Comparison between the Ultra-wide Band based indoor positioning technology and other technologies

Pengtao Wu
School of Electronic Engineering, University of Manchester, Manchester, United Kingdom
pengtao.wu@student.manchester.ac.uk

Abstract: In recent decades, there have been many applications of positioning and navigation systems, the most representative of which is GPS (Global Positioning System). This technique is very accurate for outdoor navigation, but it cannot provide reliable positioning data indoors. This paper firstly compares the different indoor positioning technologies and analyses their bottleneck. Then the suitable algorithm of UWB based on indoor positioning technology (IPT) is discussed including Angle of arrival (AoA), Time of arrival (ToA), Time difference of arrival (TDoA), and Received Signal Strength (RSS). Eventually, the paper finds that although UWB-based indoor positioning technology still has many problems such as high deployment equipment costs to be solved, it is suitable for widespread applications due to its special advantages such as strong resistance to multipath effects.

1. Introduction
In the past 30 years, the navigation system mainly represented by Global Positioning System (GPS) has had an enormous impact on human life. It has gradually become an important modern technology with multiple applications [1,2]. However, the rapid urban development has brought modern large-scale buildings with huge indoor spaces, including shopping malls, hospitals, theatres, etc. The National Human Activity Pattern Survey in the United States shows that responders spend 86.9% of their daily lives indoors [3]. Therefore, the demand for indoor positioning continues to increase. Although GPS is a very accurate positioning system, it cannot provide accurate indoor positioning data because the satellite signal can be interfered by building walls.

Indoor positioning systems (IPSs) are used to locate the accurate real-time position of people or objects indoors. Compared with the outdoor environment, the indoor environment needs more accurate positioning data, and it has technical problems due to the complicated indoor space layout and object reflection. However, this kind of technique has emerged with various types. IPSs have many practical applications, including leading customers to the target store in shopping malls, tracking cars in a multi-storey underground parking garage, and locating expensive equipment [4,5]. To realise those applications, the requirements of the corresponding type of the IPT are quite different. For example, leading customers to the target store in distinct areas is solvable for most IPT. However, helping consumers distinguish between two adjacent stores and tracking two shelves in the same store increases accuracy requirements significantly. Accuracy as a critical factor is used in the evaluation of positioning systems. UWB is a relatively new technology that could provide high accuracy of fewer than 30 centimetres [6,7]. However, a comprehensive analysis is still needed. Hence, a detailed study of the current problems faced by the UWB, such as the obstacles to its promotion, is carried out, and the actual status of this technique is analysed. This paper aims to find a positioning technology that is suitable for
widespread and use in the future. [12] shows hybrid indoor positioning technologies have provided better performance for different application scenarios and cost considerations which is the motivation for future research into hybrid indoor positioning systems.

2. Evaluation Methods
Indoor positioning systems already have various types of indoor positioning technologies. To give a brief evaluation of IPTs, different parameters are needed. The main five quality factors include system accuracy and precision, cost, effective coverage, stability and availability, and scalability. These factors affect each other, such as high accuracy normally needs higher costs.

2.1. Accuracy and precision
It refers to how close multiple measured data is to a known value. The complexity of the indoor environment has different effects on the positioning system. Therefore, to give a good user experience, the measurement should not be given as the highest and the lowest possible accuracy.

2.2. Cost
This term has analysis with different dimensions including money, space, power, time [8]. Every dimension has a cost. Firstly, the investment can visually show the cost of technical construction and subsequent maintenance. Then the installation of the indoor positioning systems and the time used for preparation needs to be based on the indoor space layout. The third is the energy consumption during the operation.

2.3. Coverage
Each indoor positioning systems has its special coverage which is decided by investment and requirement of different levels. For example, GPS needs to cover the whole world.

2.4. Stability and Availability
A good indoor positioning system needs to be stable during its running time. The availability refers to the percentage of time available during system operation, and system maintenance is also taken into consideration [8].

2.5. Scalability
At present, various indoor positioning technologies have their own limitations when used alone. Hence, scalability refers to the ability of the positioning system to simultaneously locate how many objects or people are in a unit area.

3. Indoor Positioning Algorithms
Indoor positioning technologies have their own different characteristics, but the main positioning algorithms are very similar which can be divided into three categories including RSS (Received Signal Strength), Fingerprint, Trilateration.

3.1. RSS
It is currently one of the most common algorithms used in indoor positioning technology. This measured signal strength refers to the attenuation from the access point to the base station. According to the inverse-square law, with the amount of attenuation, the distance can be approximated [9]. To improve the accuracy, one effective method is increasing the number of the access points but energy consumption also increases [10]. However, various errors can affect the signal strength value such as signal interference and reflection. Therefore, RSSI is very easy and cheap to complete but it cannot provide high accuracy.
3.2. **Fingerprint**
This refers to the need to test in advance and establish a database based on the special physical characteristics of the room. During positioning, the measured value is compared with the database to estimate the approximate position.

