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Research Article

Estimating of target coordinates based on Trilateration technique for indoor localization

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Abstract

Due to multipath and interference issues, implementing a localization system for an indoor environment has faced further challenges. Receive Signal Strength (RSS) and Time of Arrival (ToA) are the most important techniques used for such environments in this area, which need to be strengthened, especially for further interference due to enormous multipath problems. In this paper, in order to apply the suggested approach of this analysis, a case study of a chosen building is chosen. This suggestion is based on the Technique of Trilateration. To simulate the case study area, the Wireless Insite Software (WIS) was used, in such a proposal, 30 Receivers (RXs), and 3 Transmitters (TXs) deployed in suitable locations. After measuring RSS and ToA and save them into the database then, by using MATLAB software, the coordinates of RXs are calculated. The results confirm that the estimated locations are closed to the real locations by the average error of (0.49) meter for X-coordinate and (0.45) meter for Y-coordinate based on RSS, while the average error (0.55) meter for X-coordinate and (0.59) meter for Y-coordinate based on ToA. From this, we conclude that the RSS approach is more effective in evaluating indoor localization than the ToA method in the Trilateration method.

Keywords: *Indoor localization, RSS, ToA , WIS, Trilateration*

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Introduction

Recently, new technologies have played an important role in growing the demand for technology. The Indoor Localization System (ILs) is one of several systems that researchers have developed and received immense attention because of its application to the protection and security issues of humans. Indoor localization can be used to locate people inside buildings, such as train stations, airports, and hospitals, or to monitor healthy people in addition to monitoring anyone for safety aspects. The successful estimation position method is the Global Position System (GPS) out of the building (Maan M. A., Oras A. S., Mahmood F. M., and Raed A. A., 2019; Ho C. L., and Dong M. L, 2020) hough; there are drawbacks and constraints, so indoor localization solutions have been developed to solve these issues. Many systems are configured according to signal characteristics, such as ToA, Time Difference of Arrival (TDoA), Angle of Arrival (AoA), and RSS (Ho C. L., and Dong M. L, 2020; Maan M. A., Oras A. S., Mahmood F. M., and Raed A. A., 2019). Also, hybrid approaches such as RSS and ToA (Maan M. A., Oras A. S., Mahmood F. M., and Raed A. A., 2019), ToA, and AoA (Weigang W., Yunwei Z., , and Longbin T., 2020) have been used. By using smart devices such as mobile phones or tablets, the location can be determined. Wi-Fi is ubiquitously everywhere, but many Wi-Fi-based indoor localization networks are installed as in (Mohammad F. M., ALhamzah T. M., and Ahmed k. D., 2020).

As always, indoor environments are complicated, so there are challenges and limitations that influence the accuracy of devices. In the case of Non-Line of Sight (NLoS), this effect occurs when objects distinguish senders and receivers (Heydariaan M., Mohammadmoradi H., and Gnawali O., 2018). The pattern of transmission plays a significant role in measurements. The obtained signal then enters the receiver from walls or other objects, hence the deference of the ToA from the connection to another. The other result is attenuation as receivers arrive at a weak signal, so it would be difficult to estimate the right location based on this signal (Yang B., Guo L., Guo R., Zhao M., and Zhao T., 2020). The researchers suggested many solutions to increase device efficiency by minimizing the effects of NLoS and other constraints to overcome these challenges. One of these solutions is NLoS identification (Wang P., Koike-Akino T., and Orlik P. V., 2020), or the fingerprint technique suggested in several experiments, such as in (Naz A., M. Asif, H., Umer, T., Ayub S., and Al-Turjman, F., 2021), to approximate specific RSS values.

In this paper, Trilateration is proposed for testing localizability supported by the very fact that the location of an object can be determined if the distances to a few references are known. Consequently, it's the potential to spot localizable nodes during a network by iteratively applying Trilateration. In practice, Trilateration is widely used (Wiegert R. F., 2013) because it is distributed, simple to implement, and efficient in terms of communication and computation(Khelifi F., Bradai A., Benslimane A., Rawat P., and Atri, M., 2019).

