ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

# Research on the principle and positioning accuracy of ultra-wideband indoor positioning algorithm

**Xiaoyan Huang*, Chutian Sun, Yi Ying, Qing Zhang**

*College of Intelligent Systems Science and Engineering, Harbin Engineering University, Harbin, China*
**Corresponding author: 2642927271@qq.com*

***Abstract:*** *UWB, as an emerging carrierless communication technology, has become a hot area in indoor positioning research. This paper introduces the principles, advantages and disadvantages of current mainstream UWB positioning algorithms, including arrival time positioning, arrival time difference positioning, arrival angle positioning, positioning based on signal reception strength and some UWB fusion positioning methods, starting from the concept of UWB technology, and briefly explains the factors affecting indoor positioning accuracy.*

***Keywords:*** *UWB, Indoor Positioning, Fusion Positioning Algorithm, Non-visual Range*

## 1. Introduction

In recent years, with the development of Internet of Things (IoT) technology, positioning technology has become more and more diversified, and location service has become an essential and basic service in people's daily life. At present, in general outdoor environment, we have BeiDou satellite navigation system, Global Positioning System (GPS), etc. to provide us with accurate location information. However, in the complex indoor environment, the satellite signal attenuation phenomenon is very serious due to the blockage and interference of various obstacles, which leads to distortion of indoor positioning accuracy and seriously affects people's life.

With the development of indoor positioning technologies, indoor positioning technologies such as infrared, Bluetooth, WiFi, ZigBee and UWB have emerged. Table 1 shows the performance comparison of several common indoor positioning technologies in terms of positioning accuracy, reliability, cost and security[1] .

*Table 1 Comparison of indoor positioning technologies*

| Positioning Technology | Positioning accuracy | Reliability | Cost | Security |
|---|---|---|---|---|
| Bluetooth | 3~15m | Medium | High | Medium |
| Infrared | 5~10m | Low | High | High |
| Radio Frequency Technology | 5m | Medium | Low | Medium |
| WiFi | 2~10m | Low | Low | Medium |
| ZigBee | 2~5m | High | Low | High |
| UWB technology | 0.1~0.5m | High | Medium | High |

Ultra-wideband (UWB) is an emerging carrier-free communication technology in recent years[2] , which transmits data through very narrow pulses (below nanosecond or picosecond level), so it can have high temporal resolution when receiving or transmitting data, and can generally achieve high accuracy positioning through distance and distance difference calculation. For example, literature [3] proposed a UWB-based TOA ranging technique for accurate positioning of indoor users, which achieved high accuracy positioning with a minimum positioning error of 0.01m; literature [4] proposed a UWB-based weighted adaptive Kalman filter (WKF)-time difference of arrival (TDOA) positioning algorithm, which can reduce the positioning error caused by multipath effect and achieve mobile positioning. In [5], a positioning system based on the fusion of Ultra-Wide Band (UWB) sensors and Inertial Measurement Unit (IMU) is proposed to achieve high-precision indoor positioning in NLOS scenarios. Compared with traditional narrowband communication systems, the excellent transmission characteristics make UWB extremely competitive in indoor high-precision positioning technology, which can be applied to scenarios such as logistics and storage, industrial manufacturing, rescue and search, and public safety services.

ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

Therefore, this paper discusses the research on UWB technology.

## 2. UWB positioning technology algorithm and principle

In wireless positioning systems, positioning methods can be divided into two types: ranging-based and non-ranging-based, and this paper only introduces ranging-based positioning methods. In UWB technology, the range-based positioning methods include TOA, TDOA, AOA and RSSI, and the principles, advantages and disadvantages of these four positioning methods are introduced below.

### *2.1 Arrival time based positioning algorithm*

Time of Arrival (TOA) based positioning algorithm is also known as TOA. This algorithm calculates the distance between the tag node to be located and the base station directly from the signal propagation time. Figure 1 shows the schematic diagram of TOA.

