Evaluation of dynamic Localization System Based on UWB and Wi-Fi for Indoor Environments

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Abstract. Due to limitations and complexity in indoor communications, many wireless technologies deployed to correspond with those challenges. The Ultra-Wideband (UWB) wireless communication for indoor environments is one of the widespread bands developed for convey high data rate. The other widespread band is 2.4GHz based on Wi-Fi technology. Each of the mentioned bands could be convenient for specific areas and not for others based on long or short-range communications. In this paper, both bands are applied for indoor environments to find the target’s locations. A new technique based on Multi-Scale Bands with Dynamic approach (MSBD) is applied to implement an optimum system. The three dimensional (3D) case study building designed based on Wireless Insite Package with real building geometric measurements. It is worth to mention that both bands are applied based on dynamic parameters to assign specific parameters for specific environments. The average error in the whole building based on static parameters using UWB is (1.023m) while (0.452m) based on individual 2.4GHZ. The obtained results confirm that the proposed MSBD technique is significantly outperformed individual band with static parameters. The enhancement is noted from error range which improved from (1.023m) to (0.08m) for UWB and (0.452m) to (0.15m) for 2.4GHz. For optimum system, the UWB was deployed for a distance under (10m) and Wi-Fi for other distance. By deploying both technologies and using the dynamic system, the performance of the proposed system worked with accurate measurements in short and long-distance in addition to both LOS and NLOS scenarios identify relevant articles in literature searches, great care should be taken in constructing both.

1. Introduction

The advanced communications enhancements have been proceeded in the early 1990s following by several generations of communications technologies. The implementations of wireless communication systems and the integration of the networking services have fostered demand increase for WLAN in the last decade. This demand has led to a number of standards that have developed to correspond with wireless service demand. For low cost and tiny equipment, 802.11b was presented and 802.11g standards for stability [1]. In addition to many frequency ranges based on Wi-Fi technology deployed such as 2.4GHz. Such frequency is carried out for a high data rate that conveys between multi smart devices. The Ultra-wideband (UWB) technology allows several unique wireless communications capabilities in many user applications. Such technology deals with high-resolution radars in addition to high rate communications. There are great features in UWB especially in position system with short-range. Those features include high power efficiency due to low convey duty cycle in addition to high bandwidth [2].

According to those features, UWB widely recognized in the big building, especially with positioning aspects. Indoor positioning systems (IPs) have gained attention recently years according to important sectors which beneficial for these systems. Such a system is so important in emergencies such as find loss children, tracking someone in security issue into the building, and very useful for firefighters to guide themselves. According to those critical aspects that system was designed for, such a system required high accuracy and there is no chance for errors. Subsequently, there are several methods to implement positioning systems which some of those methods suitable for some applications and not for others. Such methods are Time of Arrival (TOA) which depending on the time the signal spent to reach receivers [3]. Time Difference of Arrival (TDOA) is similar to TOA, however, it is calculated the
defercence time from multi Access Points (APs) [4]. Receive Signal Strength (RSS), which measure the strength of the signal in term of (dBm) to find the distance to targets [5]. While the Angle of Arrival (AOA) method, there is an angle will generate when targets receive signal, this angle will be used to estimate position [6]. However, there are considerations in indoor environments that differ from outdoor. Therefore, the Global Positioning System (GPS) serves are constrained in a crowded building [7]. For this reason, IPs are designed with specific features to mitigate indoor challenges. One of those challenges is a multi-path phenomenon which happened when receivers receive several paths as a reflection from walls and objects [8]. To address those constraints, the developers have proposed many solutions to improve the performance of the system by mitigating the impact of NLOS and derive many mathematical equations. The major solutions were constructed based on NLOS identifications [9], or fingerprint techniques to estimate accurate RSS value [10]. However, the basic implement of any systems will be based on a database of RSS measurements measured on offline phase. Therefore, by some source of effects, the measurements of signals will be so far from real one will lead to inaccurate Reference RSS. The other scenario, the distance between the targets and reference points in term of short or long distance, hence, the preferred technology in long-distance could be unreliable in a short one. In this paper, all those considerations have taken into account to achieve optimum system works under any scenario. Such a system will use the high data rate of UWB in a short distance and high accuracy in long distances in addition to widespread of Wi-Fi. It should be noted that using both technologies is not the only solution for our system. The dynamic parameters will be the backbone of measurements to estimate accurate locations taking into consideration specific parameters for a specific area. All mentioned procedures will lead to the objective of this study by carrying out optimum positioning system works with high accuracy under different conditions.