Methodology

Indoor Localızatıon Technıque

There are various ways of representing data regarding the location of the position. A geometric description is the elementary form of spatial description. Under a Cartesian coordinate reference scheme, a graphical outline characterizes space with its geometric shape and a group of coordination points. The space model has a solid representation that is mostly used with coordinates to express an abstract space with coordinates such as (X, Y, Z). Physically, a room characterizes by different geometric forms. A geometric form indeed is a primitive form 2D or 3D. In particular implementations, the form of construction can be applied to more complex forms. Coordinates are chosen and ordered for each space in a distinctive structure in terms of the geometric form of space. The definition of the coordinates is strictly connected to the geometric form of space. Using the fundamental concepts of the intersection of various lines and the right geometric formulation to approximate the direction of a node, the exact point in the positioning location methods can be determined. The position coordinates of the nodes are calculated in many ways, such as AoA, ToA, TDoA, and RSS. In order to measure the direction positions of a node using lines and angles, these techniques were based on geometric principles. Examples of these concepts are triangulation, Trilateration, and hyperbolic (Sasiwat Y., Buranapanichkit D., Chetpattananondh K., Sengchuai K., Jindapetch N., and Booranawong A., 2020).

Trilateration technique based ToA

This is essentially an expansion of the system of triangulation of more than three points of reference. Therefore, if there are 3 points C_1, C_2, and C_3, as seen in Figure 1 and the distances from reference points to object T are known, so the point where the three circles intersect is the assumed location of object T (Burrough P. A., McDonnell R., McDonnell R. A., and Lloyd C. D., 2015).

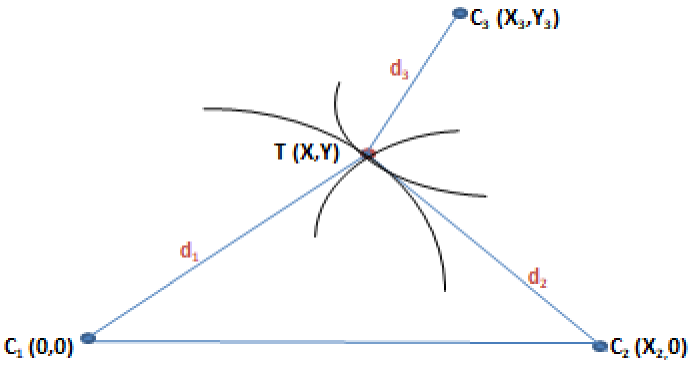


Figure 1. Trilateration method.

Radius (d_1) is the first circle, and radius (d_2) is the second circle, and the distances (d_1 and d_2) by measuring the signal's ToA, can be measured. Next, the distances between the reference nodes and the target T are determined using the following equations to calculate the coordinates for the target T (Liu Y., Yang Z., Wang X., and Jian L., 2010):

$$d_1 = (t_1 - t_0).S \quad (1)$$

$$d_2 = (t_2 - t_0).S \quad (2)$$

$$d_3 = (t_3 - t_0).S \quad (3)$$

where S is the speed of light, t_0 is the time of a signal sent from T, d_1 is the distance between C_1 and T, d_2 is the distance between C_2 and T, and d_3 is the distance between C_3 and T. Also, t_1 is the ToA of a signal that is sent from T to C_1, t_2 is the ToA of a signal that is sent from T to C_2, and t_3 is the ToA of the signal that is sent from T to C_3.

