Short Range Indoor Distance Estimation by Using RSSI Metric

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Abstract: *Indoor localization problem is a highly preferred research area in recent years. Estimating the location of a communication node is essential in many fields including swarm robotics, wireless sensor nodes etc. In applications without a reference point, relative localization of the nodes with respect to each other is preferred. In order to estimate the relative positions of the communication nodes, the distance information of each node with respect to other nodes is required. In this paper, it is aimed to estimate the distances between the nodes by using the received signal strength (RSS) information. For an indoor environment, the distances between the nodes are estimated by using the Received Signal Strength Indicator (RSSI) parameter provided by the wireless communication infrastructure, namely Wi-Fi.*

Keywords: *Indoor distance estimation, RSSI.*

1. Introduction

Many recent technologies, like wireless sensor nodes [1] or swarm robotics [2,3], employ several communication nodes for different application fields. In some applications estimating the position information of each communication node is important to achive the goal. For example in team robotics, any node is assigned a task. To accomplish the given task successfully, the nodes have to know the position of themselves and each other. Position information is also essential for localization of mobile devices in indoor environments especially for commercial applications [4]. One way to evaluate the position of each node is to estimate the distances between the nodes and locate each node by using triangulation techniques [5]. Communication metrics are parameters provided by the hardware used. Some metrics provide information that can be used to estimate the distance between the nodes. Several methods have been proposed for indoor distance estimation using wireless communication metrics. The two main methods are time based distance estimation methods [6,7] and received signal strength (RSS) based distance estimation methods [8,9]. Güvenç and Chong (2009) presents a survey of Time of Arrival (ToA) researches and compare their results [10]. Doğançay (2005) proposed a closed form Time Difference of Arrival (TDoA) based distance estimation method, he clustered the bearing angles with linear asymptotes to associate the asymptotes and the results show significant improvement [11]. Mazuelas et al. (2009) used only the real-time RSSI information to locate a node in an indoor environment that contains an unmodified WLAN network [12].

RSSI based distance estimation is preferred by many researchers and has been used in many applications for indoor positioning. The wireless communication metrics can be used in both hybrid and non-hybrid localization techniques. RSSI is used along with TDoA and ToA in the work of Laaraiedh et al. (2011) to compare the hybrid localization schemes [13]. In the work of Xiao et al. (2011), indoor wireless positioning metrics, such as ToA, TDoA, Angle of Arrival (AoA) and RSSI, are compared. In this work, the positioning precision of TDoA for an UWB system is defined as a few centimeters to tens of centimeters, while it is tens of centimeters to tens of meters for an RSSI metric of a Bluetooth system [14]. Even though it is said that TDoA based distance estimations have advantages over RSSI, Hara and Anzai (2008) compared the experimental results of both estimation methods. Results showed that, for a crowded area, where Line Of Sight (LOS) between the nodes is being interrupted frequently, RSSI has advantages over TDoA [15].

In this work, the preferred wireless communication metric is the RSSI, distance between two nodes will be estimated by using signal strength - distance relation (SSDR) models. Three of these models are International Telecommunication Union (ITU) Indoor Path Loss Model,

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Two-Ray Ground Reflected Propagation Model and the experimantally derived model named of Experimentaly Derived Signal Strength Distance Relation Model (EDR).

With the use of these three SSDR models, the distances between the communication nodes can be estimated by using RSSI metric. ITU indoor path loss model, is emphasized for the measurements taken in indoor office environment for site-specific validation of the model in the work of Chrysikos et. al. (2009) [16]. The basis of the second model, Two-Ray, can also be used as a relation model and in the work of Lassabe et. al. (2005) it is used to locate Wi-Fi terminals in an indoor environment [17]. They also compare the accuracy results of their work with the other solutions. Sommer and Dressler (2011) examined the Two-Ray Ground path loss models and they proposed an alternative model, for positioning vehicles on the road, Inter-Vehicle Communication Protocols [18]. The last model is the emprical deriven EDR model. This model is based on RSSI measurements and the real distances that RSSI measurements are recorded. Türkoral et al. (2016) proposed this experimental method as an alternative to the other indoor distance estimation techniques for a specific hardware implementation [8].