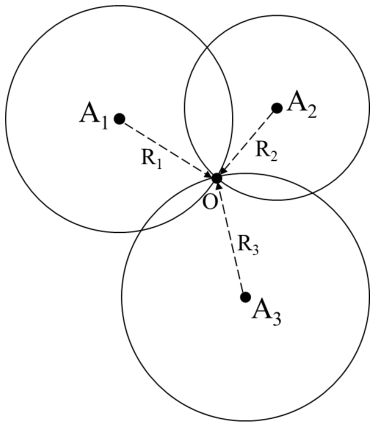


*Figure 1 TOA schematic*

In the figure, A1, A2, A3 are three base stations in the environment, R1, R2, R3 are the distances between the three base stations and the tag nodes, respectively, which are obtained by multiplying the one-way signal propagation time between the tag nodes and the three base stations by the propagation speed of electromagnetic waves in the air, respectively. 123123The intersection point O of the three circles is the reference coordinate of the tag node to be located. Let the coordinates of the label node be (x , y), the coordinates of A1 are (x1 ,y1 ), the coordinates of A2 are (x2 ,y2 ), and the coordinates of A3 are (x3 ,y3 ), which leads to Equation (1).

$$\begin{cases} \sqrt{(x_1-x)^2+(y_1-y)^2}=R_1 \\ \sqrt{(x_2-x)^2+(y_2-y)^2}=R_2 \\ \sqrt{(x_3-x)^2+(y_3-y)^2}=R_3 \end{cases} \tag{1}$$

After the coordinate transformation, the position of the label node to be located can be obtained as follows.

$$\begin{bmatrix} x \\ y \end{bmatrix}=\begin{bmatrix} 2(x_1-x_3) & 2(y_1-y_3) \\ 2(x_2-x_3) & 2(y_2-y_3) \end{bmatrix}^{-1}\begin{bmatrix} {x_1}^2-{x_3}^2+{y_1}^2-{y_3}^2+{R_3}^2-{R_1}^2 \\ {x_2}^2-{x_3}^2+{y_2}^2-{y_3}^2+{R_3}^2-{R_2}^2 \end{bmatrix} \tag{2}$$

The principle of TOA positioning algorithm is relatively simple, but due to the extremely fast signal propagation speed, resulting in a very small time measurement error can also cause large ranging errors, so it requires the transceiver node clocks to be fully synchronized, which also makes the equipment cost much higher.

### *2.2 Time-of-arrival difference-based localization algorithm (TDOA)*

TDOA (Time Difference of Arrival) is the Time Difference of Arrival (TDOA) positioning algorithm,

ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

which is an improvement of the TOA positioning algorithm. The basic principle of this algorithm is that the distance between the tag to be positioned and different UWB positioning base stations is different, and the time nodes at which different base stations receive the signal sent by the same tag are different, according to which the "time difference of arrival" is obtained. According to the mathematical relationship, the distance difference to two known points is a constant, and the expression of distance is the time required for the base station to receive the signal sent by the tag multiplied by the speed of signal propagation in the air (i.e., the speed of light), so the time difference between the signal sent by the tag to be positioned and the two base stations is a constant, and the position of the tag to be positioned must be on the hyperbola with these two points as the focus. Then there are n UWB positioning base stations, there will be n hyperbolas, and the n hyperbolas intersecting at a point is the position of the node of the tag to be positioned. Taking three UWB positioning base stations as an example, the TDOA positioning schematic is shown in Figure 2.

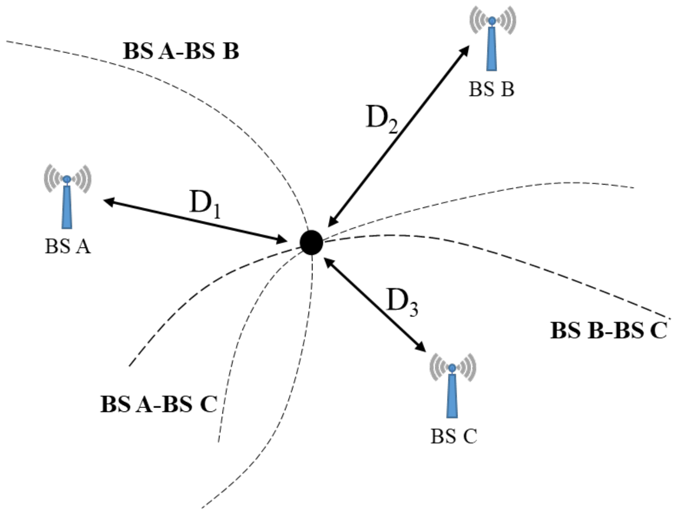


*Figure 2 Schematic diagram of TDOA positioning*

It is known that the coordinates of base station A, base station B and base station C are (x1 ,y1 ), (x2 ,y2 ) and (x3 ,y3 ) respectively, the coordinates of the tag nodes to be located are (x , y), and D1 , D2 , D3 are the distances between the tag nodes to be located and each base station by TOA ranging method[6] . Then the equation of TDOA localization algorithm is shown in equation (3).