The equations with the centres at the reference points and the radius equal to the distance from the target T for the three intersection circles are as follows (Khalel, A. M., 2010):

$$d_1^2 = X^2 + Y^2 \quad (4)$$

$$d_2^2 = (X - X_2)^2 + Y^2 \quad (5)$$

$$d_3^2 = (X - X_3)^2 + (Y - Y_3)^2 \quad (6)$$

Where d_1^2 is the distance between reference point C_1 and T, d_2^2 is the distance between reference point C_2 and T, d_3^2 is the distance between reference point C_3 and T. The target point T coordinates are (X, Y), the reference point coordinates are (0, 0), the reference point coordinates are (X_2, 0), and the reference point coordinates are (X_3, Y_3). The coordinates are given by solving equations (4),(5), and (6) (Savazzi S., Nicoli M., Carminati F., and Riva M., 2013):

$$X = \frac{X_2^2 + d_1^2 - d_2^2}{2 * X_2} \quad (7)$$

$$y = \frac{X_3^2 + Y_3^2 + d_1^2 - d_3^2 - 2 * X * X_3}{2 * Y_3} \quad (8)$$

It is possible to approximate the coordinates of T, and the location mentioned is the only one where all three circles converge (Burrough P. A., McDonnell R., McDonnell R. A., and Lloyd C. D., 2015).

Trilateration technique based RSS

RSS is a tool for assessing the direction of a target device's position. The distance between two nodes can be estimated by measuring the energy of the obtained signal at one end, based on a path loss model. The features of the channel have to be defined in order to determine the distance from RSS measurements. A constant component and a variable component may be defined by the RSS. A path loss propagation model is subject to the constant component, and a number of dynamic propagation effects are subject to the variable component. Such transmission impacts include signal attenuation, effects of multipath, and shadowing. The framework requires at least four or more reference nodes with known coordinates to approximate the location of a target node in three dimensions (3D), as shown in Figure 2. The transmitter forwards control channels or signals from the beacon, and these signals are received and processed by the target node. To evaluate the position location, the dimensions of the received signals that are collected and processed may be used (Alonso-González I., Sánchez-Rodríguez D., Ley-Bosch C., and Quintana-Suárez M. A. 2018). All radio signals suffer from a condition known as lack of free space through which the signal is transmitted (Adewumi O. G., Djouani K., and Kurien A. M., 2013). As a function of distance squared when propagating in space, according to the Friis equation, it becomes weaker (Singh P., Khosla A., Kumar A., and Khosla M., 2018).

$$p_{r=\frac{P_t * G_r * G_t * \lambda^2}{(4\pi)^2 * d^2}} \quad (9)$$

Where P_r is the received power of the device, P_t is the transmitted power, G_t and G_r are the antenna gain of the transmitter and receiver, d is the distance between a transmitter and the receiver. The equation (9) is used to calculate, based on RSS, the distance between two nodes in a wireless device after estimating the path gain P_G. The P_G can be obtained by this equation (Singh P., Khosla A., Kumar A., and Khosla M., 2018):

$$P_G = \frac{P_r}{P_t * G_t * G_r} = (\frac{\lambda}{4\pi d})^2 \tag{10}$$

If we know the frequency of the carrier, power of the transmitter, power of the receiver, and antenna gains of transmitting and receiving, we may use the equation to approximate the distance between the two sensors in (10)

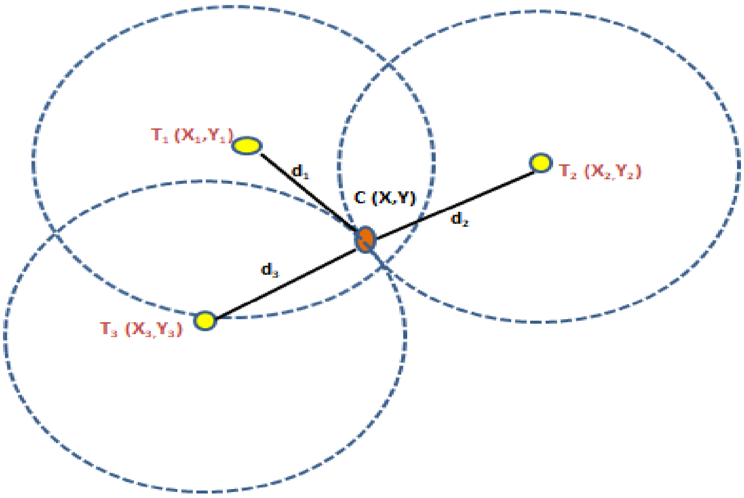


Figure 2. RSS method.

