Indoor Localization Techniques Based on UWB Technology

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Abstract. Indoor positioning attracts a lot of attention because people spend their maximum time indoors. As well as the loss of GPS signal power through walls, which requires the integration of other approaches to locate passengers indoors. With the technological growth of telecommunications systems such as 5G and the development of the Internet of Things technique, indoor location is becoming an applicable reality, in order to improve the services offered indoors. In addition, ensuring security in public environments such as airports, train stations, shopping malls, supermarkets…

In this article, we focus on the analysis of the advantages and disadvantages of UWB, and then the exposure and evaluation of different indoor location techniques based on UWB. The document is structured around the following points:

- We expose the advantages and the disadvantages of UWB technique
- We present and evaluate the indoor positioning techniques based on the UWB

Keywords: UWB · RSS · PDR · IMU · OFDM · TOA · TDOA · AOA · PDOA · RFID · Filter de Kalman · RMSE

1 Introduction

The indoor location has attracted a lot of attention because people spend a lot of time indoors, so GPS is unable to locate passengers indoors due to the constraints of GPS signal penetration through walls. For this reason, the use of other indoor positioning tools is an applicable reality. Currently, several positioning techniques are used to infer passenger positions. Among these techniques, RSS (Received Signal Strength) is the most used technique in interior positioning systems, as it uses Wi-Fi or Bluetooth, which facilitates their deployment indoors. Triangulation and Trilateration techniques such as TOA (Time of Arrival), TDOA (Time Difference of Arrival), AOA (Angle of Arrival), ADOA (Angle Difference of Arrival) are also offered. With the technological development of smartphones, the use of IMU (Inertial Measurement Unit) inertial measurements of sensors integrated into mobile devices such as accelerometers, gyroscope, magnetometers, barometers, etc. Are more reliable in the case of CROWDSOURCING/CROWDSENSING.

H. Elbiaze et al. (Eds.): UNet 2021, LNCS 12845, pp. 3–15, 2021.
https://doi.org/10.1007/978-3-030-86356-2_1

Appel has built passive boxes called iBeacons which are based on low-energy Bluetooth (BLE) capable of communicating with the outside environment. RFID radio wave identification can also be used to identify the positions of passengers inside a building by a simple TAG/READER communication. The majority of approaches use radio waves, such as Wi-fi, Bluetooth, RFID, RADAR, ZigBee, UWB… Despite the diversity of localization techniques in the literature, these systems remain limited under specific conditions of use, due to the positioning constraints that show their positioning qualities. For example, the RSS method suffers against the calibration constraints of the database, heterogeneity of devices, change of environment… Otherwise, techniques based on inertial measurements are still confronted with problems of measurement instability, heterogeneity of mobile devices… The precision of techniques based on triangulation and trilateration decreases because of the multiple path constraints, undetected direct path, and signal interference. To solve these problems, researchers have proposed to integrate some mathematical tools into their systems. These tools are divided into two categories, one probabilistic and the other deterministic, for probabilistic approaches, the Kalman filter is used to reduce measurement instability and noise errors, Bayesian filtering, Map (Maximum a posteriori), maximum likelihood, Gaussian filter, Viterbi algorithm, least-square algorithm, for deterministic methods such as Dijkstra algorithm, particle filter, nearest neighborhood algorithm KNN etc. The UWB very short pulse radio modulation technique has attracted the attention of researchers because this tool can improve the quality of positioning systems.

Thanks to certain positive properties, for example, low energy consumption, low cost, simple to deploy, low communication time (less than nanoseconds), centimetric precision. In this article, we focus on the analysis of the advantages and disadvantages of UWB, and then the exposure and evaluation of different indoor location techniques based on UWB. Section 2 presents the advantages and disadvantages of UWB, Sect. 3 presents the exposure and evaluation of the different indoor locating techniques based on UWB, Sect. 4 presents the results and discussion, for the rest Sect. 5 presents the future work, Sect. 6 presents the conclusion.