$$\begin{cases} D_1 - D_2 = \sqrt{(x-x_1)^2 + (y-y_1)^2} - \sqrt{(x-x_2)^2 + (y-y_2)^2} \\ D_1 - D_3 = \sqrt{(x-x_1)^2 + (y-y_1)^2} - \sqrt{(x-x_3)^2 + (y-y_3)^2} \end{cases} \tag{3}$$

Compared with the TOA positioning algorithm, TDOA does not require strict clock synchronization between individual base stations and the tags to be located, but only clock synchronization between base stations. Since the base stations are fixed, it is obviously easier to achieve clock synchronization between the base stations than between the base stations and the tag nodes to be located, which can greatly reduce the equipment cost. However, this method requires high hardware requirements, and its positioning accuracy will be reduced in a non-visual range environment.

### *2.3 Angle of arrival signal-based positioning algorithm (AOA)*

The principle of Angle of Arrival (AOA) based positioning algorithm is to install an antenna array on each base station with known location and use the antenna array to determine the angle of incidence based on the signal emitted by the tag node to be positioned, and the coordinate position can be obtained through the triangular relationship between the base station and the tag node to be positioned[7] . The schematic diagram of AOA positioning algorithm is shown in Figure 3.

ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

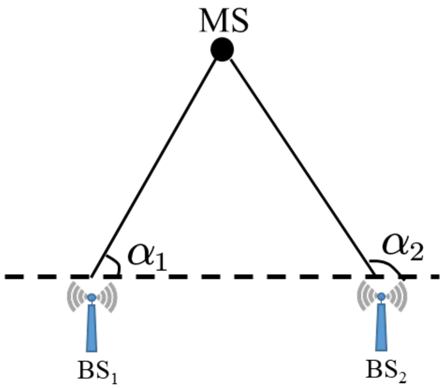


*Figure 3 Schematic diagram of AOA positioning*

Let the coordinates of the tag MS to be located be (x, y), the coordinates of the base stations BS1, BS2 are (x1, y1), (x2, y2), and the angles of the tag nodes to be located reaching the base stations BS1 and BS2 are $\alpha_1$、$\alpha_2$ , respectively, then the coordinates of the tag nodes to be located can be obtained from equation (4).

$$\begin{cases} \tan\alpha_1 = \dfrac{x-x_1}{y-y_1} \\ \tan\alpha_2 = \dfrac{x-x_2}{y-y_2} \end{cases} \tag{4}$$

The AOA positioning algorithm is simple in principle, easy to calculate, and does not need to consider the problem of clock synchronization between the transmitting and receiving ends, but it is easy to fail to measure the relative angle accurately in the NLOS environment due to the multipath effect; on the other hand, in the actual measurement, it may encounter the situation that the signals emitted by the tags to be positioned are perpendicular to the baseline composed of two base stations, which may lead to ambiguity in the algorithm.

### *2.4 Localization based on signal reception strength algorithm (RSSI)*

The principle of RSSI (Received Signal Strength Indication) is to transmit UWB radio signals through a positioning base station with known coordinate locations. The distance between the tag node to be located and the positioning base station can be found out by using the known channel loss model and the signal strength received by the tag node, and then the specific location of the unknown tag node can be found out by using the equation in the TOA positioning algorithm.

At present, wireless signal propagation theoretical models are mainly free space propagation model (Free Space Propagation Model), Hata model (Hata Model), log-normal distribution model (Log-Distance Path Loss Model) and so on. In the actual environment, the signal propagation is inevitably affected by the interference of occlusion, noise, multipath effect, etc. After a large amount of data analysis, these interferences obey Gaussian random distribution, and the signal power loss and RSSI values are normally distributed after transmitting the same distance. The log-normal distribution model is most widely used because it integrates the consideration of these interference factors and is more applicable to the actual environment.

