

## Accurate indoor positioning system based on modify nearest point technique

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### ABSTRACT

Wireless fidelity (Wi-Fi) is common technology for indoor environments that use to estimate required distances, to be used for indoor localization. Due to multiple source of noise and interference with other signal, the receive signal strength (RSS) measurements unstable. The impression about targets environments should be available to estimate accurate targets location. The Wi-Fi fingerprint technique is widely implemented to build database matching with real data, but the challenges are the way of collect accurate data to be the reference and the impact of different environments on signals measurements. In this paper, optimum system proposed based on modify nearest point (MNP). To implement the proposal, 78 points measured to be the reference points recorded in each environment around the targets. Also, the case study building is separated to 7 areas, where the segmentation of environments leads to ability of dynamic parameters assignments. Moreover, database based on optimum data collected at each time using 63 samples in each point and the average will be final measurements. Then, the nearest point into specific environment has been determined by compared with at least four points. The results show that the errors of indoor localization were less than (0.102 m).

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## 1. INTRODUCTION

In the last decade, positioning systems have seen demand that encouraged researchers and developers to construct positioning systems based on new techniques and methods. The aims of those techniques and methods are increase the reliability of systems in order to correspond with positioning system environments. Where, indoor localization could be used in sensitive issue such as, find victims, loss children, and guide firefighters. There are number of methods to design indoor positioning such as, time of arrival (TOA) [1], time deference of arrival (TDOA) [2], angel of arrival (AOA) [3], receive signal strength (RSS) [4]. The global positioning system (GPS) is common system which widely used as a prefer system, however, such system is suffer into big building lead to deny service [5].

In other hand, there are many challenges in indoor systems such as, multi path phenomenon, multi user interference, and regressive [6], [7]. Therefore, many systems designed to mitigate those problems and carried out positioning systems with high accuracy. The authors in [8] was applied positioning system using

scattering model. In this study, the authors have been tried to distinguish between deference environments to develop system deal with each scenario. Many techniques investigated through apply sectoring model such as statistics measurements which matching for each moment, also expectation maximization in addition to Bayesian algorithms was applied. The results that obtain from proposed algorithms are more accurate in estimate position compare with traditional algorithms. The authors in [9] have been proposed (RITEM) algorithm to improve indoor localization based on TOA. The authors implemented their algorithm by classify the ranging error based on signal measurements in data transmission. This classification includes four classes, with RSS and error interval for each class according to measurements which proceeded initialization of positioning system. In this case, the proposed algorithm has ability to estimate ranging error in online. The authors in [10] evaluated new algorithm to address the non-line-of-sight (NLOS) impact subsequently, improve system accuracy.

To utilize indoor positioning system based on both TOA and RSS, they applied the Triangle Centroid algorithm (TC) based on couple area. The idea of selected two areas is obtain the accurate measurements from each geometric area which selected. By substitute the enhance data into TC algorithm, the localization system will be implemented. Even with those solution, there are many challenges lead to rang of errors such as the unstable RSS measurements and the system could be suitable for some environments will suffer in other. Hence, the systems should take in account all challenges to carry out optimum system work under any scenario. Such system construct with accurate signal measurements and high quality in implementations and calculations by assigned suitable parameters. To reach that, modify nearest point (MNP) proposed in this paper. Such proposal aims to build accurate database to be reference measurements based on real measurements using number of samples. The nearest point will apply to find accurate RSS measurements lead to estimate correct position based on suitable parameters.

## 2. LOCALIZATION BASED ON RSS AND TOA

As mentioned Wi-Fi is common way to estimate location using RSS, the problem with this method is unstable RSS due to harsh indoor environments specifically in NLOS scenario and crowded signals. With those challenges, RSS measurements will be unpredictable. To solve those problems, Wi-Fi fingerprint technique can be used to find accurate RSS and then accurate distance based on those signal as the authors in [11]–[20], [21], [22]. The weighted K-nearest neighbor (WKNN) algorithm was used in estimate RSS by using nearest fingerprint to estimate location. Two scenarios presented in traditional WKNN, online scenario in addition to offline one. In offline situation there is database which contain measurements of signals measured as a reference. In online phase, actual RSS was measured and compared with reference RSS which measure previously to estimate the accurate RSS as in (1) [11].

