

Hybrid localization algorithm based on received signal strength and angle-of-arrival for indoor location estimation

Mahmood F. Mosleh¹, Riam M. Zaal², Eyad I. Abbas³

¹Department of Computer Engineering Techniques, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq

^{2,3}Department of Electrical Engineering, University of technology, Baghdad, Iraq

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ABSTRACT

The huge ubiquitous deployment of wireless technologies and the pervasive availability of smart devices, indoor localization has become one of the most interesting topics in numerous location-based services. Where several methods have been adopted to estimate and localize the mobile and user location. The earliest and most interesting method was based on received signal strength (RSS) measurement. However, such method has showed weakness in handling the accurate estimation results. Recently, researchers start gather several different methods to achieve the advantages of each method and achieve higher accurate estimation. Hence, in this paper a hybrid localization algorithm has been designed and proposed based on the use of both RSS and angle-of-arrival (AoA). The algorithm has been tested in a three-dimensional indoor building; we are taking the effects of different building materials. The results were obtained depending on the measurement of RSS and AoA gathered from each received point and by using two AP devices for more accuracy in positioning coordination, the type of the transmitters is directional.

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Corresponding Author:

Mahmood. F. Mosleh

Department of Computer Engineering Techniques, Electrical Engineering Technical College

Middle Technical University

Baghdad, Iraq

Email: drmahmoodfarhan@gmail.com

1. INTRODUCTION

Location-aware based services have been known to be one of the most interesting element of localization process. And this done by computing the locations of wireless received points within the targeted area [1]. Localization can be defined as the process of determining the absolute value of physical location of a specific received point or target [2]. Although, global positioning system (GPS) has a capability to provide an accurate location information. However, it shows ineffectiveness in indoor environment due to the huge effects of multipath propagation of wireless signal [3].

In the last past years, several researches focus on localization estimation and developed many approaches to increases the estimated accuracy. Localization based outdoor environment could be performed by depending on GPS and could achieve acceptance accuracy and reliability in location estimation [4]. However, moving forward indoor environments GPS has showed a weakness in estimation, due to many reasons related with these environments such as its complexity and the presence of different walls, objects and obstacles [5]. As a result, it is very important to perform indoor localization at a lower cost and higher accuracy [6].

Generally, localization schemes could be classified into two types which are range-free and range-based schemes. In the first type, localization of the received point depends on the network connectivity and such method don't require extra hardware. However, its accuracy is lower and require many numbers of access points (AP's) devices to improve its accuracy [2]. On the other hand, ranged-based method could achieve better accuracy where several methods have been presented to measure the time of arrival (ToA), angle-of-arrival (AoA), time difference of arrival (TDoA) and received signal strength (RSS) to obtain the distance or angles, which in turn would be used to calculate the location coordination's [7-10]. Several types of these measurements require extra hardware and cost. For example, ToA and TDoA shows higher sensitivity to time error and thus require synchronized timers to synchronous the AP device. Furthermore, it sometimes requires a special medium to handle the timing issue. On the other hand, AoA based localization method has been utilized in widely manner. However, it requires higher cost equipment to obtain the required angles. In addition, it would show ineffectiveness within indoor environment which include several reflections and diffractions. Unlike all other methods, RSS based localization could be represented as the lowest cost method and the easiest method to be performed, but with relatively lower accurate results. RSS based localization can be classified into groups such as propagation model [11, 12], proximity [13, 14] and fingerprinting [15, 16]. In the first group, it analyzes the relation between the RSS and the distance based on some known parameters such as path loss exponent (PLE). In proximity-based methods the received point broadcast an initializing packet for initialization the process. Then a measured RSS value from reference node is reported in order to nominate the received point or target. In the group of fingerprinting, its measure the value of RSS from a static set of points during the first phase (initialization phase) then the localization phase require matching between the fingerprint values and estimated values [2].