2. Methodology

In this paper, it is aimed to estimate distances between communication nodes in a wireless communication network by using the RSSI metric provided by the communication infrastructure. The RSSI metrics are recorded and the corresponding distance is estimated by using three distance etimation methods presented previously.

2.1. Measurement

Every communication node consists of a single board computer (Raspberry Pi 1st Gen.) as the controller and a USB Wi-Fi dongle with a Realtek RTL8723BU integrated circuit on board. The measurement process is done in two ways.

2.1.1. 1st Measurement Method

This method relies on the measurements between only one receiver and one transmitter. The measuring process of this method is presented in Figure 1.

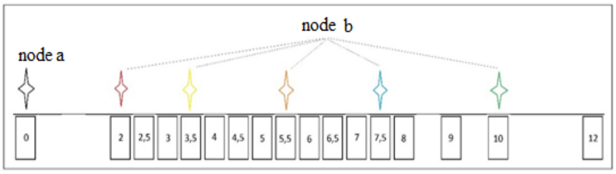

Figure 1. Representation of the 1st Measurement Method

The measurements are performed in an office building. One node is set to the origin and the other is moved according to the measurement points which are denoted as numbers as presented in Fig. 1. The measurement points are placed between 2 -12 m. Because, when the distance is lower than 2 m and higher than 12 m, the RSSI outputs are kept at a constant level determinde by the hardware. Hence, the distance cannot be estimated besides these limits. Until the distance reaches 2 m. between the nodes, the RSSI is always at its maximum value, -47 dBm, and after 12 m the signal strength is at its minimum value, -70 dBm.

2.1.2. 2nd Measurement Method

The 2nd method can be used more for the localization systems. The nodes are located by a layout, and the measurements are taken according to that layout. The representation of the 2nd method is illsutrated in Figure 2.

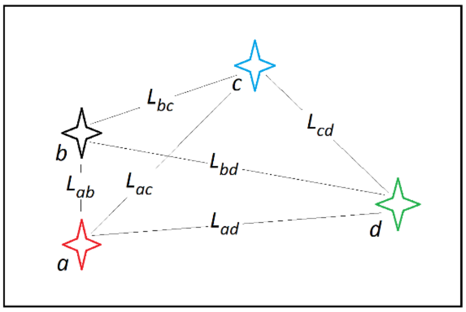

Figure 2. Illustration of the 2nd Measurement Method

The distances between the nodes that are estimated by using the RSSI recordings taken with this method can be directly used in a localization algorithm. The RSSI metrics are recorded 20 times for each measurement setup in order to eliminate the instant errors. The mean of the 20 recordings are the actual RSSI metric that is going to be used in the distance estimation process. This process is done in a basement of a school building. Hence, both the method and the environment is different for the two measurement methods.

2.2. Distance Estimation

The three distance estimation methods used in this work are presented in this section.

2.2.1. ITU Indoor Path Loss Model

ITU is an indoor path loss model that depends on some exponents and constants. ITU Model is presented in Equation 1.

$$P_t - P_{RSSI} = 20\log_{10}(f) + N\log_{10}(d) + L_f(n) - 28dB \qquad (1)$$

where,

P_t is the transmitted signal stregnth,
P_{RSSI} is the received signal strength,
f is the frequency, which is 2.4 GHz
N is the power loss coefficient,
$Lf(n)$ is the floor penetration loss,
n is the floor difference of the receiver and transmitter,
and d is the estimated distance [19,20].

P_t is given as 13 dBm at the product datasheet [21]. The transmitter and the receiver are always at the same floor so the floor difference n is *0*. When all the values are set, the equation becomes;

$$13 - P_{RSSI} = 20\log_{10}(2.4*10^9) + N\log_{10}(d) + L_f(0) - 28dB \tag{2}$$

This estimation model depends on the number floors between the receiver and the transmitter, operating frequency and the ambient conditions. For different frequencies and different environmental materials, these factors change and the total loss differs from one another.

2.2.2. Two-Ray Ground Reflected Path Loss Model

This model is based on the free space propagation model but it also utilizes the reflected signal which is the ground reflected one of the same source. In Figure 3, the illustration of the signal paths for this model can be seen.