The main aim of the place location method is to determine the coordinates of the target node. Reference nodes must reside in the wireless coverage area of established geometrical coordination to chart measurements obtained to identify the target node location in order to approximate the unknown target node position (Alonso-González I., Sánchez-Rodríguez D., Ley-Bosch C., and Quintana-Suárez M. A. 2018).

To calculate the location of a target node in the RSS process, the Trilateration technique is used. To approximate the location of positioning in the case of 2D, three reference nodes or more are expected. In the case of 3D, four reference nodes or more are required. Each reference node is assumed to be in the center of the circle. At the diameter of the circle lies the target node (Singh P., Khosla A., Kumar A., and Khosla M., 2018).

From these equations, the distances between the reference nodes and the target node can be calculated (Adewumi O. G., Djouani K., and Kurien A. M., 2013):

$$d_1 = d_0 \sqrt[n]{\frac{P_0}{P_1}} \quad (11)$$

$$d_2 = d_0 \sqrt[n]{\frac{P_0}{P_1}} \quad (12)$$

$$d_3 = d_0 \sqrt[n]{\frac{P_0}{P_1}} \quad (13)$$

The loss of an exponential path is defined as (Savazzi S., Nicoli M., Carminati F., and Riva M., 2013):

$$\frac{P_r}{P_0} = (\frac{d_0}{d_i})^n \quad (14)$$

Where d_i (i = 1, 2, 3…) is the distance between a reference node and a target node C, d_0 is the distance of reference, P_r is the power of the receiver, P_0 is the power of the receiver at a reference distance d_0, and n is the path loss exponent of different environments (n=2 for free-space path loss).

It is possible to determine the estimate of the location of the target using the information derived from the circle radius describing the distance between the reference nodes and the target point. Where the number of reference nodes should be greater than or equal to 3, the maximum likelihood estimation approach can be used.

Case study area

In order to implement the proposal, the Electrical Engineering Technical Building Campus chose the indoor localization framework for implementation. In simulation and experimental scenarios, such a framework was implemented; the simulation side was based on Wireless Inside Software (WIS). Such a program has the ability to calculate appropriate parameters in the side portion of the simulation. Whereas, in the experimental side section, the experimental data collected by using the WIS program will represent the specifics of RSS and ToA measurements and using the MATLAB program to determining the coordinates of receivers.

Side of simulation

Three-dimensional (3D) WIS-based architecture, taking actual geometric dimensions into account. In addition to three positions for transmitters, ten positions were chosen to deploy the receivers to measure RSS and ToA, as seen in Figure 3.