2 Advantages and Disadvantages of UWB Technique

Ultra-wideband radio communication: this is a technology developed to transfer large amounts of data wirelessly over short distances, over a very wide frequency spectrum, in a short period of time. UWB technology has the capacity to handle the very wide band required to carry multiple audio and video streams. The UWB reel is ideally suited for data transmission between consumer electronics, PC peripherals and short-range mobile devices at very high speeds while consuming little power. This technology operates at a level that allows most systems to interpret noise and therefore does not cause interference with other radios such as mobile phones.

In this framework we quote some advantages of UWB:

- Extremely difficult to intercept: wideband pulsed radar spreads the signal to allows more users access to a limited amount of scarce frequency spectrum.

- Multipath Immunity: A low path loss and low energy density minimizes interference to other services, UWB is very tolerant of interference enabling operation within buildings urban areas.
- Precision: The continuous localization of the position in real-time with up to one-centimeter resolution gives good results.
- Low cost: Requires minimal components resulting in smaller size and weight.
- Low power: Typical consumption is in microwatt.

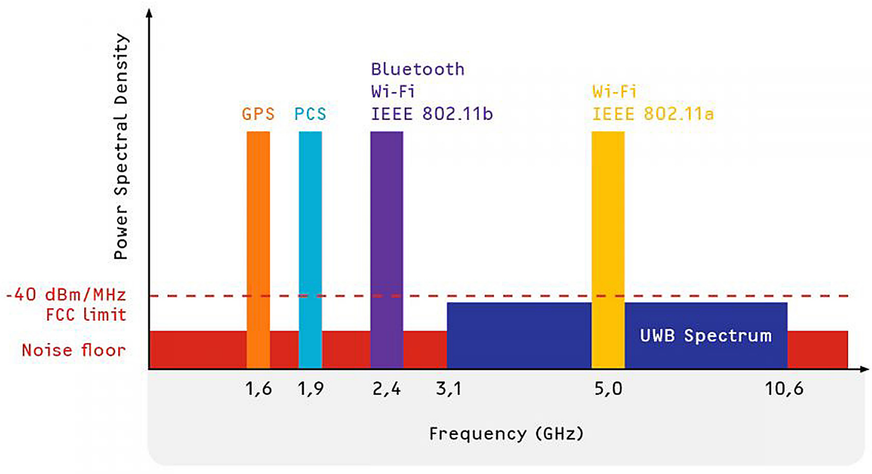

Fig. 1. UWB frequency spectrum

Figure 1 shows the UWB frequency spectrum with a width between 3.1 and 10.6 GHz. In general, [15] UWB technology is divided into two parts: narrowband (impulse radio) and multiband using some type of modulation such as OFDM (Orthogonal frequency-division multiplication). Figure 2 shows the power spectral density of the wideband and narrowband, where W_{NB} is the width of the N.B and W_{UWB} is the width of the wideband.

Despite of large advantage of UWB but, this technique stays in front of the constraints of shadow effect caused by multiple problems, amplitude variation, timing variation and shoulders effect. Challenges in developing such a system include UWB pulse generation, [8] pulse dispersion due to antennas, modeling complex propagation channels with severe multipath effects, the need for extremely high sampling rates for digital processing, synchronization between transmitter and receiver clocks, clock jitter, local oscillator (LO) phase noise, frequency offset between transmitters and receivers, and antenna phase center variation. The UWB system is sensitive to channel fading and will generate a non-negligible number. of outliers under NLOS conditions (Table 1).