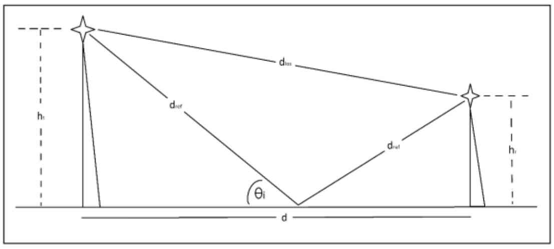

Figure 3. Two-Ray Model signal paths

The mathematical expression of this model is presented in Equation 3.

$$P_{RSSI} = P_t + G_r + G_t - L_{tr} \tag{3}$$

In Equation 3, P_{RSSI}, P_t, G_r, G_t and L_{tr} represent the received signal strength, transmitted signal strength, receiver antenna gain, transmitter antenna gain and the path loss respectively [22]. P_{RSSI} is provided by the RSSI recordings, P_t is determined by the hardware and is given by 13 dBm, both the receiver and the transmitter are identical so the antenna gains G_r and G_t are 1.7 dBm (taken from product datasheet, [23]). The path loss is defined as;

$$L_{tr} = 20\log(\frac{d^2}{h_t h_r}) \tag{4}$$

where h_t, h_r and d are the transmitter antenna height, receiver antenna height and the desired distance respectively. Since the receiver and transmitter antenna heights are equal, the formula becomes;

$$L_{tr} = 20\log(\frac{d^2}{h^2})$$
(5)

where h represents both the antenna heights. Hence, the resulting path loss model is;

$$P_{RSSI} = P_t + 2G - 20\log(\frac{d^2}{h^2}) \tag{6}$$

where G represents the identical antenna gains. As can be seen, Two-Ray Model relies on the antenna heights and gain aside of the transmitted and received signal strengths.

2.2.3. EDR Model

This model is based on the actual measurements and the relating distances. For both the measurement methods presented in the previous section, the mean of the RSSI recordings are plotted with respect to the distances they are measured. Then an exponential curve is fitted to the RSSI-distance plot and that curve is called the EDR Model. For the 1st MM, the EDR Model is presented in Figure 4 and Equation 7. For the 2nd MM, the 2nd EDR Model is presented in Figure 5 and Equation 8.

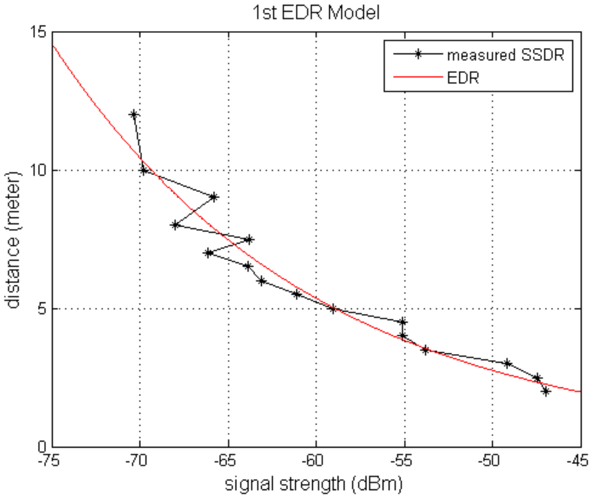

Figure 4. EDR Model for the 1st MM

The black line in Figure 4 represent the actual measurements versus the corresponding distances. An exponential function is fitted to that curve and the EDR Model for the 1st MM is defined (red curve) by using the Matlab Curve fitting function. The mathematical expression of the 1st EDR Model is presented in Equation 7.

$$d = 0.09878.e^{-0.06658P_{RSSI}} \tag{7}$$

The 2nd EDR Model is presented in Equation 8 and Figure 5 for measurements taken with using the 2nd MM.

$$d = 0.1777.e^{-0.06364P_{RSSI}} \tag{8}$$

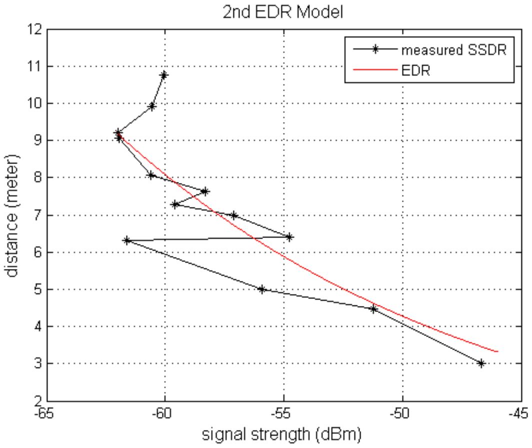

Figure 5. Derivation of the 2nd EDR Model

EDR Model is a specific model that strictly relies on the environmental conditions. Hence, to use this method, at least one EDR Model should be derived for every measurement area.