$$d_{es_i} = (\sum_{i=1}^m |m_{RSS} - ref_{RSS}|^2)^{\frac{1}{2}} \quad (1)$$

Where  $m_{RSS}$ , is RSS which found in online phase,  $ref_{RSS}$ , is reference RSS which measured in offline phase and  $m$  is the number of access points (APs). Each reference points have been saved its euclidean distance in data base, with K-Nearest Neighbors (KNN), the postion with coordinate of  $(x, y)$  has minimum K reference points will be found as in (2):

$$(x, y) = \frac{1}{K} \sum_{i=1}^K (x_i, y_i) \quad (2)$$

The WKNN used to find the average of weight, hence, find suitable location as in (3):

$$(x, y) = \frac{\sum_{i=1}^K \frac{(x_i, y_i)}{dis_i}}{\sum_{i=1}^K \frac{1}{dis_i}} \quad (3)$$

To mitigate regressive signal problem, the value of RSS at each scenario will be stored in fingerprint data base. To implement that reference points defined as,  $RP_i = [RP_{i,OP1}, RP_{i,OP2}, \dots, RP_{i,OPn}]$  where  $i$  is number of RP, and  $RP_{i,OPj} = [RSS_{i,OPj,1}, RSS_{i,OPj,2}, \dots, RSS_{i,OPj,t}]$ , where  $j$  is number of APs. In this case the RPs have been matched with each APs, in fact,  $RSS_{i,j}$  is equal to test points in actual estimate position. Where  $TPs = [TP_{OP1}, TP_{OP2}, \dots, TP_{OPn}]$ , the smallest distance between  $TP_{OPj}$  and  $RP_{i,OPj}$  calculated as in (4):

$$d_{smallest} = \min |RSS_j - RSS_{i,OPj..k}| \quad (4)$$

where  $k$  is the result of ( $k$  th) fingerprint which stored in data base.

Now the smallest distance has been presented after compared with each APs, the final distance will be determine as in (5) [11]:

$$dis_i = \left( \sum_{i=1}^m d_{smallest}^2 \right)^{\frac{1}{2}} \tag{5}$$

Also, there is ability to apply multi matched with nearest APs as in (6) [11]:

$$dis_i = \left( \sum_i^m \left( \frac{d_{smallest}^2 + |rss_j - \overline{rss}_{i,opj}|^2}{rss_j} \right) \right)^{\frac{1}{2}} \tag{6}$$

where  $\overline{rss}$  is the mean values of each APs, now when distance with each RPs available the position of targets will be estimate using (6).

The estimated distance between RPs and targets can be estimated depending on spent time needs to reach receivers, where RPs could be access points or anchor points while the targets is the receives points. The exact distance can be calculating as in (7) [1].

$$d_i = ||x - x_i|| = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad i = 1.2. \dots . k \tag{7}$$

The distance between RPs and targets can be calculate depending on time of arrival as in (8) [1]:

$$d_i = C * (time_{arrival} - time_{sent}) \tag{8}$$

where  $C$ , is speed of light. As mentioned, there are constrains due to multipath environments. Therefore, (1) can be written as in (9) [1]:

$$d_i = ||x - x_i|| + \beta_i + m_i \tag{9}$$

where  $\beta_i(m)$  equal to 0 in line-of-sight (LOS) and greater than 0 in NLoS,  $m_i$  is noise value.

To estimate targets position, reference path loss calculates in one meter which recommended in [23], in addition there is called interested distance which can calculate as in (10) [1], [24]:

$$PL(d) = Plo - b_i - 10\gamma \log_{10} \frac{||x-x_i||}{d_o} \tag{10}$$

where  $Plo$  reference path loss,  $b_i$  is positive bias,  $\gamma$  is path loss exponent,  $z$  is the log normal shadowing express as a zero-mean Gaussian random variable, i. e.  $n_i \sim N(0, \sigma_{ni}^2)$  and  $m_i \sim N(0, \sigma_{mi}^2)$  is level of noise ( $m$ ).

When measurements of TOA and RSS as a one vector,  $p = [p_i]^T$  and  $d = [d_i]^T$ , ( $p, d \in \mathbb{R}^N$ ). Then joint likelihood function can write as following [25]:

$$\Lambda(p, d|x, b_i, \beta_i) = p(p|x, b_i) p(d|x, \beta_i) = \frac{1}{\sqrt{2\pi\sigma_{ni}^2\sigma_{mi}^2}} \left\{ \exp - \frac{(p_i - p_o + b_i + 10\gamma \log_{10} \frac{||x-x_i||}{d_o})^2}{\sigma_{ni}^2} - \frac{\sigma_{mi}^2 + (d_i - ||x-x_i|| - \beta_i)^2}{\sigma_{mi}^2} \right\} \tag{11}$$