2. Related Works
The positioning system in most projects implemented based on one of the signal characteristics methods such as TOA and RSS. Moreover, many wireless technologies deployed to achieve IPs deals with indoor environments. The authors in [11] carried out an indoor positioning system based on UWB. Such a system implemented based on STM32 on the hardware side for control issues. The low power and high data rate are the main features that weighted UWB technology to use in their system rather than others. The system evaluated based on time of flight (TOF) as a preferred method to measure the distances. However, there is a range of errors due to the multipath scenario. Therefore, the system needs additional techniques to support the good features in UWB. In [12] calibration the obtained data presented based on Bayesian filters to achieve high performance. The authors assumed two scenarios to accomplish their system. The first one was the high speed in data updating based on the linear regression aspect. The second one is using the filter to improve the data and the system performance at all. In [13] the trilateration method presented, in this method, the target location can be obtained based on the distance measurements. Such distances between targets and reference points will create three circles. The intersections between those circles will be the expected locations for targets. The other technique was min/max positioning based on both ToA and RSS measurements. Besides, both UWB as a propagation model and VNA are presented in their study to measure ranging of many frequencies used in the system. Bi-conical antennas are installed with a range of frequencies is between 3-11 GHz in addition to. To show the performance of both techniques, CDF has been chosen to measure distance error. The results obtained based on trilateration technique is better than min/max technique. The authors in [14] proposed the IPs system based on the new propagation model. They tried to improve positioning system technologies based on UWB to corresponding with indoor environments. The main aim of their study is to discover the error due to distance. Also, they have been compared both ToA and RSS method. Moreover, the operating frequency was between 3GHz and 11GHz. The results obtained in their study indicate to ToA is better than the RSS method. The authors in [15] evaluated the IPs based on UWB which lead to a range of distance errors when applying in indoor environments. The UWB is suitable in the short-range distance, whereas, there constrain in other situations. Therefore, they proposed a new algorithm based on RSSI to estimate the required distance that leads to targets location. To mitigate the error which happened due to regressive RSS or NLoS phenomenon, they proposed weight centroid
localizer (WCL). The results obtained based on the proposal confirm that the error is under one meter in the indoor environment.

3. Indoor Positioning System

There are several aspects considered to the basic and important at the same time for any indoor communication system. Path loss is one of those aspects play the main role to carried out communication model corresponds with the indoor environment. The simple definition of path loss is the loss undergone by an electromagnetic wave in the convey the signals from transmitters to reach receivers and defined as [1]:

\[
PL = \frac{p_t}{p_r}
\]  

(1)

where \(p_t\) is the transmitter power, \(p_r\) is the receive power, in other word equation (1) can be written in log scale as follows:

\[
PL = p_t(dB) - p_r(dB)
\]

(2)

In the interested area, receive power is expressed as:

\[
p_r = p_t G_t G_r \left(\frac{c}{4\pi fd}\right)^2
\]

(3)

where \(G_t\) and \(G_r\) are the transmitters and the receiver’s antennas gain respectively, \(c\) is the speed of light, \(d\) is the distance between the receivers and transmitters, \(f\) is the operating frequency. In UWB communications, there is the ability to convey a high data rate of obtained information. This ability comes due to the use of whole bandwidth for transmitting data. However, there are constraints in long distances based on the selected frequency. According to [1] there are limitations to use frequency bands for indoor and outdoor-based on Federal Communications Commission (FCC) Equivalent using Isotopically Radiated Power (EIRP) as depicting in table 1 [1]. On the other hand, table 2 shows the constrains in Wi-Fi signal and the quality of each level that should take into considerations [16].

| Frequency ranges          | Indoor EIRP (dBm/MHz) | outdoor EIRP (dBm/MHz) |
|---------------------------|-----------------------|------------------------|
| 960MHz - 1.61GHz          | -75.3                 | -75.3                  |
| 1.61GHz - 1.99GHz         | -53.3                 | -63.3                  |
| 1.99GHz - 3.1GHz          | -51.3                 | -61.3                  |
| 3.1GHz - 10.1GHz          | -41.3                 | -41.3                  |
| Above 10.6GHz             | -51.3                 | -51.3                  |

| Signal Strength | Expected Quality |
|-----------------|------------------|
| -30 dBm         | Maximum signal strength. |
According to table 1, there are constraints in some frequency ranges, therefore, the indoor communication model should take into account those limitations. To measure the required distances, there are several methods like RSS and TOA, according to [17], the distance based on TOA can be found as follows:

\[ d_i = (time_{send} - time_{receive}) \times c \]  

(4)

where \( c \) is the speed of light. Practically, in harsh indoor environments equation (4) is so far from a practical distance due to NLOS phenomenon as shown in the Figure 1.