3. Results

In this section, the distance estimations for both of the methods is presented. Two measurement methods and three distance estimation methods yield a result set of six parts. In the following, ITU Model, Two-Ray Model and EDR Model results are presented.

3.1. ITU Model Distance Estimation Results

In order to estimate the distances by using the RSSI metric data, first, we need to set the exponents for the specific environmetal and working conditions. The remaining unknown exponents of the ITU Model are *N* and L_f. For both measurement methods, these exponents must be set to estimate the distances properly. To do that, the differences of the actual distances and the estimated distances are calculated for various combinations of *N* and L_f. From 10 to 40, for every *N* and L_f combination, the distance error is evaluated. The illustration of this distance error is presented in Figure 6 for the 1st MM.

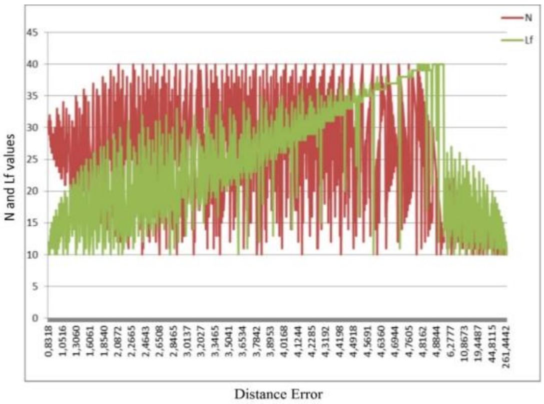

Figure 6. ITU exponents vs. distance error

With this approach, the ITU exponents are set for both measurement methods. The resulting N and L_f values that give the minimum mean distance error are 28 and 11 for the 1st MM, 25 and 10 for the 2nd MM respectively. These values are also consistent with the literature [11,12]. The resulting ITU equations when the desired value, the distance *d*, is left alone at one side of the equality, are presented in Equation 9 and 10 for the 1st and 2nd MM respectively.

$$d_{1st} = 10^{-\frac{(P_{RSSI}+38.44)}{28}} \tag{9}$$

$$d_{2nd} = 10^{-\frac{(P_{RSSI}+37.44)}{25}} \tag{10}$$

The distance estimation results of ITU Model for the 1st MM is presented in Figure 7. The resulting mean distance error which is the average value of the absolute differences of each actual and estimated distances, is found approximately 66 cm. The distance estimations and the actual distances are compared and illustrated in Figure 8 for the 2nd MM.

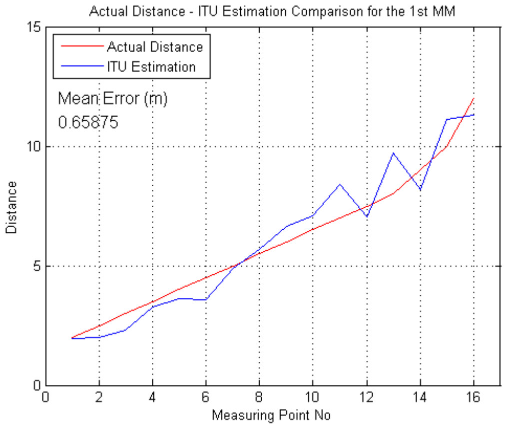

Figure 7. ITU estimations for the 1st MM

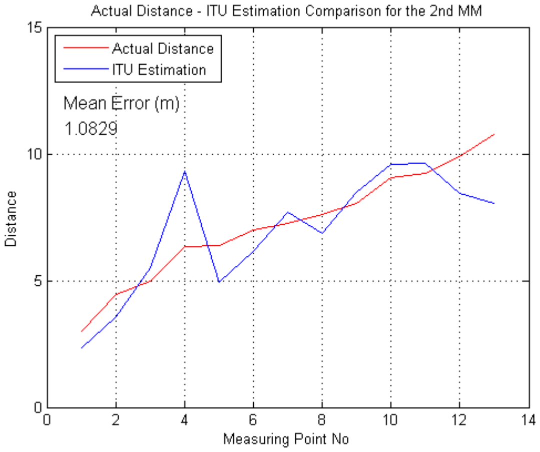

Figure 8. ITU estimations for the 2nd MM

This set of results yield a mean distance error of approximately 108 cm for the 2nd MM.