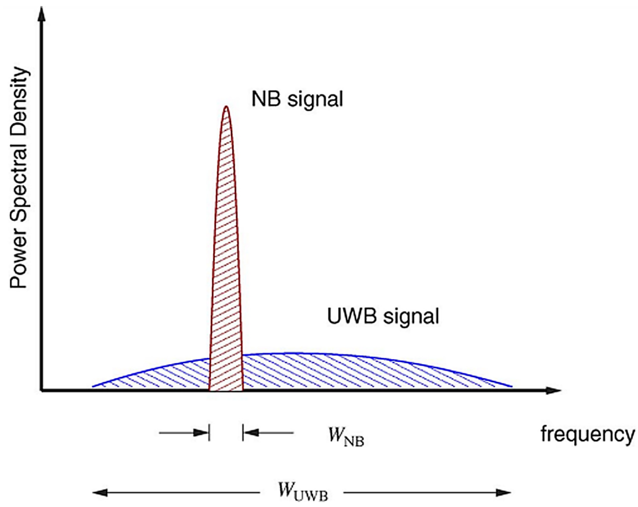

Fig. 2. Power spectral density of UWB and NB signals

Table 1. Features of UWB technique

Usable frequency range	Max range	Optimal range of highspeed data	Theoretical max data rate	Practical data rate	Max transmission power	Indoor localization accuracy	Duty cycle
3.1–10.6 GHz	200 m	<10 m	480 Mbit/s	27 Mbit/s	<1 mW	Centimetric	Low (max on-time 5 ms)

3 Exposure and Evaluation of the Different Indoor Locating Techniques Based on UWB

With the availability of Ultra-Wide-Band in smartphones, as well as the positive influence of UWB indoor positioning systems. The realization of a high-quality indoor positioning system becomes less complex. [11] An ultra-wideband based time- delay (TOA) indoor human localization scheme has proposed to provide indoor human localization with time-delay measurements. The author proposed an extended finite impulse response (EFIR) estimated employing the time delay localization model in purpose to solve the problem of EKF (Extended Kalman Filter). Which EFIR does not require the noise statistics. The experimental results have shown that the EFIR estimation is more robust than the extended Kalman filter. The average error of UWB only is between 0,19 m and 0,72 m, EKF based method error is between 0,21 m and 0,58 m. EFIR his accuracy is higher than EKF his average error is between 0,19 m and 0,54 m.

In [1] author has presented the results of the measurement and modeling of Ultra-Wide-Band time of arrival (TOA) based ranging in different indoor multipath environments. The author provided the characterization of the spatial behavior of ranging, where the author focused on the statistics on the spatial of the ranging error in the presence and absence of the direct path (DP) and evaluated the path loss behavior in the former case, which is important for indoor localization coverage characterization. The approach used two different bandwidths 500 MHz and 3 GHz with a nominal frequency of 4,5 GHz. The author used three different ranging scenarios ITI (Indoor to Indoor), OTI (Outdoor to Indoor) and RTI (Roof to Indoor). The method showed that the ranging coverage is inversely related to the bandwidth of the system and the harshness of the ranging scenario and environment. In addition, the statistics of the measured the ranging error showed that they follow normal and lognormal distributions in the presence and absence of DP. [5] A short-range UWB indoor localization system with millimeter-range accuracy has many promising applications. The author has proposed a system architecture similar to available commercial systems, sub-sampling the incoming pulse train and detecting the main LOS peak. The author has addressed the main challenges being faced in building this system, including sampling limitations, multipath interference, phase center error, and timing errors due to clock jitter, temperature effects, etc.

Subsampling techniques, sophisticated receiver- side leading edge detection increased number of base stations, phase-center calibration, and high fidelity PRF (pulse repetition frequency) crystals combined with a TDOA approach have been proposed as solutions to these problems, while the experimental results show the feasibility of achieving millimeter-range accuracy with a UWB indoor positioning system is highly reflective in indoor environments. The sub-sampling mixer is a usable option for sampling the incoming pulse train with a high sample rate. The effects of clock jitter can be mitigated by using PRF clocks with low phase noise and temperature compensation, although the total effect of PRF clock jitter on the sub-sampling process can cause substantial errors on the order of 1 mm. Time scaling originating from PRF clock stability has been shown through simulation to not impact final system accuracy by using a modified version of the TDOA algorithm.