In this work, a hybrid-based localization algorithm would be represented by combining both methods of AoA and RSS measurement and by using two directional antenna type AP devices as a reference device to localize several received points (targets) distributed within the two floors of our case study. Directional antennas focus the RF energy in a particular direction, where increasing the gain of the directional antenna would increase the coverage distance, but the effective coverage angle would be decrease. For directional antennas, the lobes are pushed in a certain direction and little energy is there on the back side of the antenna, Unlike the Omni directional AP antennas which would have a similar radiation pattern. These antennas provide a 360-degree horizontal radiation pattern. Our presented algorithm would consider the indoor localization and the effects of different building materials on path propagation by depending on the results obtained from Wireless InSite (WI) software [17]. The rest of paper is formed as follow, related works is discussed in section 2, section 3 and 4 presents the hybrid algorithm and its methodology respectively. Section 5 presents the case study, and finally section 6 and 7 discussed the results and conclusion.

2. RESEARCH METHOD

The recent efforts of researcher and industry have resulted in the development of different approaches for both accurate and low-cost localization methods for indoor environment. One of the most interesting method was based on the use of AoA measurement, where it can be estimated by finding the maximum or minimum signal strength, during the rotation of a directional or a non-ideal omnidirectional antenna as in [18, 19], Other researchers in [20] proposed an alternative method for emulating the function of directional antenna and developing an outdoor localization system. In this approach, the user would carry the measurement device or smartphone and rotate his body by 360 degree and records groups of RSS measurement. The estimated angular error was ranging between 30-50 degree for line-of-sight (LoS) cases and about 60 degrees for non-line-of-sight (NLoS) cases. On the other hand, researcher in [21] uses channel state information (CSI) instead of RSS for localization and by using four AP devices, the researchers could achieve and accuracy of 6.5 meter. While, by increasing the number of utilized AP devices such accuracy has been increased up to 5 meters. However, their method has been reported to be required many devices and the results didn't reach the required. Furthermore, in [22] localization based AoA has been presented by using two AP devices to estimate the location of 10 random unknown locations. However, their method shows inaccurate results where the estimation error for each location was about 2.5 meter. In addition, the researchers in [23] proposed AoA localization with RSS difference (ALRD), this system is to obtain the AoA by analyzing the RSS measurement obtained from the two directional AP devices. Such method could achieve average localization error of 1.24 m. However, this method doesn't include the rotational function in collecting data. In addition to that, an infrastructure for the estimation of AoA has been proposed in an indoor environment [24]. However, this method achieve accuracy of less than 2 meter. Meanwhile, great efforts have been made by researchers in [25] to propose system for localization and based on using both received signal strength (RSS) and AoA. Their presented algorithm could achieve about 10 cm average in localization error for a small area. However, the presented algorithm has not been tested for a large indoor environment.

A new combination of localization has been adopted recently and known as hybrid localization. Such localization has gained much attention by researchers due to its high accuracy and being used in a wide range of applications. Range based hybrid approach is one type of such localization, which can be any combination of ToA, TDoA, AoA and RSS [26, 27]. The most interesting combination was the RSS-AoA based hybrid localization, which has a significant in improving the estimation accuracy at lower cost, where AoA measurement can be utilized to achieve self-localization. While, RSS measurement could be obtained easily with low accuracy in the harsh environment. Furthermore, such hybrid method doesn't require a time synchronization procedure as it required in ToA and TDoA [28].

3. METHODOLOGY OF PROPOSED ALGORITHM

In this section, we will introduce the steps and flowchart of the proposed method. The proposed technique depends on measuring the angle of arrival and RSS at each received signal. The methodology includes a precise description of the steps to be taken to reach an accurate determination of the target location.

3.1. AoA Based localization with 2 known AP devices

The site that was discussed in this work includes building the electricity department at the University of Technology, the building consists of five floors taking into consideration the materials used in the construction and their effect on the signal. In this research it has been considered two floor investigation of 2nd and 3rd floors. Additionally, it has been considered the presence of 2 static and directional AP devices to perform localization in each floor, where each AP device would calculate the RSS and AoA values for each received point to be localize and as seen in Figure 1. AoA can be defined as the angle between the orientation and the path propagation direction of an incident wave. AoA is measured and presented in degree and it has an absolute value when the orientation is zero or pointing to the north. Otherwise, it would have relative value [29]. AoA can be represented by two main values, which are (θ) and (ϕ). The representation of these two angles in the axis coordination can be seen in Figure 2. It is worth to mention that calculating both previous parameters would be through the use of WI software and in a multipath scenario, where several paths of wireless signal would be obtained. Then the results obtained would be gathered in a database as a first phase of our proposed algorithm to be handed with second phase as described in next section.