Also, the hybrid ML for ( $x, b_i, \beta_i$ ). can be written as in (12) [26]:

$$\{x, b_i, \beta_i\} \text{ rgmin } \sum_{i=1}^N x, b_i, \beta_i \tag{12}$$

However, according to [25], the equation above does not close from exact results, also it's difficult to distinguish between LOS and NLoS. Accordingly, hybrid ML is not perfect solution for multipath impact. The authors in [25], suggested an integrated TOA and RSS to employ the advantage for both techniques which can be mitigate the corresponding drawback for each one. To estimate targets located, trilateration method could be applied as shown in Figure 1, which depending on distances between RPs and targets [24], [27]. Then, the coordinate of targets can be calculated as following [28].

$$x = \frac{x_2^2 + d_1^2 - d_2^2}{2 \times x_2} \quad (13)$$

$$y = \frac{x_3^2 + y_3^2 + d_1^2 - d_3^2}{2 \times y_3} \quad (14)$$

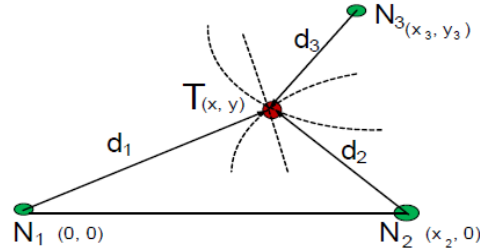


Figure 1. Estimate position using trilateration methods

### 3. SYSTEM MODEL

For simulation issues, wireless InSite package (WIP) used to implement case study building that corresponding with real one. Firstly, one of very important feature in WIP is the material's conductivity and permittivity calculated to be close from real building. According to [29], there are different effect based on the type of materials used for construction. Therefore, by simulate indoor environments, it should be taking into considerations the content of building. Table 1, depict the parameters of many materials which used to setup both  $\sigma$ ,  $\eta$  in WIP and calculate as following [30]:

$$\sigma = c f^d \text{ GHz} \quad (15)$$

$$\eta' = a f^b \text{ GHz} \quad (16)$$

where a, b, c and d are defining by International Telecommunication Union (ITU) and worth to know that the ITU recommended to assign zero to constant b in term of permittivity to be constant for each frequency.

Table 1. Constant values for common indoor materials [30]

Material Type	Constants for calculating $\eta'$		Constants for calculating $\sigma$	
	a	b	c	d
Concrete	5.31	0	0.0326	0.8095
Brick	3.75	0	0.038	0
Wood	1.99	0	0.0047	1.0718
Glass	6.27	0	0.0043	1.1925
Ceiling Board	1.50	0	0.0005	1.1634
Plaster Board	2.94	0	0.0116	0.7076
Floor Board	3.66	0	0.0044	1.3515
Metal	1	0	10E7	0

In this paper, the transmitters setup based on 2.4 GHz frequency to deal with experimental transmitters. For calculate conductivity and permittivity, MATLAB geographic user interface (GUI) designed to implement conductivity and permittivity calculations. The input of GUI is the type of required material and the operating frequency. The output is the suitable conductivity and permittivity for selected materials. By apply (16) and (17), the conductivity and permittivity for 2.4 GHz as show in Table 2 will be gotten to be ready to use in WIP. Moreover, in Table 1 clearly noted the permittivity equal to constant a due to constant b equal to zero. The three dimensional (3D) designed with exactly real building measurements based on WIP as shown in Figure 2 after prepared the required parameters of materials. In the selected areas as shown in Figure 3, 80 points tested to be reference RSS in addition to 9 targets deployed in interested area. Such building is separated to 7 environments to assigned specific parameters when estimate the targets.

The reference pointes tested by using WIP in similation side and Net Spot sftware in expermental side, such software has a lot of abilities to measure the RSS that propogated in interested area without connect to those sources. The other important things is the impact of other sources such as the movments of persons

who use mobiles. Therefore, the measurements measured based on average values of RSS at period of time and all steps of targets estimation depict in Figure 4.

Table 2. Conductivity and permittivity for 2.4 GHz

Material type	Conductivity	Permittivity
Concrete	0.0926	5.31
Brick	0.1079	3.75
Wood	0.0134	1.99