The designed peak subtraction algorithm is robust to multipath interference. System performance in dense indoor environments can be further increased by a greater some base stations and optimal base station placement. The mean error in the unsynchronized 1-D experiment is 3,07 mm.

In [2] the experimental investigations and analysis of Ultra-Wide-Band localization of body-worn antennas in an indoor environment has proposed. Simple and effective techniques for identifying and mitigating NLOS situations have been applied and analyzed and the UWB localization scheme for the human body, tracking has been proposed using TOA technique, various features such as RMS delay spread, Kurtosis and signal amplitude has been used to classify the channel type between each antenna location and base station. GDOP (Geometric Dilution of Precision) analysis has been performed for validating the compact base-station configuration used with results showing GDOP values in the range of 1 to 2 which are considered as high accuracy values. Numerical analysis has been carried out on the effect of body-worn antenna localization. It has been observed that the radiation patterns are more directive in the presence of the human body and the area of the patterns decreases when the antenna is placed on the thick muscular region (torso) in comparison to the upper limbs. Hence the localization accuracy will be higher for the limbs in comparison to the torso. High accuracy 3D localization results in the range of 1 to 2 cm are obtained with the antennas placed on the limbs and 1 to 3 cm in the torso region as there will be more interference in the signal propagation by the torso. Best results are obtained when the antenna is placed on the elbow (0,5 to 1,5 cm). [9] UWB ranging measurements is influenced by the human body shadowing effect with biased ranging error up to 1,6 m and the error has a close relationship with RHA between Tag and ANC.

A UWB ranging error model addressing the problem has proposed based on measurement data obtained from three measurement campaigns covering both the typical environment and outdoor open space. The model is further integrated into a particle filter pedestrian tracking algorithm with gyroscope information fusion. The proposed algorithm is then evaluated in two indoor walking tracks which reduce mean positioning error up to 41,94% and demonstrate the robust and accurate tracking performance compared to existing solutions. It is noted that human body obstruction is the main cause for NLOS between TAG and Anchors in the tracking experiment setup. In scenarios with both the human body and environment obstruction such as walls, a more complex measurement model may be required. The mean error for T1 and T2 12,48 cm and 16,42 cm respectively. [6] The author has proposed an analytical approach to optimized ANs placement for efficient TDOA UWB-based localization of a TN moving along a corridor in large indoor scenarios. The approach imposed the realistic design constraints that the ANs are equally spaced and placed at the same height. Assuming that the TN moves along a straight line in the middle of the corridor, the author derived a closed-form expression for the optimal distance between consecutive ANs that minimizes the average MSE (Mean Square Error) of the TN position estimates the validity of the closed-form expression has been confirmed by simulations, which also show that the proposed placement strategy is also effective even when the TN follows other paths different from the linear one in the middle of the corridor.