Hereby, the results of the first path loss model that is used to estimate the distance values are presented in this subsection.

3.2. Two-Ray Model Distance Estimation Results

The 2nd method to estimate distances is the Two-Ray Model. When the results of this model are observed, ,the actual distance curve and the estimation curve were nearly parallel but with a difference as can be seen in Figure 9. This difference is considered as an extra loss factor caused by the environment. Hence, two different equations are for MM1 and MM2. The equation that is used to estimate the distance for the 1st and the 2nd measurement methods are presented in Equation 11 and 12 respectively.

$$d_{1st} = h.10^{\frac{P_t + 2G - P_{RSSI} - P_l}{40}} \tag{11}$$

$$d_{2nd} = h.10^{\frac{P_t + 2G - P_{RSSI}}{40}} \tag{12}$$

P_t is 13 dBm and G is 1.7 dBm for both of the equations and the extra loss factor P_l is found to be approximately 7 dBm. The results of Two-Ray Model are presented in the following illustrations for both the measurement methods, the effect of the extra loss factor P_l is shown with another curve by observing the results of the lossless system.

Figure 9 illustrates the distance estimation results of the 1st MM. As can be seen, when the loss factor is added to the system for this specific environment, the mean distance error decreases to an acceptable level. Where the mean distance error is 281 cm for the lossless system, it is approximately 57 cm when the extra loss factor is added for the first environment.

Figure 9. Two-Ray estimations of the 1st MM

The distance estimation results of the 2nd MM are presented in Figure 10. Even if the extra loss factor P_l is not added to the system, the mean error performance is close to the previous application where the current mean error is approximately 87 cm. The environment and the measurement method is different, but Two-Ray Model yields considerably acceptable results.

Figure 10. Two-Ray estimations of the 2nd MM

3.3. EDR Model Distance Estimation Results

EDR Model is the last distance estimation method that is used in this study. This experimental method is derived for both of the measurement methods. The resulting distance estimations yield a mean distance error of approximately 53 cm and 84 cm for the 1st and 2nd MM respectively. As a general rule, the less the mean distance error the better the algorithm. As can be seen from Figure 10, even if the mean distance error is considerably low, for some measurement points, the distance error is very high. Measuring point no:4 is a great example to this statement. Figures 11 and 12 show the actual and estimated distance comparison for both MMs for EDR Model.

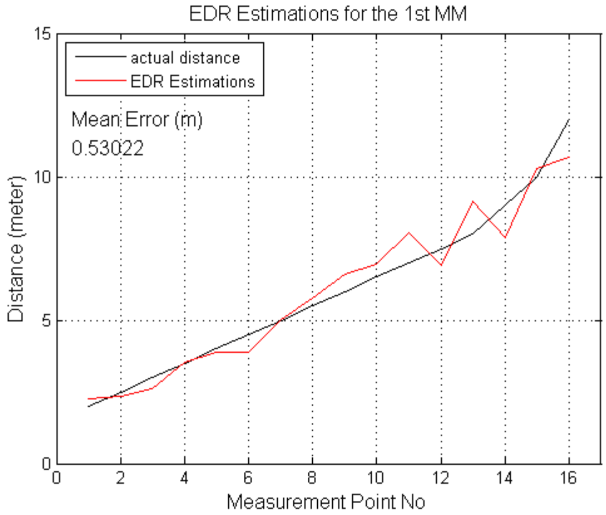

Figure 11. EDR estimations of the 1st MM

In Figure 11, the distance estimation results of the EDR Model for the 1st MM is presented.