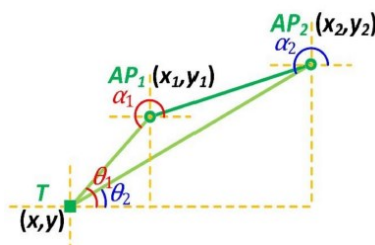


Figure 1. Methodology of AoA based localization by using two known AP devices

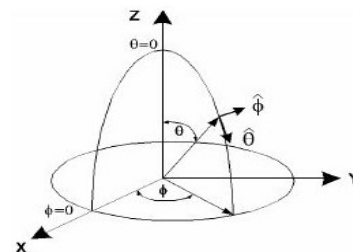


Figure 2. The representation of theta and phi angle for AoA based method

3.2. The procedure of proposed algorithm

In this work it has been designed a hybrid algorithm for the purpose of localization estimation for indoor environments. This algorithm has been designed by using MATLAB program with a graphical user interface (GUI) window as seen in Figure 3. The steps of this algorithm would be described in the below steps
Step 1: Prepare the database and collect the data from WI software based on both RSS and AoA parameters.
Step 2: Enter the AP coordination of XT_x and YT_x, which is supposed to be known for our localization algorithm.

Step 3: By clicking on the best path calculation button, the algorithm would obtain the optimum path based on the values of RSS of each received point and from each AP device.

Step 4: Based on the previous step the several parameters of optimum path would be selected such as distance, theta (θ) and phi (Φ). The algorithm would calculate the angle between the AP and the received point $\beta_{AP,Rx}$ and based on (1).

$$\beta_{AP,Rx} = \alpha + \pi. \quad (1)$$

where α is direction of arrival in phi (Φ) which has been calculated using WI software and for each received point.

Step 5: The final step includes calculating the values of x and y coordination for the received point or target within the indoor environment based on (2) and (3) respectively.

$$XR_x = XT_x + d \times \cos(\beta) \tag{2}$$

$$YR_x = YT_x + d \times \sin(\beta) \tag{3}$$

where (XR_x, YR_x) represent the coordination of the targeted received point which represent the output of our presented algorithm. The flowchart describing these steps can be seen in Figure 4.