A [13] novel architecture for UWB positioning systems has presented, which combines the signal-channel carrier-based UWB system and traditional energy detection (ED) based UWB positioning system. The UWB localization system is equipped with the low phase-noise carrier at both the transmitter and receiver and the advanced sub-sampling of the incoming pulse train. A proper modulation factor is intentionally chosen between the transmitter and receiver carrier and is combined with an ED step to eliminate the requirement of carrier synchronization. The approach has addressed step by step the main challenges the I/Q mismatch jitter errors due to phase noise in the carrier offsets, the Shoulder effect in static and dynamic scenarios, etc. Both simulation and measurement results show the robustness of the proposed system architecture with reduced timing jitter error and improved system dynamic range. By comparing two 1-D experiments, the ranging error has been improved significantly with the reduced timing jitter and Shoulder effect through the application of a low phase noise carrier-based UWB architecture together with advanced sub-sampling and ED. To further validate the theories, extensive 3-D static and dynamic experiments have been performed, including a tag moving randomly in a 3-D space and a tag attached to a robot arm with preplanned motion, where constant millimeter range accuracy in both static and dynamic scenarios has been demonstrated. The RMSE for Tag-free random motion is 6,37 mm, for robot dynamic tracking is 5,24 mm. A [8] joint TOA and AOA estimator has proposed for accurate indoor UWB localization applications. The device employs an array of antennas, each feeding a demodulator consisting of a square and low-pass filter. The signal samples from the filter outputs are processed to produce TOA and AOA estimates. Simulation has been run, assuming transmitted pulses with a bandwidth of either 0,5 GHz (type-2 pulses) or 1,5 GHz (type-1pulses), requiring sampling rates of 1 GHz and 3 GHz, respectively. Ranging accuracies of about 20cm and angular accuracies of about 0,8° are achieved at an SNR of practical interest with type-1 pulses and two antennas at a distance of 50cm. Some degradations are incurred with type 2-pulses. [3] An improved PDR-UWB integrated system based on the VNV Kalman filter algorithm was proven to be able to accurately provide pedestrian locations in indoor environments. The first contribution refers to initial sensors is a complete gait detection based on the dual-frequency Butterworth filter and the multi-feature linear combination model involving the step frequency, the amplitude of acceleration. The second contribution refers to UWB is that they use the positioning information of a UWB system to estimate parameters of the linear combination model in real-time based on the L-nearest neighbor gradient descent method. The author used the drift-free heading direction of UWB to calibrate the heading angle of PDR processed by the periodic heading calculation function. In the improved PDR-UWB integrated structure, UWB system plays a crucial role in term of system position accuracy, the NLOS assessment function could accurately reflect the attenuation of received signals, and ensure the accuracy of systems under short-term NLOS conditions.

The improved system fusion strategy that dynamically adjusts the noise variance according to the probability of signal, attenuation can provide a robust and accurate positioning trajectory when the UWB signal is blocked in a short period of time by obstacles for indoor navigation applications. The average error is 0,326 m.

[10] The received signal strength (RSS) as a function of the distance, a localization simulator for an RSSI-based fingerprint positioning technique has carried out with conventional wireless USB sticks using OFDM HDR (High Data Rate) UWB radio technology. The results have been compared to simulation results using TOA-based positioning. With a measured log-normal fading process with a standard deviation of 0,53 dB the RSSI-based positioning provided that the synchronization in the accuracy of the TOA process is larger than 1ns. The weakness of the RSSI-based approach is the decreasing ranging accuracy with increasing distances between transmitter and receiver. The applied least square (LS) trilateration seems therefore not to be the best localization approach and can be further improved by evaluating the estimated distances to the anchor node with respect to their different reliabilities which depend on the RSSI. However, the main advantage of the RSSI-based positioning systems can easily be implemented in the software when using conventional low-budget UWB hardware. The mean estimation error depends on the number of anchor nodes, in all bases it remains below 0,2 m. In [4] author has analyzed a localization in MB OFDM UWB systems based on the TDOA method. The author proposed a new space-temporal signal model in IEEE 802.15.3a channel in which cluster delays in the channels between the transmitter and each sensor

in the sensor array are correlated due to the scattering on the scatters with a known position. The approach showed that this correlation decreases localization accuracy significantly. If the position estimates with significant error, MB OFDM UWB systems are suitable for indoor localization based on TDOA.

[14] PDOA assisted UWB positioning method (PDOA-UWB) for location-based user service in the smart home has proposed. The author has calculated the phase difference of arrival from PDOA chip integrated in the UWB BSs to obtain a coarse location of the elderly. This is used to distinguish which nearby BSs are in a LOS environment and those in an NLOS environment combined with the UWB positioning method. The approach proposed a PDOA assisted UWB (PDOA-UWB) positioning method to improve the positioning accuracy of the elderly. The Fig. 3 shows the workflow of PDOA-UWB method.