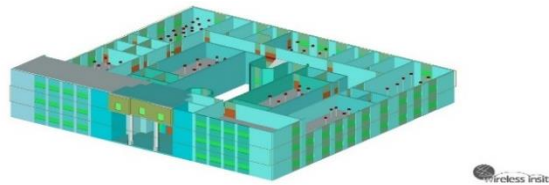


Figure 2. The case study building

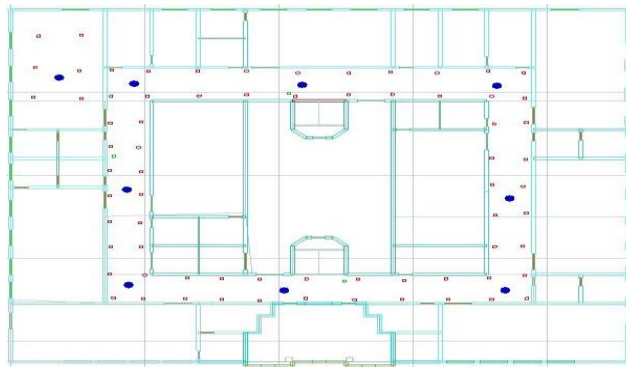


Figure 3. The targets and reference points deployments

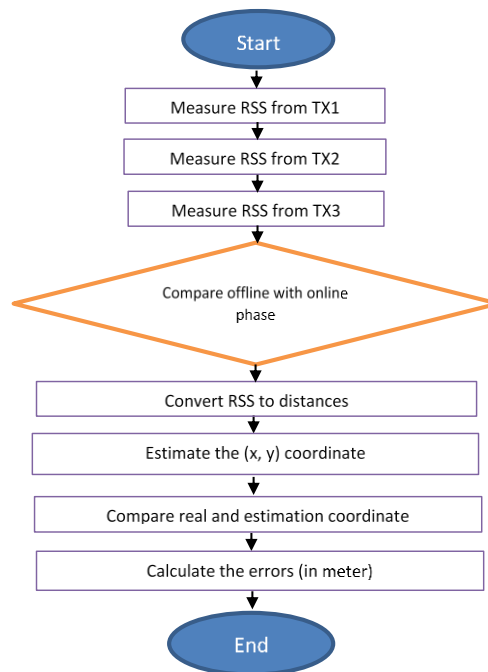


Figure 4. The flow chart of the proposed system

#### 4. RESULTS AND DISCUSSION

In case study building there are 9 targets was deployed, the RSS measurements play main role to find the accurate position of those targets. In Table 3, the measurements of test and reference RSS listed. In case of the RSS measurements are inaccurate comparing with the reference one as clearly shown in Table 3, the system will be inaccurate also.

The distances of targets will calculate based on (13) when the RSS measurements available to find the location in first estimation. In this scenario, the error is high but this step applied to determine the environments of the targets and this very useful for next step. Table 4, shows the estimate and the real coordinates to determine the environments. The error in first estimation was (2.6 m), but even with this error the environments determined to apply the second step by find nearest point and then final estimation. To modify the RSS measurements to be so close from reference one, nearest points applied by using (4) through (6) to find nearest access point (APs) and correct the measurements. In Table 5, clearly noted how to the RSS values modified to be nearest from Predictable one.

Table 3. The RSS measurements before matching data

RXs	Test RSS (dBm)	Reference RSS (dBm)
1.	-52.66	-46.57
2.	-61.72	-56.65
3.	-52.13	-54.22
4.	-61.69	-61.64
5.	-54.44	-49.21
6.	-62.41	-54.34
7.	-65.88	-53.67
8.	-62.17	-63.19
9.	-63.34	-54.18

Table 4. The targets coordinates in real & estimate scenarios.

x-axis	y-axis	Estimat(x-axis)	Estimat(y-axis)	x-axis error(m)	y-axis error(m)
4.78	-7.01	5.61	-7.91	0.82	0.91
10.07	-7.65	9.08	-7.59	0.98	0.05
22.55	-8.07	26.67	-9.27	4.13	1.1
37.26	-7.86	35.65	-10.76	1.62	0.91
38.21	-21.61	36.98	-22.69	1.22	1.07
37.78	-32.83	40.55	-33.85	2.17	1.01
21.07	-32.51	22.09	-31.58	1.03	0.94
9.45	-32.09	9.49	-33.12	0.05	1.02
9.54	-22.45	10.04	-23.58	0.4	3.02

Table 5. The RSS measurements after matching data

RXs	Test RSS (dBm)	Reference RSS (dBm)
1.	-43.98	-45.87
2.	-54.34	-55.65
3.	-57.13	-59.22
4.	-61.69	-60.64
5.	-47.35	-48.21
6.	-54.89	-56.34
7.	-57.32	-57.67
8.	-62.88	-63.19
9.	-57.34	-58.18
10.	-51.21	-51.58
11.	-70.23	-70.33
12.	-53.11	-53.82
13.	-53.69	-53.66
14.	-64.9	-63.34
15.	-65.65	-66.78
16.	-64.9	-64.22

The second step apply to find accurate position, in this step dynamic parameter assigned based on different areas. In Figure 5, the calculation of errors recalculated based on the new measurements denoted by (OP-RSS) and parameters, the results shown error (0.18 m) in distance (34 m) between targets and transmitter. By using the measurements obtained from WIP, the location of targets estimated based on dynamic TOA denoted by ( D-TOA) and the error as shown in Figure 6, is (0.221) therefore, the RSS is slightly better than

TOA. Finally, Table 6, shown coparsion between proposed technique in term of OP-RSS and D-TOA compared with traditional RSS and TOA.