3.3. **Trilateration**
This refers to the distance to the test point measured by the circle centered on the base station. Each radius can be calculated based on the signal strength or time of flight (ToF) at the receiver. According to the figure 1, the two intersection points of the circle formed by the two base stations can give two positions, so it is still uncertain. However, if a third base station is used, an approximate location of the test point X can be determined. This technique entirely depends on the real-time ranging accuracy.

![Figure 1 Trilateration](image)

4. **Indoor Positioning Technologies**
Nowadays, there are already many indoor positioning technologies including WIFI [10,11], LED visible light [12], Geomagnetism [13], Image Identification [14], and Bluetooth [15] that can be used for commercial purposes. Some of these technologies can be directly located by mobile phones after the device has been deployed based on the indoor layout, such as WIFI, Bluetooth, etc. There are also technologies that can be implemented without deploying equipment but require database support, such as Geomagnetism and Image Identification. The following table 1 shows the comparison between various IPTs with different parameters. Then more detailed analysis below table 1.

| IPT          | Positioning Algorithm          | Support by mobile Phone | Device Deployment | Positioning Accuracy |
|--------------|--------------------------------|-------------------------|-------------------|---------------------|
| WIFI         | RSS, Fingerprint, Trilateration| Yes                     | Yes               | 5 meters            |
| Bluetooth    | RSS, Trilateration             | Yes                     | Yes               | 3 meters            |
| LED          | AoA, TDoA                      | Yes                     | Yes               | 1 meter             |
| Geomagnetism | Fingerprint                    | Yes                     | No                | 1 meter             |
| UWB          | ToA, TDoA                      | No                      | Yes               | <30 centimetres     |
| Image Identification | Pattern Recognition   | Yes                     | No                | <1 meter             |
4.1. WIFI
This technology mainly uses RSS and Trilateration to estimate distance [11]. Because the WIFI base station in the building can be used directly, the deployment cost is relatively low. To achieve higher accuracy, the deployment of additional equipment can cause mutual interference. Also, the number of users in the same unit area is limited due to its performance. If the fingerprint algorithm is used, it can be more accurate than the trilateral positioning. However, the movement of indoor objects such as decoration needs to re-establish the database.

4.2. Bluetooth
This technology mainly uses a trilateral positioning algorithm like WIFI, and estimates the distance based on RSS [15]. Its cost is relatively low, so the accuracy can be improved by increasing the deployment density. Energy consumption is also low, and it can be directly located with a mobile phone. However, the intensive deployment greatly increases the maintenance cost in the later period.

4.3. LED
This technology can transmit signals by modifying indoor lighting and using its high-frequency flashing. Users can directly use the mobile phone camera to receive signals to find their own location. Its positioning accuracy is higher than WIFI and Bluetooth. However, there are requirements for indoor lamps and lanterns, so if the LED positioning is needed after the indoor decoration, the transformation cost is very high. Also, without correct installation of LED infrastructure, can cause huge impact on its performance [12].

4.4. Geomagnetism
This technology builds a database by measuring the magnetic field distribution data at different locations in the room [13]. When the user needs to use it, the device can be equipped with a magnetic sensor and the database can be compared to determine the location. Although there is no need to deploy equipment, all magnetic data needs to be measured in advance, so it takes a certain amount of time to prepare. When there are electrical appliances or wall materials that affect the magnetic field in the room, the positioning cannot be used. Therefore, the subsequent maintenance cost is very high.

4.5. UWB
Ultra-wideband transmits data by sending a pulse signal of only 1 ns, so it presents an ultra-wide bandwidth in the frequency domain [6]. Also because of its extremely short time-domain signal pulse, it still can operate even in the presence of severe multi-path effects. It usually measures ToF by sending signals between fixed base stations and access point. Then the distance can be calculated, with trilateration algorithm, the accurate position can be determined. Because there is no need to transmit a carrier, its power consumption is low. However, because most mobile phones currently do not have integrated UWB transceivers, it is still inconvenient for users to use. Also, the cost of deploying base stations is very high.

4.6. Image Identification
This technology is very similar to geomagnetic-based positioning technology. It locates by comparing the image captured by the camera with the image in the database. Using efficient image recognition algorithms can provide higher accuracy. However, this image recognition has high demand of computer device and power consumption [14]. And it is difficult to identify in some special environments, such as a long section of white-painted corridors on the surrounding walls.
5. UWB Positioning Algorithms

5.1. AOA-based Positioning Algorithm:
AOA-based algorithm obtains the angle between the tag and the base station by transmitting the signal from the antenna array. After multiple angle values are measured, an estimated position can be calculated. Therefore, the accuracy of the algorithm depends on the measured angle. The non-line-of-sight (NLOS) positioning environment and multipath effects will further affect its accuracy [7].

\[ \tan(\phi_1) = \frac{y_1 - y}{x_1 - x} \]
\[ \tan(\phi_2) = \frac{y_2 - y}{x_2 - x} \]

(1)

Where \((x_1, y_1)\) and \((x_2, y_2)\) are the coordinates of the base stations, \((x, y)\) is the coordinate of the tag, \(\phi_1\) and \(\phi_2\) are the angle between the tag and the two base stations respectively.

