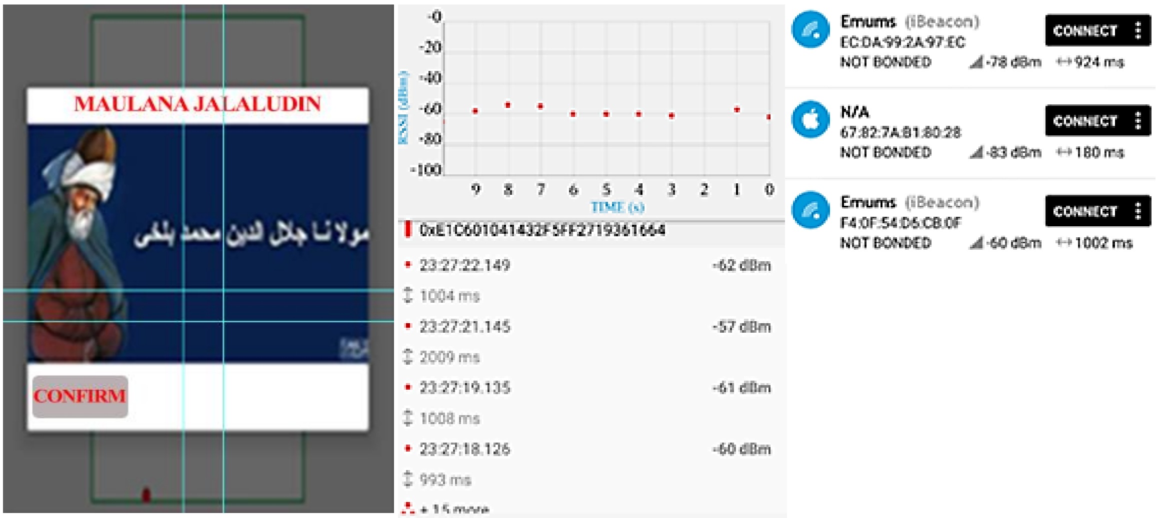

Figure 5. Indoor multimedia services related to the Maulana Jalaludin (Mac Address: F4:0F:54:DG:CB:0F) in case of receiving RSSI equal to or more than.

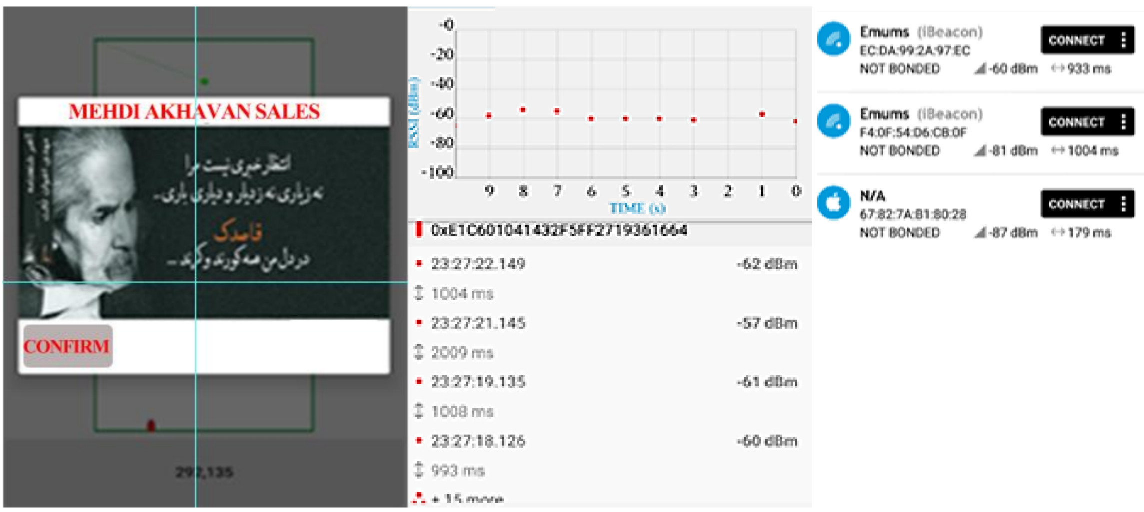

Figure 6. Providing multimedia services related to the Mehdi Akhavan Sales (Mac Address: EC:DA:99:2A:97:EC) if receiving RSSI equal to or more than -60db.