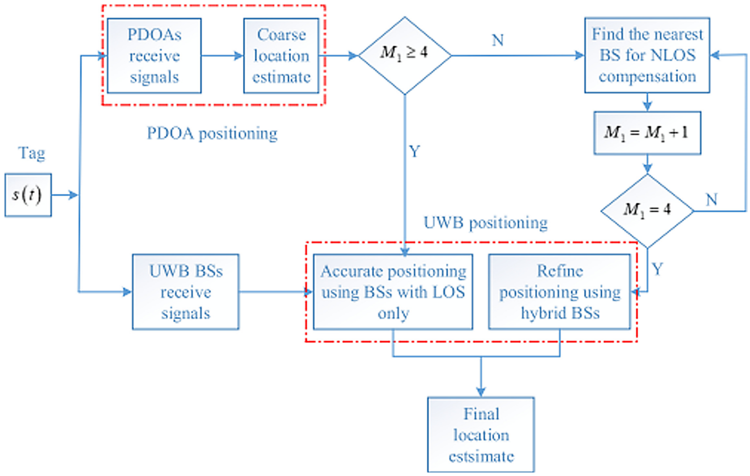

Fig. 3. The workflow of PDOA-UWB positioning method

Compared with some existing methods, this method can achieve higher accuracy with less NLOS compensation, and is easier to be implemented in complex practical indoor environments. The proposed PDOA-UWB method can efficiently select the minimal and optimal BSs for positioning, thus avoiding the blind compensation and the calculation burden of traditional UWB positioning methods. The proposed method is mainly designed for fast and robust, practical engineering applications, which reduce the computational burden of the convex-based methods greatly without remarkable performance loss the proposed positioning scheme can not only solve the problem of elderly care in smart homes, it also has better application. The probability of RMSE is less than 0,45m for 95,38%.

[7] the author has presented an experimental evaluation of three commercially available UWB positioning systems Ubisense, Decawave, and BeSpoon. The evaluation has been done in an NLOS environment is similar to an industrial warehouse with a diverse

equipment, which perturbates UWB radio propagation. Under these conditions, the performance of the Decawave system is slightly better than the BeSpoon System and significantly more reliable, in terms of accuracy and outlier content, then the Ubisense system. The conclusion that Decawave is more accurate than BeSpoon system these results are somehow logical since Decawave is using a more advanced antenna system than the BeSpoon equipment. The performance results for the Ubisense equipment are lower than Decawave and BeSpoon, and this occurs in case of only using TDOA data and also when using the integrated localization solutions that fuse TDOA and AOA. With Ubisense (TDOA and AOA) the AOA is more information and accurate for correct positioning, and contains fewer outliers, than TDOA data. Decawave is based on TOF (Time of Flight), it's fair to mention that Ubisense system dates from 2009 and BeSpoon from 2015, while Decawave is from 2016. The RMS is 0,59 m for Decawave, 0,86m for BeSpoon, 2,266 m for Ubisense, and 1,82m for Ubisense (AOA).

In [12] WUB-IP is a high precision positioning scheme using a UWB ultra-wideband telemetry system, recently solutions for accurate positioning in NLOS multipath and non-line-of-sight conditions have attracted a lot of attention, on the other hand, it is expected that WDMA Waveform Division Multiple Access technologies for multi-user UWB positioning applications will be indispensable soon, in this respect, a positioning scheme based on WDMA-UWB has studied. The author has used the TOA method to infer user positions using a communication (BS-User) a base station and user. The author has developed an approach based on information entropy to detect the primary paths, while entropy is used to measure the randomness of received signals. Simulation results show that the position error in channels CM1 to CM4 are 3,44 m, 7,42 m, 4,21 m and 5,04 m.