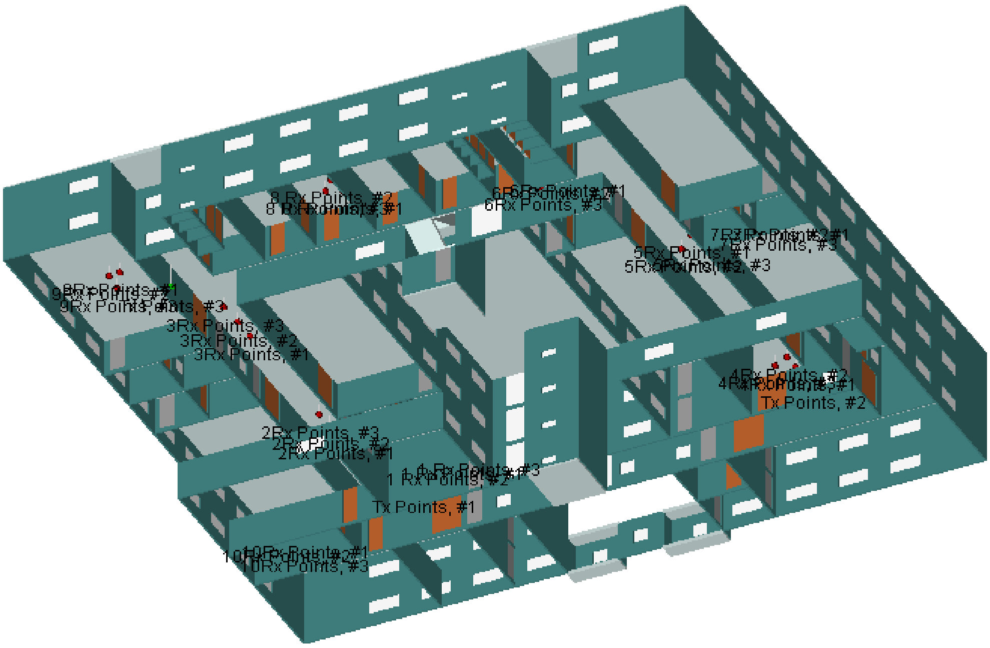


Figure 3. The case study building

In WIS, the transmitter and receiver properties can be modified to fit the experimental devices so that the chosen properties of both TXs and RXs described in Table 1 are allocated. The operating frequency is 2.4 GHz, and all TXs and RXs antennas are Omni-Directional to one experimental antenna.

Table 1

The properties of antennas

Properties of antennas	TX	RX
Antennas type	Omni.D.	Omni.D.
Input Power (dBm)	12.5	-
Gain (dBi)	7.5	2.2
E-Plane HPBW	13˚	94˚
Waveform	Sinusoid	Sinusoid
Temp. (k)	296	296
Polarizations	V	V
Received Threshold (dBm)	-150	-150

One of the main features of WIS is the configuration of all materials' Permittivity and Conductivity to deal with actual ones. There are constant parameters as mentioned in table 2 and table 3 to apply that. Conductivity and Permittivity are determined for each material based on those parameters. The Conductivity denoted by (σ) can be determined as follows, according to (ITU-R, 2013):

$$\sigma = c \times f^{d} \qquad (15)$$

The constant *c* and *d* are illustrating in Table 2. The Permittivity (η) is determined as follows:

$$\eta = a \times \mathrm{f}^{\mathrm{b}} \qquad (16)$$

The constant *a* and *b* are related to each material used to construct the chosen building, which is listed in Table 3 (Ahmed K. D., Mohammad A. T., and Mosleh M. F. 2020).

Table 2.

The constant (c and d) is used in (15).

Material type	*c*	*d*
Concrete	0.0326	0.8095
Brick	0.038	0
Wood	0.0047	1.0718
Glass	0.0043	1.1925

Table 3.

The constant (a and b) is used in (16).

Material type	*a*	*b*
Concrete	5.31	0
Brick	3.75	0
Wood	1.99	0
Glass	6.27	0

As stated, the frequency of 2.4GHZ used in this study will be based on equations (15) and (16). Table 4, for reference frequency, displays the Permittivity and Conductivity. For the materials used in building construction, the values in Table 4 will be set out in the WIS.

Table 4.

Permittivity &Conductivity for 2.4GHZ frequency.