5.2. TOA-based Positioning Algorithm:
ToA-based positioning obtains the distance by measuring the absolute propagation time of the signal [12]. According to Figure 3, take the measured distance as the radius and the base station as the centre to draw a circle, and the intersection point with the curve is the location of the tag. To be accurate, the algorithm requires the base station to keep clocks synchronized with the tag. However, in actual testing, it is difficult to achieve or maintain complete synchronization between the tag and the base station, so large errors are difficult to avoid. As the tag moves quickly, the error can be greater.

\[ R_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \]
\[ R_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \]
\[ R_3 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} \]

(2)

Where \((x_1, y_1)\), \((x_2, y_2)\) and \((x_3, y_3)\) are the coordinates of the base stations, \((x, y)\) is the coordinate of the tag, \(R_1\), \(R_2\) and \(R_3\) are the distance from the tag to the base stations respectively.

5.3. TDOA-based Positioning Algorithm:
TDOA-based algorithm measures the time difference of signal propagation between the positioning tag and two different base stations, and then calculates the distance difference between these two paths [6]. Therefore, TDOA is based on the difference of the measured values of ToA for positioning. Also, according to Figure 3, but this algorithm uses the tag and the base station as the intersection point to
establish a hyperbola. This algorithm no longer requires complete synchronization of the clock, only the ToA value needs to be measured.

\[ R2 - R1 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \]
\[ R3 - R2 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} - \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \]
\[ R3 - R1 = \sqrt{(x_3 - x)^2 + (y_3 - y)^2} - \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \] (3)

Figure 4 TDOA-based Positioning Algorithm

Where \((x_1, y_1), (x_2, y_2)\) and \((x_2, y_2)\) are the coordinates of the three base stations, \((x, y)\) is the coordinate of the tag. By compared with TOA based algorithm, (3) calculates the distance difference between the tag to each of the two base stations [8]. When there are three hyperbolas, the precise position of the label can be determined. The system of two equations is solved by associating the hyperbola and its unique coordinates can be determined by assuming that the coordinates of the tag should appear in the first quadrant. Although TDOA only needs to synchronise the clocks between base stations to provide high accuracy, its accuracy is still dependent on the sampling rate and signal bandwidth [16].

5.4. Comparison between Algorithms:
The signals strength is very easy to cause signal attenuation changes due to changes in the indoor environment. Therefore, the algorithm based on AoA has higher accuracy than the algorithm based on RSS. However, AoA is difficult to provide high positioning accuracy in a non-line-of-sight environment due to the multipath effect and the requirement of clock synchronization for both the base stations and the tag. ToA also needs clock synchronization which is relatively difficult to realise while TDoA only needs to realize the clock synchronization between the base stations, for this reason, the base station group can be connected in the same network. Therefore, this algorithm is currently the most suitable for UWB positioning technology.

6. UWB Challenges and Potential Analysis
The main features of UWB technology are described in [6] as high transmission rate, large space capacity, and strong anti-interference ability. However, UWB occupies a huge bandwidth, so it may interfere with other wireless communication systems. In order to avoid interference with other communication systems, each country has its own but similar regulations on UWB. For example, the U.S. Federal Communications Commission (FCC) stipulates the frequency band of UWB from 3.1GHz to 10.6GHz and limits its power spectral density to less than -41 dBm/MHz. European countries also specify the same bandwidth but the power spectral density must not exceed -53.3 dBm/MHz without a transmit power control. Currently, no country including the United States, Singapore, Japan, European countries allow UWB to be used outdoors [8]. The large instantaneous power brought by the signal pulse generated in a very short time is likely to interfere with the operation of other systems, such as the airport tower control system. At the same time, most mobile phones currently do not have integrated UWB chips. Compared with WiFi, this greatly limits the application. Furthermore, UWB equipment deployment costs are still high because it also requires multiple positioning base stations like Bluetooth. Nevertheless, UWB positioning technology has obvious advantages over other IPTs. With the development of this technology and more devices that can integrate UWB chips, it will have more
applications and commercial value, such as providing users with three-dimensional precise positioning in shopping malls and guiding passengers to the boarding gate quickly.