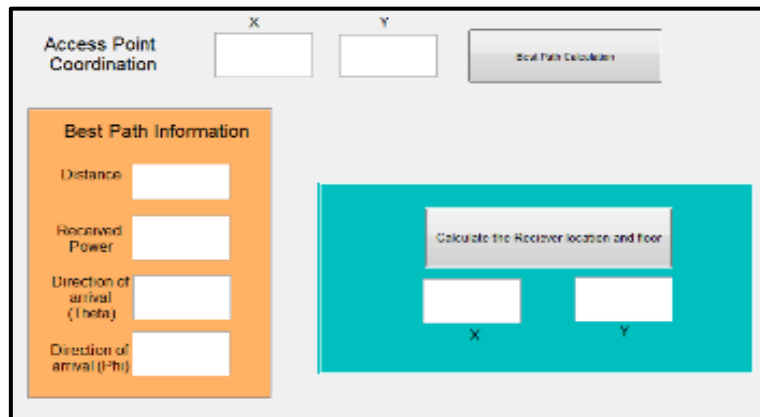


Figure 3. GUI window for the hybrid localization algorithm

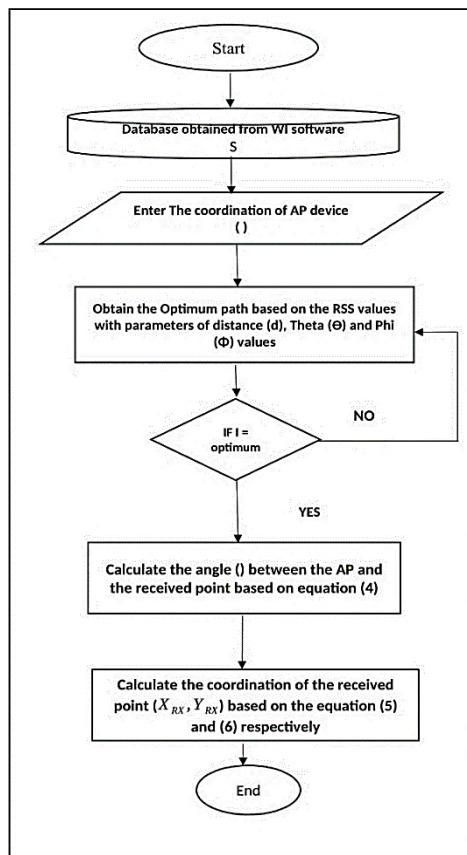


Figure 4. Flowchart of our proposed localization algorithm

4. CASE STUDY

The site intended for investigation in this work is the building of electrical department in university of technology which consist of ground and 4 floors. The case study has been designed, modelled and simulated using wireless InSite software and as seen in Figure 5. The floors selected for investigation were the 2nd and 3th floors, where it has been deployed two predefined transmitters per each floor. For the received point which will be considered as the target points for testing our presenting localization algorithm, it has been distributed 11 and 10 points for the two investigated floors respectively. Such distribution was based on the structure requirement of our targeted building. The distribution location of each AP and received point per each floor can be seen in Figure 6. In addition, the properties of these devices were listed in Table 1. In context, the serious effects of different building materials on propagation characteristics were taken into consideration by obtaining the value of relative permittivity (ϵ) and conductivity (σ) as listed in Table 2 and as recommended by International Telecommunication Union (ITU) [30-32]. It is worth to mention, that the selected bandwidth is 20 MHz working with 2.4 GHz frequency.

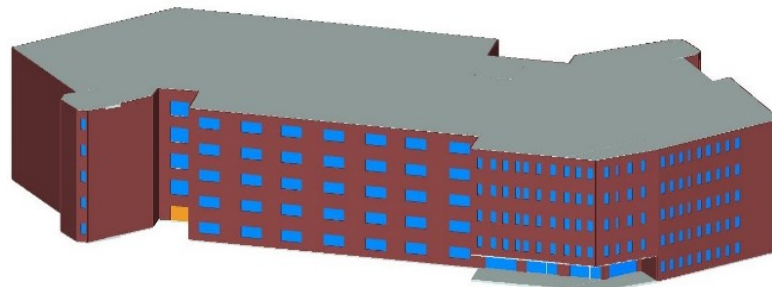


Figure 5. The simulated model of the targeted building

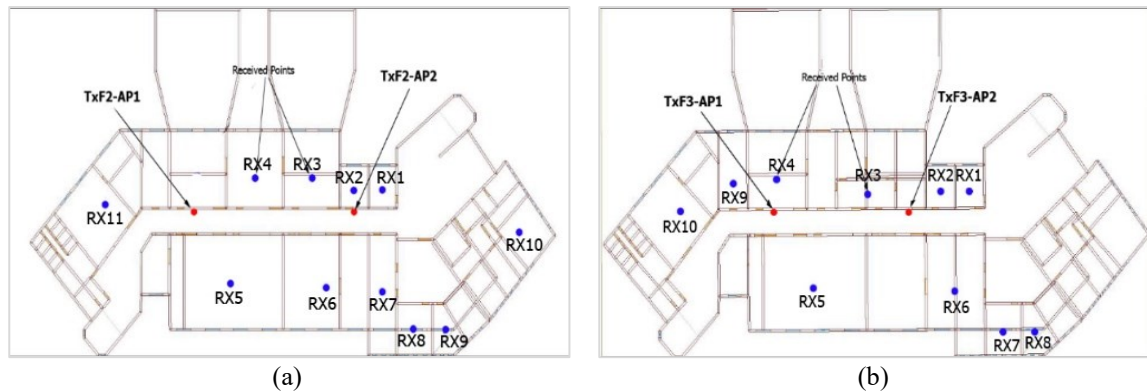


Figure 6. The distribution of AP's and received points per (a) 2nd floor and (b) 3rd floor