Material type	Conductivity	Permittivity
Concrete	0.0926	5.31

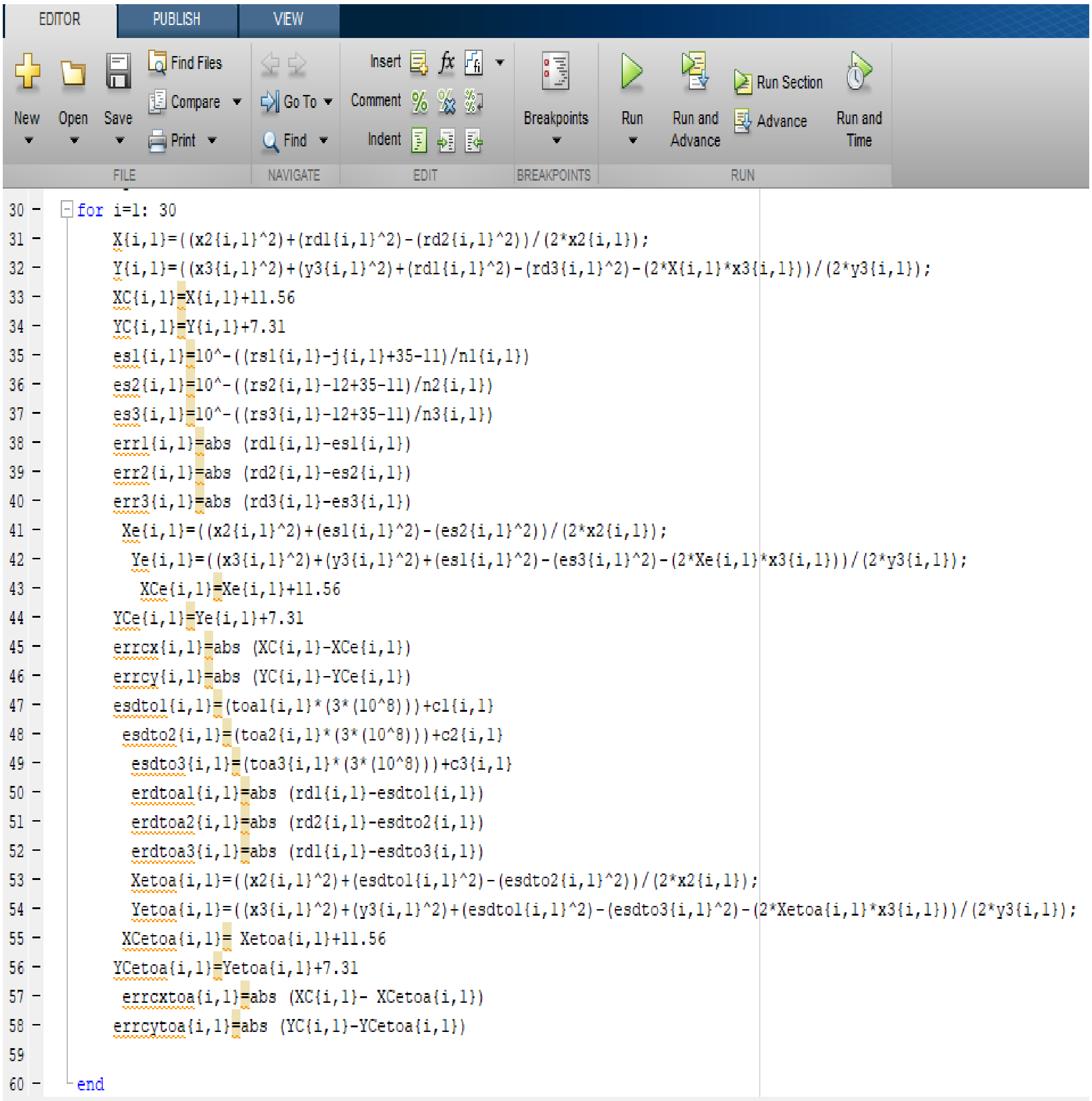
Brick	0.1079	3.75
Wood	0.0134	1.99
Glass	0.0122	6.27

Side of experimentation

On the experimental side, Using WIS's data for RSS and ToA in the MATLAB program to extract the coordinates of the receivers as shown in Figure 5.

By taking various locations in the case study building, the efficiency of measurements to deal with practical measurements in the whole building improves in different environments. Three points were used in the case study environment to experimentally measure RSS and ToA with 30 samples each. These measurements are deposited with the other measurements at the other three sites in the database.