The log-normal distribution model is shown in equation (5).

$$PL(d) = \overline{PL}(d_0) - 10n\lg\left(\frac{d}{d_0}\right) + X_\sigma \tag{5}$$

Where $n$ is the environmental attenuation factor, the range of values is generally [2~6]; $d_0$ is the reference distance, generally taken as 1m; $d$ is the distance between the signal receiving point and the

ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

signal transmitting point in m; $PL(d)$ denotes the received signal strength in dBm at a distance of $d$ from the signal transmitting node; $\overline{PL}(d_0)$ denotes the received signal strength in dBm at a distance of $d_0$ from the signal transmitting node; $X_\sigma$ is a Gaussian distribution with a mean value of 0 and a mean square deviation of $\sigma$ variables.

The advantage of RSSI positioning algorithm is that it can make full use of indoor wireless devices to receive their channel fading components, so the cost is lower; however, the relationship between its measured distance and signal fading depends on a channel loss model suitable for the current environment, and the UWB signal strength is very sensitive to changes in the indoor environment, so RSSI positioning errors are usually large.

### *2.5 Fusion positioning algorithm*

By analyzing the principles of the above major UWB indoor positioning algorithms, TOA, TDOA, AOA and RSSI positioning algorithms have their own advantages and disadvantages, and it is difficult to obtain ideal positioning accuracy in a complex indoor environment by relying on one algorithm alone. Therefore, the current indoor positioning technology is bound to develop in the direction of multi-technology and algorithm integration, so as to make full use of the advantages of a single positioning algorithm to bridge the shortcomings of a single positioning algorithm, thus improving the overall positioning accuracy and stability, and at the same time reducing the system cost and improving the feasibility of the solution.

For example, in the literature [8], in order to solve the challenges of low accuracy and poor stability of UWB localization technology in indoor localization process, an indoor localization data enhancement processing method based on the extended Kalman filter (EKF) framework fusing UWB and IMU sensor information is proposed. Where the IMU measurements are used as the prediction of the filter and the UWB measurements are used as the filter measurement update. The fused localization algorithm can compensate for the short-term localization data loss, reduce the jitter of the localization data, improve the stability of the localization system, and provide better engineering advantages in a semi-structured environment.

The literature [9] proposes a combined positioning system that incorporates the Strapdown Inertial Navigation System (SINS) and UWB indoor positioning technology. The system consists of 2 independent measurement systems, SINS and UWB ranging equipment: the INS uses SINS based on microelectromechanical system and outputs its position and attitude information in real time; the UWB system measures the distance from the mobile station to the base station and obtains the coordinates of the mobile station by to TDOA algorithm. Then the position difference of the 2 systems is selected as the observed quantity, and the extended Kalman filter, which takes a loose combination approach, is designed to solve the problem, and the solved result is then fed back to the INS, which is used to ensure the positioning accuracy of the INS. This system effectively weakens the inherent errors of INS and UWB systems, and optimizes the positioning algorithm by improving the discriminative ability and reconstruction ability of the non-line-of-sight measurements in the NLOS case, which makes the positioning results more accurate and smooth.

In the literature [10-11], an indoor localization system based on the fusion of UWB and IMU is proposed, where the IMU sensor data is used to establish the filter state equation and the UWB sensor measurements are used as the filter observation equation, and then the two sensors are fused using the extended Kalman filter operator (EKF). Experimental verification shows that the fused indoor positioning algorithm can effectively suppress the effects of multipath effect and non-line-of-sight (NLOS) in UWB positioning in a short period of time, while overcoming the problem that the least squares method cannot be solved due to the singular matrix, thus improving the positioning accuracy and stability of the positioning system.

## 3. The main factors affecting indoor positioning accuracy

### *3.1 Non-Line-of-Sight Propagation*

The transmission conditions of wireless signals in the transmission process are Line of Sight (LOS) and Non Line of Sight (NLOS). In the line-of-sight environment, the signal can be propagated in a straight

ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

line between the transmitter and the receiver without any obstacle. However, in a complex indoor environment, the complex structure of the building, the placement of many items, and the large flow of people will certainly lead to the emergence of non-line of sight phenomenon. At this time, the UWB signal propagation is blocked by various obstacles and can only reach the signal receiver through reflection, refraction, scattering and diffraction, which will eventually lead to signal lag, signal strength attenuation and even signal loss at the receiver, thus affecting the accuracy of UWB indoor positioning. Figure 4 is a schematic diagram of NLOS propagation and LOS propagation.