![Figure 1. Multipath propagation](image)

According to [1], the exact distance can be determined by:

\[ d_i = ||x - x_i|| = \sqrt{(x - x_i)^2 + (y - y_i)^2} \]

(5)

where \( x \) and \( y \) is estimate coordinate, \( x_i \) and \( y_i \) reference coordinate. To make equation (5) more practical, there are additional parameters that will be added to modify the distance estimation [18]:

\[ d_i = ||x - x_i|| + \beta_i + m_i \]

(6)

where \( \beta_i \) is equal to zero in LOS and greater than zero in NLOS, \( m_i \) is noise value.
In the RSS method, path loss propagation model will present to measure the distance as following [18]:

\[
PL(d) = Plo - b_i - 10\gamma \log_{10} \left( \frac{|x-x_i|}{d_o} \right) + Q
\]  

(7)

where \( Plo \) path loss in reference distance, \( b_i \) is positive bias, \( \gamma \) is path loss exponent, \( Q \) is the log-normal shadowing. Therefore, RSS can be measured by [19]:

\[
RSS = P_T - PL_O - 10\alpha \log(d) + S
\]  

(8)

Where \( P_T \) is transmitted power, \( PL_O \) is the reference path loss recommended in one meter \( \alpha \) is path loss gradient between 2 in LOS and 6 in NLOS [1], \( d \) is the distance between reference point such as APs and targets, \( S \) is shadow fading.

For integrate the system, the distance measure in both TOA and RSS and normalize the results as following [18]:

\[
(d_i)_{RSS} = 10^{-\frac{\frac{P_{oT}}{10} - b_{max}}{10y}}
\]  

(9)

\[
(d_i)_{TOA} = d_i - \frac{\gamma}{2}
\]  

(10)

\[
\epsilon = \frac{|d_i^{RSS} - d_i^{TOA}|}{\max\{d_i^{RSS}, d_i^{TOA}\}}
\]  

(11)

By using integrating TOA and RSS, the authors in [18] obtained better performance after improving previous works. However, there is a range of errors still due to unstable in measurements between estimated and real measurements. Therefore, this paper will create an optimum system based on both advantages of UWB and Wi-Fi. Such a system will use from equation (1) through (11), however, the dynamic parameters for each environment in addition to optimum reference data will lead to significant enhancements.

4. Simulation Environment

In this paper, the implementation of the positioning system has done for case study building (CSB) which consists of three floors as shown in Figure 2. The required measurements of both UWB and Wi-Fi in addition to design CSB accomplished based on Wireless Insite software. Three transmitters (TXs) are installed in the selected locations with a height of 2m with radiant power 12 dBm and Gaussian pulse. Moreover, the applied frequency is 3.1GHz. On the other hand, 20 points determined as of show in Figure 3, to deployed 20 receivers at the height of one meter. The same deployments applied for 2.4GHz with other characteristics as shown in Table 3.
Figure 2. The case study building

Figure 3. The deployment of transmitters and receivers

Table 3: The characteristics of TXs and RSs antennas

| Antenna properties    | TXs            | RXs            |
|-----------------------|----------------|----------------|
| Antenna type          | Omni-Directional | Omni-Directional |
| Input Power (dBm)     | 12             | -              |
| Gain (dBi)            | 7.5            | 1.5            |
| E-Plane HPBW          | 10°            | 90°            |
| Waveform              | Sinusoid       | Sinusoid       |
| Temperature (k)       | 291            | 291            |
| Polarize              | V              | V              |
| Received Threshold (dBm) | -142        | -142          |
5. Results & Discussion
To show the performance of both UWB and 2.4GHz technologies, the cumulative distribution function (CDF) selected to measure distance error. In terms of UWB, as shown in Figure 4, the error ranges are so accurate in a short distance. Those measurements measured in LOS and NLOS. In long-distance especially in NLOS environments, UWB suffers from the regressive signal. In contrast, the results obtained based on Wi-Fi using 2.4GHz show high accuracy in long-distance and so close from UWB in a short distance but the UWB slightly outperforms 2.4GHz. By used both technologies in the same system, the results will be more accurate in both short and long-range under any scenario. The measurements of RSS in both UWB and Wi-Fi technologies play the main role to measure accurate distances. In Figure 5, clearly show all RSS measurements based on Wi-Fi under -60 dBm even with long-distance. In 25m the measured signal is under -50 dBm and this considers according to Table 2, excellent signal strength. In the distance above 36m, the signal strength slightly exceeded the -50 dBm and this increase the complexity of the system. Based on those measurements of RSS for each environment, the specific parameters assigned to estimate accurate positions. In another hand, the RSS measurements based on UWB exceeded -50 dBm for distance above 10m, therefore, Wi-Fi is better for the distances above 10m. In contrast, the UWB is better in the short distance where the RSS under -30 dBm while in Wi-Fi exceeded -30 dBm in the mentioned distance. For the distance under 10m, the error is (0.421m) based on Wi-Fi while (0.08m) based on UWB. For the long distances, the Wi-Fi is better such as in 40m the error is 0.15m while 0.851 based on UWB. In table 4, all receiver's coordinates depict in real and estimate scenarios with an error resulting in different measurements. The minimum error for coordinate x is 0.02m and the maximum is 0.12m. in the coordinate y, the minimum error is 0.08m and the maximum error is 0.19m. The performance of the system shows in Figure 6, which illustrates the real and estimate positions for targets.