Table 1. AP and receiver antenna proprieties

Antenna properties	Tx Antenna	Rx Antenna
Antenna type	Directional	Directional
Input Power (dBm)	30	-
Gain (dBi)	9	2
E-Plane HPBW	90°	90°
Waveform	Sinusoid	Sinusoid
Temperature (k)	293	293
VSWR	1	1
Polarization	V	V

Table 2. Material thickness, conductivity and permittivity values

Materials	Thickness (m)	ϵ	σ
Concrete	30	5.31	0.066
Wood	4.5	1.99	0.012
Glass	0.3	6.27	0.012
Brick	28	3.75	0.038
Ceiling Board	0.9	3.66	0.001
Floor Board	2.2	1.5	0.014
Drywall	0.9	2.94	0.021

5. RESULT AND ANALYSIS

The case study described in section 4 has been modelled using WI software, the results obtained will be formed in a database with our proposed algorithm. Results obtained for localization estimation for both 2nd and 3rd floor has been illustrated in Figures 7 and 8 Respectively. It can be seen that the estimated coordination from our algorithm has showed a convergence to the actual coordination for some points which in turn will

increase the accuracy. While, for other points it shows divergence between this two coordination and resulted in an inaccurate result. To analyze the data in a much proper manner, the results of the two previous cases were listed in Tables 3 and 4 for both floor respectively. The reason for the variation in coordination and accuracy backs to the facts of using directional antenna of half power beam width (HPBW=90°) for AP devices in both floor, where in such antenna the power is concentrated in one direction known as main lobe. While, for other directions the power would be loser in value and knowing as side and back lobes. It is worth to mention, that the direction of the both antenna in each investigated floor were facing each other. Hence, several point which suffer from convergence results would fed from the main lobe and resulted in a higher accurate results in localization estimation. On the other hand, the point located far from the directional of antenna would fed from either the side or back lobes of the radiation pattern, where it will suffer from lower values of RSS and resulted in a low accurate localization estimation.