Finally, the MATLAB program provided to translate the optimum data was stored using the trilateration method in the database to distance lead to coordinates of receivers.




```
for i=1: 30
    X{i,1}=((x2{i,1}^2)+(rd1{i,1}^2)-(rd2{i,1}^2))/(2*x2{i,1});
    Y{i,1}=((x3{i,1}^2)+(y3{i,1}^2)+(rd1{i,1}^2)-(rd3{i,1}^2)-(2*X{i,1}*x3{i,1}))/(2*y3{i,1});
    XC{i,1}=X{i,1}+11.56
    YC{i,1}=Y{i,1}+7.31
    es1{i,1}=10^-((rs1{i,1}-j{i,1}+35-11)/n1{i,1})
    es2{i,1}=10^-((rs2{i,1}-12+35-11)/n2{i,1})
    es3{i,1}=10^-((rs3{i,1}-12+35-11)/n3{i,1})
    err1{i,1}=abs (rd1{i,1}-es1{i,1})
    err2{i,1}=abs (rd2{i,1}-es2{i,1})
    err3{i,1}=abs (rd3{i,1}-es3{i,1})
     Xe{i,1}=((x2{i,1}^2)+(es1{i,1}^2)-(es2{i,1}^2))/(2*x2{i,1});
      Ye{i,1}=((x3{i,1}^2)+(y3{i,1}^2)+(es1{i,1}^2)-(es3{i,1}^2)-(2*Xe{i,1}*x3{i,1}))/(2*y3{i,1});
       XCe{i,1}=Xe{i,1}+11.56
    YCe{i,1}=Ye{i,1}+7.31
    errcx{i,1}=abs (XC{i,1}-XCe{i,1})
    errcy{i,1}=abs (YC{i,1}-YCe{i,1})
    esdto1{i,1}=(toa1{i,1}*(3*(10^8)))+c1{i,1}
     esdto2{i,1}=(toa2{i,1}*(3*(10^8)))+c2{i,1}
      esdto3{i,1}=(toa3{i,1}*(3*(10^8)))+c3{i,1}
      erdtoa1{i,1}=abs (rd1{i,1}-esdto1{i,1})
      erdtoa2{i,1}=abs (rd2{i,1}-esdto2{i,1})
      erdtoa3{i,1}=abs (rd1{i,1}-esdto3{i,1})
      Xetoa{i,1}=((x2{i,1}^2)+(esdto1{i,1}^2)-(esdto2{i,1}^2))/(2*x2{i,1});
      Yetoa{i,1}=((x3{i,1}^2)+(y3{i,1}^2)+(esdto1{i,1}^2)-(esdto3{i,1}^2)-(2*Xetoa{i,1}*x3{i,1}))/(2*y3{i,1});
     XCetoa{i,1}= Xetoa{i,1}+11.56
    YCetoa{i,1}=Yetoa{i,1}+7.31
     errcxtoa{i,1}=abs (XC{i,1}- XCetoa{i,1})
    errcytoa{i,1}=abs (YC{i,1}-YCetoa{i,1})

end
```

Figure 5. MATLAB program.

Results and analysis

Based on RSS and ToA measurements, the approximate distance was performed; hence, accurate RSS and ToA measurements would lead to accurate distance estimation. Figure 6 indicates the error ratio for the RSS method between the true and the approximate coordinates, where the X-maximum coordinates error ratio is 0.8 and the Y-coordinates are 1.3. The X-lowest coordinates error ratio is 0.04, and the Y-coordinates are 0.01. Figure 7 indicates the error ratio for the ToA method between the true and the approximate coordinates, where the x-maximum coordinates the error ratio is 1.5 and Y-coordinates are 1.7. In the X-lowest coordinates, the error ratio is 0.004, and the Y-coordinates are 0.02. These results are compared with the research (Chaisang A., and Promwong S., 2018). The results achieved in such reference reported that ToA is better than the RSS method and that errors have been identified (0.48-1.52) meter. Also, the researcher of (Monta S., Promwong S., and Kingsakda V., 2016) used min/max positioning based on static values of both ToA and RSS measurements. The Biconical antennas were installed with a range of frequencies between (3-11) GHz in order to apply the trilateration technique, which gives better results than the min/max method with a range of errors between (0.21-2.09) meter as compared with our results which indicate that the average error of (0.49) meter for X-coordinate and (0.45) meter for Y-coordinate based on RSS, while the average error (0.55) meter for X-coordinate and (0.59) meter for Y-coordinate based on ToA.