Figure 4. Distance error for UWB & Wi-Fi based on CDF
Figure 5. The RSS obtained from Wi-Fi and UWB

Table 4. The exact and estimate targets coordinates based on propose MSBD

| x-axis  | y-axis   | Estimat(x-axis) | Estimat(y-axis) | x-axis error(m) | y-axis error(m) |
|---------|----------|-----------------|-----------------|-----------------|-----------------|
| 8.6049  | -33.8042 | 8.5049          | -33.6042        | 0.1             | 0.2             |
| 15.5957 | -33.5258 | 14.7957         | -33.3958        | 0.8             | 0.13            |
| 29.4004 | -33.6681 | 29.4904         | -33.8581        | 0.09            | 0.19            |
| 29.4004 | -33.6681 | 29.5204         | -33.5781        | 0.12            | 0.09            |
| 36.689  | -33.6651 | 36.799          | -33.5151        | 0.11            | 0.15            |
| 37.5232 | -25.3233 | 37.4332         | -25.4233        | 0.09            | 0.1             |
| 37.055  | -18.0132 | 36.9855         | -17.8932        | 0.12            | 0.12            |
| 37.1061 | -9.0568  | 37.3061         | -8.9568         | 0.2             | 0.1             |
| 28.2081 | -8.9178  | 28.0881         | -9.0778         | 0.12            | 0.16            |
| 21.4307 | -9.0473  | 21.3107         | -8.9473         | 0.12            | 0.1             |
| 15.1687 | -8.7626  | 15.2887         | -8.8526         | 0.12            | 0.09            |
| 8.6222  | -8.6203  | 8.7022          | -8.5203         | 0.08            | 0.1             |
| 8.3375  | -18.2979 | 8.3575          | -19.0979        | 0.02            | 0.8             |
| 8.4659  | -24.7672 | 8.4159          | -24.8672        | 0.05            | 0.1             |
| 2.0705  | -3.2176  | 1.9805          | -3.1376         | 0.09            | 0.08            |
| 1.7924  | -6.9714  | 1.8424          | -7.0614         | 0.05            | 0.09            |
| 1.6534  | -10.5861 | 1.5634          | -10.4861        | 0.09            | 0.1             |
| 5.2682  | -3.0785  | 5.1682          | -3.1685         | 0.1             | 0.09            |
| 5.1292  | -7.3885  | 5.0792          | -7.2885         | 0.05            | 0.1             |
| 5.2682  | -10.7252 | 5.3482          | -10.8052        | 0.08            | 0.08            |
Figure 6. The real and estimate locations
6. Conclusions
The main major of this research is to achieve an optimum system based on both the affectedness feature of UWB and Wi-Fi. In the Wi-Fi technology scenario, widespread availability encourages developers to use it for target localization. On the other hand, UWB considers high accuracy and data rate technology. Both major advantages can combine in the strongest system to work under any scenario. To achieve that the indoor positioning system with 2.4GHz and UWB is carried out in this paper. The system combines the affectedness feature of both 2.4GHz and UWB, thereby realize the goal of reliable and high precision. A new technique MSBD applied to implement an optimum system. It proves by simulation that 2.4GHz and UWB positioning system with the propose MSBD has higher precision than the system with individual aspect. The three dimensional (3D) case study building carried out based in (WIP) corresponded with real geometric of the selected building. The results confirm that the UWB is better in short-range with error under (0.08m) in contrast, 2.4GHz is better in long-range with error under (0.15m). It is worth to mention that both bands applied based on dynamic parameters for specific environments. The average error in the whole building based on static parameters using individual UWB is (1.023m) while (0.452m) based on individual 2.4GHz. while the dynamic system is high accuracy in both long and short-range with (0.08m) and (0.22m). The obtained results confirm that the proposed MSBD technique is significantly outperformed individual bands with static parameters.

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