7. Conclusion
This paper compares and analyses with various parameters including accuracy and precision, cost, effective coverage, stability and availability, and scalability for multiple indoor positioning technologies and finds that UWB positioning technology will be more suitable for future IPS with its special advantages. What is more, using TDoA-based algorithms can further improve the positioning accuracy of UWB. The existing problem and potential faced by UWB are analysed such as it is still not integrated in most mobile phones and there is still a high demand for providing accurate positioning information in large indoor complex layout places. However, there is no detailed discussion about the accuracy and robustness of integration system with different IPTs in this paper. The future work will focus on the hybrid indoor positioning system and the development of UWB based IPT.

References
[1] Y. Suimon and M. Yanai, "Analysis of economic activity using mobile phone GPS data and estimating impact of COVID-19," 2020 9th International Congress on Advanced Applied Informatics (IIAI-AAI), pp. 725-728, doi: 10.1109/IIAI-AAI50415.2020.00145.
[2] Y. Li, X. Zuo and F. Yang, "Research on Urban Resident Activity Patterns and Hotspot Area Based on GPS Floating Car Data," in IEEE Access, vol. 8, pp. 2694-2707, 2020, doi: 10.1109/ACCESS.2019.2962536.
[3] KLEPEIS, N., NELSON, W., OTT, W. et al. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J Expo Sci Environ Epidemiol 11, 231–252 (2001). https://doi.org/10.1038/sj.jea.7500165
[4] B. Molina, E. Olivares, C. E. Palau and M. Esteve, "A Multimodal Fingerprint-Based Indoor Positioning System for Airports," in IEEE Access, vol. 6, pp. 10092-10106, 2018, doi: 10.1109/ACCESS.2018.2798918.
[5] V. Renaudin et al., "Evaluating Indoor Positioning Systems in a Shopping Mall: The Lessons Learned From the IPIN 2018 Competition," in IEEE Access, vol. 7, pp. 148594-148628, 2019, doi: 10.1109/ACCESS.2019.2944389.
[6] X. Lou and Y. Zhao, "High-Accuracy Positioning Algorithm Based on UWB," 2019 International Conference on Artificial Intelligence and Advanced Manufacturing (AIAM), pp. 71-75, doi: 10.1109/AIAM48774.2019.00021.
[7] M. Malajner, P. Planinšič and D. Gleich, "UWB ranging accuracy," 2015 International Conference on Systems, Signals and Image Processing (IWSSIP), pp. 61-64, doi: 10.1109/IWSSIP.2015.7314177.
[8] Alarifi, A. (2016). Ultra Wideband Indoor Positioning Technologies: Analysis and Recent Advances. Sensors., 16(5).
[9] S. Sadowski and P. Spuchos, "RSSI-Based Indoor Localization With the Internet of Things," in IEEE Access, vol. 6, pp. 30149-30161, 2018, doi: 10.1109/ACCESS.2018.2843325.
[10] H. X. Jian and W. Hao, "WIFI Indoor Location Optimization Method Based on Position Fingerprint Algorithm," 2017 International Conference on Smart Grid and Electrical Automation (ICSGEA), pp. 585-588, doi: 10.1109/ICSGEA.2017.123.
[11] G. Guo, R. Chen, F. Ye, X. Peng, Z. Liu and Y. Pan, "Indoor Smartphone Localization: A Hybrid WiFi RTT-RSS Ranging Approach," in IEEE Access, vol. 7, pp. 176767-176781, 2019, doi: 10.1109/ACCESS.2019.2957753.
[12] Y. Zhuang et al., "A Survey of Positioning Systems Using Visible LED Lights," in IEEE Communications Surveys & Tutorials, vol. 20, no. 3, pp. 1963-1988, thirdquarter 2018, doi: 10.1109/COMST.2018.2806558.
[13] M. Hehn, E. Sippel, C. Carlowitz and M. Vossiek, "High-Accuracy Localization and Calibration for 5-DoF Indoor Magnetic Positioning Systems," in IEEE Transactions on Instrumentation and Measurement, vol. 68, no. 10, pp. 4135-4145, Oct. 2019, doi: 10.1109/TIM.2018.2884040.

[14] Y. Xia, C. Xiu and D. Yang, "Visual Indoor Positioning Method Using Image Database," 2018 Ubiquitous Positioning, Indoor Navigation and Location-Based Services (UPINLBS), pp. 1-8, doi: 10.1109/UPINLBS.2018.8559714.

[15] K. Phutcharoen, M. Chamchoy and P. Supanakoon, "Accuracy Study of Indoor Positioning with Bluetooth Low Energy Beacons," 2020 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT & NCON), pp. 24-27, doi: 10.1109/ECTIDAMTNCON48261.2020.9090691.

[16] F. Zafari, A. Gkelias and K. K. Leung, "A Survey of Indoor Localization Systems and Technologies," in IEEE Communications Surveys & Tutorials, vol. 21, no. 3, pp. 2568-2599, thirdquarter 2019, doi: 10.1109/COMST.2019.2911558.