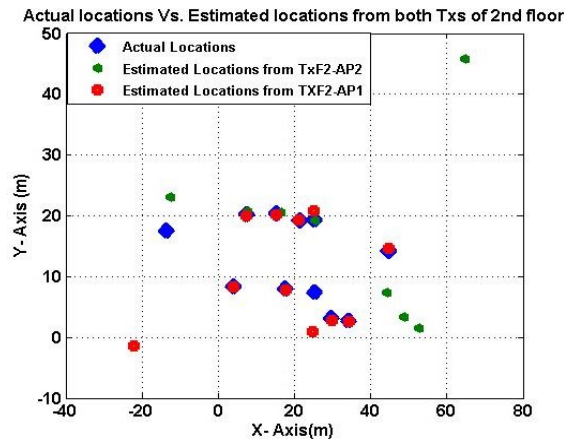


Figure 7. The actual and estimated coordinates of RXs in the 2nd floor

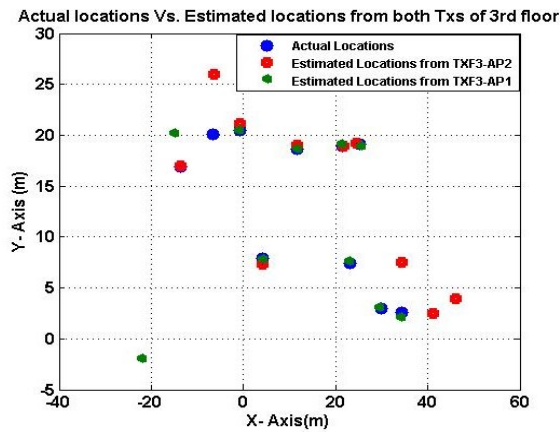


Figure 8. The actual and estimated coordinates of RXs in the 3rd floor

Table 3. The Tx locations and estimated Rx locations for 2nd floor

Rx's	TXF2-AP2 (21.4158,16.7108)					TXF2-AP1 (-1.0245,16.4809)				
	OP(RSS) (dBm)	d (m)	α°	x°	y°	OP(RSS) (dBm)	d (m)	α°	x°	y°
Rx1	-53.20	7.28	200.30	25.25	19.24	-57.31	31.17	344.49	25.06	19.82
Rx2	-36.58	3.96	220.39	21.43	19.28	-57.53	23.55	199.58	21.17	19.37
Rx3	-41.58	6.43	324.04	16.21	20.49	-55.80	18.51	208.21	15.29	20.23
Rx4	-51.63	13.47	343.22	7.51	20.60	-44.58	12.07	225.32	7.46	20.06
Rx5	51.07	18.52	26.69	3.87	8.39	-36.53	9.60	121.41	3.98	8.29
Rx6	-47.74	17.34	150.01	17.44	8.04	-39.20	20.70	155.34	17.79	7.84
Rx7	-54.25	24.65	157.51	44.19	7.28	-65.33	30.05	148.97	24.73	0.99
Rx8	-69.23	30.44	154.00	48.78	3.37	-60.19	33.65	155.93	29.70	2.76
Rx9	-80.73	34.62	153.80	52.48	1.43	-83.39	37.85	158.50	34.20	2.61
Rx10	-119.03	52.05	213.98	64.58	45.80	-68.74	45.71	177.74	44.65	14.68
Rx11	-43.56	34.56	349.51	-12.57	23.00	-80.75	27.56	40.40	-22.02	-1.38

Table 4. The Tx locations and estimated Rx locations for 3rd floor

Rx's	OP(RSS) (dBm)	TXF3-AP2 (17.1219,16.6987)				TXF3-API (-0.9786,16.6043)				
		d (m)	α°	x°	y°	OP(RSS) (dBm)	d (m)	α°	x°	y°
Rx1	-70.49	11.60	192.40	24.45	19.19	-56.87	27.18	193.50	25.45	18.95
Rx2	-55.29	8.00	195.88	21.81	18.89	-55.56	27.06	346.02	21.23	19.14
Rx3	-33.19	9.08	306.53	11.72	18.99	-43.27	14.45	209.18	11.64	18.65
Rx4	-49.94	20.20	331.97	-0.71	21.19	-43.60	9.23	335.50	-0.94	20.43
Rx5	-45.13	15.95	35.86	4.19	7.35	-37.27	10.23	120.46	4.21	7.79
Rx6	-49.05	19.60	152.12	34.44	7.54	-43.73	28.18	147.93	22.90	7.64
Rx7	-57.63	27.84	149.25	41.05	2.46	-56.80	36.28	147.14	29.50	3.08
Rx8	-74.54	31.70	156.19	46.12	3.90	-78.76	37.93	157.45	34.05	2.06
Rx9	-58.02	25.21	338.46	-6.32	25.95	-61.29	14.51	345.80	-15.05	20.16
Rx10	-41.03	30.89	359.50	-13.76	16.97	-79.55	28.14	41.18	-22.16	-1.92

In order to analyse the localization procedure and compare the actual coordination with estimated in much proper manner. It has been taken the average coordination value for each received point (Rx) from both AP's in each floor and compare it with actual coordination obtained from WI software per the deployment of our case study. These results were collected in Tables 5 and 6 for 2nd and 3rd floor respectively. It can be deduced that some Rx's were closer to the actual coordination as the Rx in 2nd floor ranging between (1-6) with error ranging between (0.002-0.2) m. However, points of Rx (7-11) were different in large manner due to the utilization of direction antenna and its allocation. The error ranging in this case were up to 10 m.