4 Results and Discussion

In this section, we evaluate the different techniques of indoor positioning systems based on the UWB on certain criteria such as Precision, Energy consumption, Cost, Ease to deploy, Stability, Response time, Adaptation to changes in the environment, and heterogeneity of devices, and complexities. Table 2 presents the evaluation of different approaches to indoor location-based on UWB. In this table, some criteria remain unchangeable such as energy consumption, cost, simplicity of deployment, response time. Because these depend on the UWB communication techniques serve to correct the errors produced by indoor positioning systems. The rest of the changeable criteria in the table are highly dependent on the UWB localization tools and type of implementation. It can also be said that the complexity criterion relates to all evaluation criteria. In general, the choice of a good indoor positioning system depends on the localization objective, which determines the nature of the criteria and thus the achievement of a high-quality system.

Table 2. Evaluation of the different techniques of indoor positioning systems based on the UWB

Approach title	Accuracy	Energy consumption	Cost	Simple to deploy	Stable	Response time	Adapting to a changing environment and device heterogeneity	Complexities
UWB-Based Indoor Human localization [11]	The error is between 0,19 m to 0,58 m	Low	Low	Yes	No	Low	No/–	Medium
Measurement and Modeling of UWB TOA based Ranging [1]	The error is less than 0,6m	Low	Low	Yes	No	Low	No/–	Low
Investigation of High-Accuracy Indoor 3Dpositioning [5]	The error in 1-D is 3,07 mm, in 3-D mean error is 5,77 mm	Low	Low	Yes	Yes	Low	Yes/–	Low
Experimental investigation of 3-D Human Body Localization [2]	The error is between 1 to3 cm	Low	Low	Yes	No	Low	– /–	Medium
Human body shadowing effect on UWB-based [9]	The mean error for T1 and T2 are 12,48 cm and 16,42 cm respectively	Low	Low	Yes	No	Medium	No/No	Medium

(*continued*)

Table 2. (*continued*)

Approach title	Accuracy	Energy consumption	Cost	Simple to deploy	Stable	Response time	Adapting to a changing environment and device heterogeneity	Complexities
UWB-based localization in large indoor scenarios [6]	–	Low	Low	Yes	No	Low	No/–	Medium
Real-Time Non-coherent UWB positioning [13]	3-D RMSE is 6,37 mm	Low	Low	Yes	Yes	Low	No/–	Low
Joint TOA and AOA [8]	1-pulse 10 cm, 2-pulses 35 cm	Low	Low	Yes	Yes	Low	No/–	Low
An improved PDR-UWB Integrated system [3]	The average error is 0,326 m	Low	Low	Yes	No	Low	– /No	Low
Positioning in Multiband OFDM-UWB utilizing RSS [10]	The error is less than 0,2 m	Low	Low	Yes	Yes	Low	No/–	Low
Localization of users in multiuser MBOFDM-UWB [4]	The SNR is 30 dB	Low	Low	Yes	–	Low	No/–	Medium
Toward Elderly [14]	The RMSE is 0,4 5m in 95,38%	Low	Low	Yes	–	Low	No/–	Low

5 Future Works

We have three types of UWB implementations: Impulse Radio, Ds-UWB (Direct sequence), and Mc-OFDM (Multiband). In our future perspective, we will elaborate on a fingerprint RSS-based localization system, we will improve the different handling criteria (accuracy, stability, simplicity of deployment, response time, cost…) to have a high-performance system, for this, we will integrate the MB-OFDM-UWB technique into the system.

6 Conclusion

In this article, we have focused on different positioning tools such as PDR, RSS, TOA, AOA, TDOA, PDOA based on UWB. First, we have analyzed the characteristics of UWB, then their advantages and disadvantages. In the second part, we have outlined some of the UWB-based localization techniques presented in the literature. In the third part, we have examined these approaches based on the criteria such as accuracy, power consumption, cost, simplicity of deployment, stability… As a result, the UWB method succeeded in reducing errors for the majority of the systems studied, with low power consumption, simplicity of deployment, low cost, low response time, and low complexity. Despite the quality of UWB, stills limited under precise conditions which determine its quality.

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