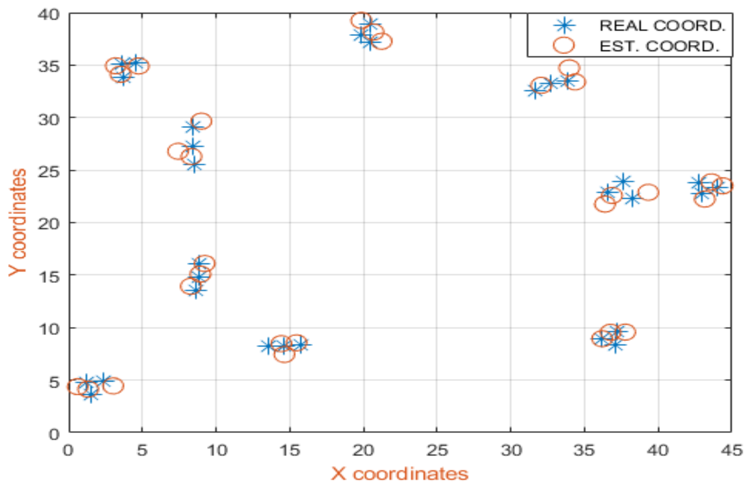


Figure 6. RSS coordinates.

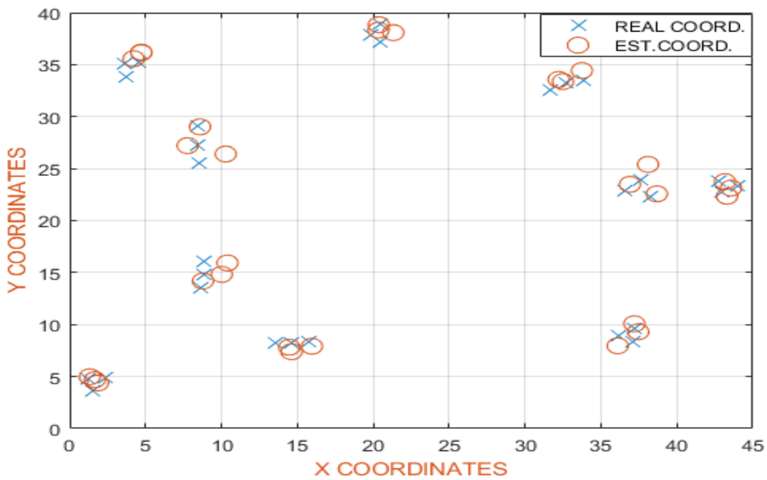


Figure 7. ToA coordinates.

Conclusions

In this research, with RSS and ToA techniques, a suggested Trilateration technique is carried out in order to find target locations in 10 positions deployed in a selected building. These buildings have been constructed to calculate RSS and ToA based on WIS. In a suitable location inside the case study building, three 2.4 GHz-based transmitters were deployed. WIS was used to measure RSS and ToA in 3 positions with 30 samples on each of them on the experimental line. The findings indicate that the suggested MATLAB and WIS are used to achieve a substantial decrease in error (calculated as the differences between the theatrical and simulated RSS and ToA). The results of our experiment show the average error for coordinates of RSS (0.49,0.45) m and the average error for coordinates of ToA (0.55,0.59) m. From this, we conclude that the RSS approach is more effective in evaluating indoor localization than the ToA method in the Trilateration technique.

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