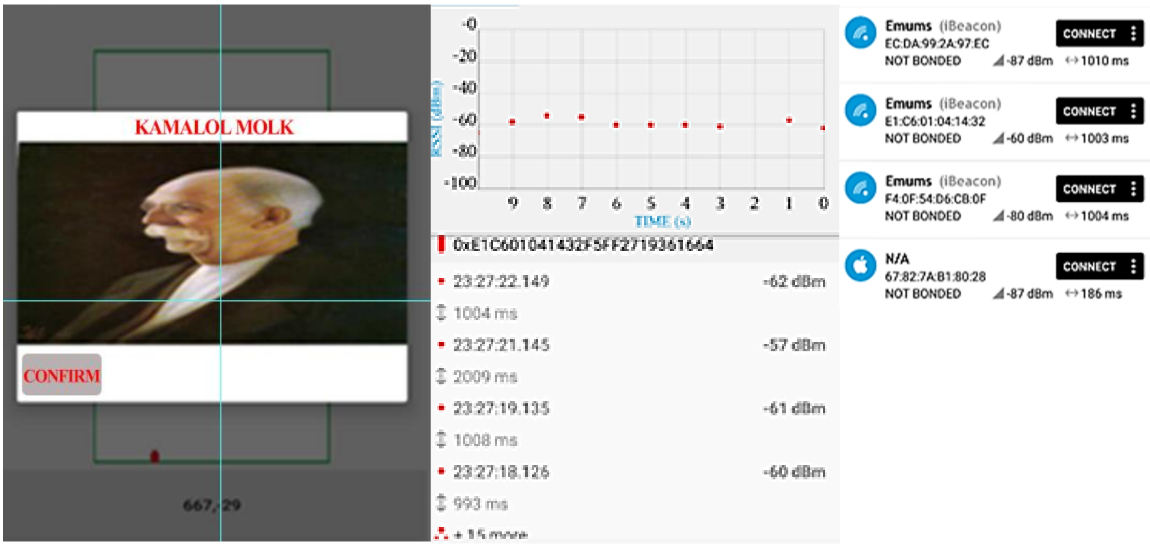

Figure 7. Providing multimedia services related to the artist Kamalol Molk (Mac Address: E1:C6:01:04:14:32) in case of receiving RSSI equal to or more than -60db.

CONCLUSION

Considering the importance of location-based service systems as a part of spatial information systems and the need to determine the position in these systems, because GPS provides a position with an error of more than 10 m in closed spaces, we discuss alternative algorithms and technologies for the implementation of the positioning system in a museum environment with closed space based on the triangulation algorithm and transmitters based on the low-energy Bluetooth standard. In addition to determining the location and guidance of people in the environment using location-based service systems, providing multimedia services within a certain range is one of the requirements of location-based services.

To test and test the location-based service system in this research, we divided the system developed in this research, which is Android software, into two parts. The first part includes testing the accuracy of positioning and guiding people to the selected artist’s work. The second part tested the accuracy of presenting multimedia information related to artists within a certain range (geofences).

The amount of RMS error calculated for the whole system is equal to 1.174 m, and the RMS error range in the X dimension is equal to (0.36687872–0.669985) and in the Y dimension is equal to (2.60–1.0626899). In this study, the apparent error of the system is calculated. The final apparent error is equal to 1.02975, the minimum apparent error obtained for the positioning system is 0.43, and the maximum apparent error is 1.44 meters, which in 20% of cases the apparent error is less than 0.5 meters, in 20% of the cases the apparent error is between 0.5 and 1 meter and in 60% of cases the apparent error is between 1 and 1.5 meters. The results were obtained according to the limited hardware facilities in this research and the problems related to the implementation time and according to the research of other previous researchers regarding the use of triangulation algorithms and low-energy Bluetooth-based transmitters. Among others, it can be said that the system has suitable accuracy for determining the position.

An important factor to consider when determining the position using the triangulation algorithm is the Z dimension; in fact, it is one of the variables of the triangulation algorithm. Considering that the location system implementation environment and in general all environments in the world are three-dimensional, the visitor’s phone has a height difference compared to the installation location of the BLE transmitters and has a Z dimension. In this study, because we were limited in terms of the number of BLE transmitters and to determine the three-dimensional position (X, Y, Z), we needed at least four transmitters. To avoid errors during the positioning test, we kept the phone exactly in line with the transmitters and performed the measurements. Our insistence on using BLEs is to pay attention to the fact that today, the standard related to BLE has become very important in the development of location-based service systems both in research discussions and in commercial discussions around the world; therefore, this research used this standard to develop the system.

The functionality of the location-based service system was tested based on the concept of geofencing and multimedia information. Based on the finding that whenever the user's smartphone with the Android software developed in this research is installed on it, the signal based on the Bluetooth Low Energy Standard receives -60 dB or more, the software will provide multimedia services.

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