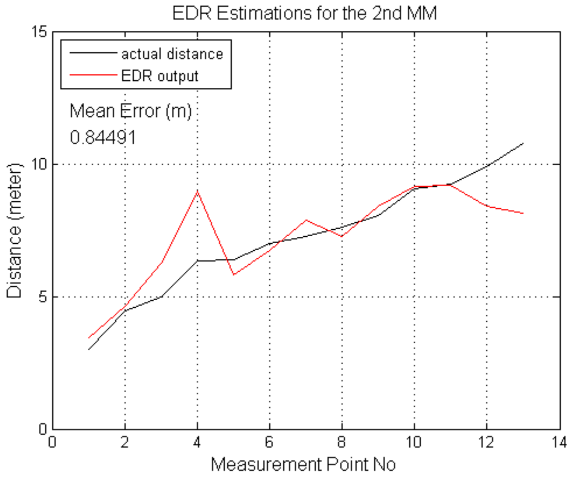

Figure 12. EDR estimations of the 2nd MM

Figure 12 illustrates the distance estimation result of the EDR Model for the 2nd MM.

3.4. Performance Comparison

In this section, the distance estimation results of the 3 methods are compared for both the measurement methods.

Table 1 and Table 2 contains the mean distance estimations of each measurement point. Also the mean distance error of all the distance estimation methods are presented in the tables.

Table 1. Performance comparison for the 1st MM

Results of the 1st MM				
M. Point	Actual Distance (m)	ITU Estimations (m)	Two-Ray Estimations (m)	EDR Estimations (m)
1	2,00	1,93	2,57	2,25
2	2,50	2,01	2,64	2,37
3	3,00	2,26	2,96	2,74
4	3,50	3,27	3,90	3,65
5	4,00	3,67	4,25	4,04
6	4,50	3,61	4,23	3,96
7	5,00	4,82	5,15	5,05
8	5,50	5,73	5,79	5,79
9	6,00	6,74	6,54	6,67
10	6,50	7,11	6,81	6,99
11	7,00	8,42	7,74	8,11
12	7,50	7,04	6,86	6,97
13	8,00	9,72	8,62	9,19
14	9,00	8,20	7,73	7,98
15	10,00	10,52	9,36	9,84
16	12,00	10,93	9,68	10,33
approximate mean distance error		0,66	0,57	0,53

According to Table 1, there are 16 measurement points which the RSSI recordings are taken at between 2 m and 12 m. Resulting distance error values show that the best results are provided by the EDR Model, than Two-Ray Model and lastly ITU Model. The mean distance error values are close, 66 cm for ITU, 57 cm for Two-Ray and 53 cm for EDR Model.

Table 2. Performance comparison for the 2nd MM

Results of the 2nd MM				
M. Point	Actual Distance (m)	ITU Estimations (m)	Two-Ray Estimations (m)	EDR Estimations (m)
1	3,00	2,36	3,78	3,47
2	4,47	3,65	4,95	4,68
3	5,00	5,56	6,45	6,27
4	6,32	9,34	8,94	8,98
5	6,40	5,00	6,03	5,82
6	7,00	6,26	6,94	6,80
7	7,28	8,34	8,18	8,18
8	7,62	6,88	7,38	7,27
9	8,06	8,49	8,42	8,41
10	9,05	9,66	9,12	9,19
11	9,22	9,69	9,14	9,21
12	9,90	8,47	8,41	8,40
13	10,77	8,10	8,17	8,14
approximate mean distance error		1,12	0,88	0,87

The distance estimation results of the 2nd MM yields that, the error performances of the distance estimation models are similar to the results of the 1st MM. However, the mean distance error values are considerably different from the predecessor. The mean distance errors of ITU, Two-Ray and EDR Model are approximately 112 cm, 88 cm and 87 cm respectively. The resulting performances of the EDR model and Two-Ray Model is nearly the same even if the individual distance estimations for the measurements points vary.

5. Conclusions

In this study, distance estimation between two nodes using three different propagation models based on the RSSI metric data are presented. The propagation models employed are, ITU Indoor Path Loss Model, Two-Ray Ground Reflected Path Loss Model and EDR Model for a specific environment. For two different environments, the results of each model are examined. The results show that, for a short range indoor distance estimation, with the particular hardware and environment selection, EDR Model provides the best results.

By applying these set of distance estimations into a positioning algorithm, one can locate a node with a considerably acceptable error depending on the application. This positioning error can also be reduced by smoothing the distance estimations by weighting the results of each distance estimation methods. After the determination of which method is best for what range, with the proper weighting of each method, all three methods can be used together to reduce the error.

Consequently, this work provides a basic knowledge about indoor distance estimation methods and metrics.

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