Table 5. Comparison between the actual and estimated locations in the 2nd floor scenario and ranging error

Rx's	Actual Location		Av. Estimated Location		Ranging Error	
	X	Y	X	Y	X	Y
Rx1	25.26	19.30	25.15	19.53	0.11	0.23
Rx2	21.29	19.23	21.30	19.33	0.01	0.10
Rx3	15.33	20.39	15.75	20.36	0.42	0.03
Rx4	7.49	20.28	7.49	20.33	0.00	0.05
Rx5	3.91	8.39	3.92	8.34	0.01	0.05
Rx6	17.53	7.97	17.61	7.94	0.08	0.03
Rx7	25.27	7.42	34.46	4.13	9.19	3.28
Rx8	29.67	3.18	39.24	3.06	9.57	0.12
Rx9	34.08	2.74	43.34	2.02	9.26	0.72
Rx10	44.60	14.22	54.61	30.24	10.01	16.02
Rx11	-13.62	17.58	-17.29	10.81	3.67	6.77

Table 6. Comparison between the actual and estimated locations in the 3rd floor scenario and ranging error

Rx's	Actual Location		Av. Estimated Location		Ranging Error	
	X	Y	X	Y	X	Y
Rx1	25.13	19.14	24.95	19.07	0.17745	0.0682
Rx2	21.41	18.97	21.52	19.01	0.11335	0.042
Rx3	11.60	18.68	11.68	18.82	0.0778	0.14185
Rx4	-0.81	20.48	-0.82	20.81	0.018293	0.3348
Rx5	4.15	7.88	4.20	7.57	0.052755	0.311475
Rx6	23.10	7.45	28.67	7.59	5.56645	0.14253
Rx7	29.87	2.96	35.28	2.77	5.4012	0.191085
Rx8	34.24	2.61	40.09	2.98	5.84605	0.373265
Rx9	-6.57	20.09	-10.68	23.06	4.111785	2.97045
Rx10	-13.73	16.91	-17.96	7.52	4.23145	9.388575

6. CONCLUSION

In this work, it has been investigated the localization by using the proposed algorithm and based on two known AP devices. These devices were considered as a directional antenna device, where it has been set the two devices in the same pre-located coordination in our targeted building and make these devices facing each other. It has been distributed several received points within the entire floor rooms for testing and measuring the RSS signal. Results obtained from our proposed algorithm in localization for each of these received points have been compared with the actual location. It has been concluded that our method achieve significant higher accuracy for localization in indoor environment. On the other hand the accuracy should be consider the location of these received point to be localize. Where some points as (1-6) showed high accuracy

with lower error ranging between (0.002-0.2). While other points located in relatively dead zones has failed to achieve the localization with high ranging error ranging upping to 10 meter.

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BIOGRAPHIES OF AUTHORS



Mahmood F. Mosleh Department of Computer Engineering Techniques, Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq. He received his B. Sc, M. Sc and Ph. D degrees in 1995, 2000 and 2008 respectively from University of Technology, Baghdad. He has been a Prof. of Communication Eng. at the Middle Technical University, Iraq. He has more than 60 publications in National and International Journals. Also, participate more than 20 International Conferences in the field of Communication Systems. Prof. Mahmood is the Head of Iraqi Electro-Technical Committee which joint the International Electro-Technical Committees, Member of Editorial Committee Technical Journal, and Member of various Committees for many International Conferences Organization.



Riam M. Zaal Department of Electrical Engineering, University of technology, Baghdad, Iraq. She received her B. Sc, and M. Sc degrees in 2005 and 2009 respectively from AL-Nahrain University, Baghdad, Currently, a PhD student in the Deepartment of Electronic and Communication Engineering, and I work as a teacher at AL-Mamon University College.



Eyad I. Abbas Department of Electrical Engineering, University of technology, Baghdad, Iraq. He received his M.Sc., M. Sc., and Ph.D. degrees in 1985, 1998, and 2004 respectively from University of Technology, Baghdad. He has been Asst. prof. of Electronic Engineering. In the Department of Electrical Engineering. He has more than 30 publications in National and International Journals. Also, participate more than 15 International Conferences in the field of Electronic and Communication Systems.