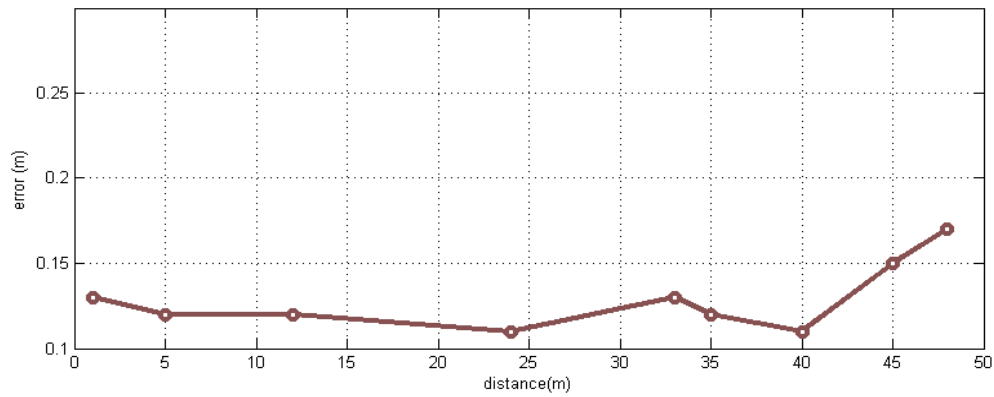


Figure 5. The errors (m) compared with the distance in second estimation based on OP-RSS

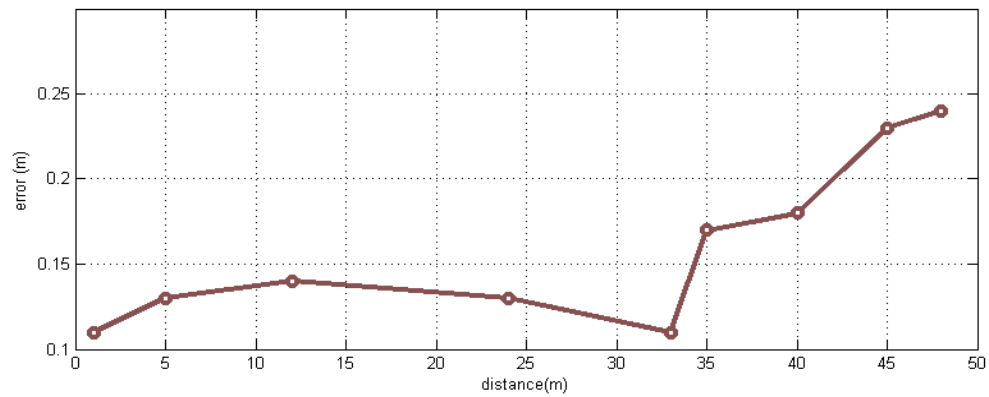


Figure 6. The errors (m) compared with the distance based on D-TOA

Table 6. The comparison between propose technique and traditional RSS and TOA

Index	Error(m) based on TOA	Error(m) based on D-TOA	Error(m) based on RSS	Error(m) based on OP-RSS
1	1.22	0.11	1.01	0.13
2	1.23	0.134	1.13	0.121
3	1.74	0.145	1.51	0.12
4	1.66	0.139	1.27	0.115
5	1.45	0.111	1.52	0.138
6	2.28	0.171	2.23	0.122
7	2.44	0.182	2.14	0.113
8	2.85	0.231	2.25	0.153
9	2.56	0.242	2.28	0.173

### 5. CONCLUSION




Indoor localization system carried out based on accurate RSS measurements, such system applied by using sequence of important procedures to reach in the end optimum system. First procedure is testing 78 RSS in term of simulation and experimental scenarios. The experimental side implemented based on Net Spot software while the simulation side was done by using WIP. Such measurements take in consideration the multiple source of noise such as the movements of humans into building who used the mobile phone in addition to number of deployed APs. The first estimation was very useful to determine the target's environment. The matching of the RSS values with nearest points in determined environment improved the accuracy. The second estimation is by assigning a specific parameter which calculated previously for each area into building. Those procedures improve the performance of the system. In the first estimation the average distance error was (2.5 m) while (0.125 m) in the second on.

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