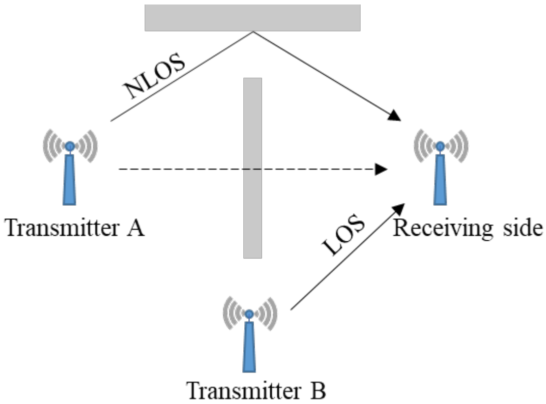


*Figure 4: NLOS path diagram*

The impact of non-visual range on UWB indoor localization cannot be ignored, and therefore, many improvement works have been carried out based on it. For example, Dong Jiazhi in the literature [1] combined the center-of-mass Taylor algorithm and the geometric relationship of TOA to design the N-Taylor algorithm, which can detect the transmission path with large relative error and effectively eliminate the error caused by non-line-of-sight; Xiang Zheng in the literature [12] proposed to effectively improve the positioning accuracy by increasing the positioning line and weighted averaging method under NLOS; Li Xinchun in the literature [13 In the paper [13], Li Xinchun proposed a UWB indoor positioning algorithm based on TDOA difference discrimination and NLOS error reduction, which effectively reduced the positioning error and improved the positioning accuracy by combining the advantages of Kalman filter to optimally update the prediction equation to reduce the positioning error and Chan-Taylor positioning algorithm with high iterative accuracy.

### *3.2 Multipath effect*

In a variety of very complex indoor environments such as cell houses, offices, shopping malls, underground parking lots, etc., due to interference from obstacles, UWB signals will be reflected, refracted, scattered and diffracted in the transmission process, and the signals will often arrive at the receiving end in multiple different paths, making the time for each signal to arrive at the receiving end different, which in turn leads to the superposition of each signal according to its own amplitude and phase, bringing a series of problems such as signal attenuation, link instability and delay. The signal attenuation, link instability and time delay are not synchronized and a series of problems. Anti-multipath interference mainly has the following measures: improve the distance measurement accuracy of the receiver, such as narrow correlation code tracking loop, phase ranging, smooth pseudorange; use anti-multipath antenna, etc.

## 4. Conclusions

This paper starts from the concept of UWB technology and explains the reasons for choosing UWB technology for the introduction by comparing it with other indoor positioning technologies. Then the principles of several main algorithms of UWB technology and some fusion algorithms are introduced, and their advantages and disadvantages are briefly analyzed. Then the factors affecting indoor positioning accuracy are elaborated. At present, the domestic UWB indoor positioning technology is still in the preliminary development stage, but with the update of technology and the increase of social demand, it will certainly promote the development of this technology more deeply, and the fusion with other positioning methods, improve the non-visual positioning accuracy, weaken the non-visual error and the influence of multipath effect will become the key direction to improve the positioning accuracy of UWB. It is believed that the continuous development of UWB positioning technology will also benefit more

ISSN 2616-5775 Vol. 6, Issue 6: 133-139, DOI: 10.25236/AJCIS.2023.060621

fields [14].

**References**

*[1] Jiacheng Ge. Research on indoor positioning with UWB technology [D]. Nanjing University of Posts and Telecommunications, 2020. DOI: 10.27251/d.cnki.gnjdc. 2020. 001240.*
*[2] Xu Jiaxuan. Research on UWB-based wireless sensor network localization method [D]. Nanjing University of Posts and Telecommunications, 2022. DOI: 10. 27251/d.cnki.gnjdc. 2022. 001090.*
*[3] Wang M. T. , Wang W. Y., Ye Yalin, Lu Y. L., Wang G. M., He Tao. Research on key technologies for indoor wireless positioning with high accuracy UWB [J]. Electrical Automation, 2022, 44(05):78-80+83.*
*[4] Hao Zhanjun, An Ying, Chen Honghong, Dang Xiaochao, Zhang Jinlong. Weighted adaptive Kalman filtering indoor localization algorithm based on UWB [J]. Sensors and Microsystems, 2022, 41(09): 116-120. DOI: 10. 13873/J. 1000-9787(2022)09-0116-05.*
*[5] Peng JJ, Li YH, Wang CHQ, Zhou SQ. IMU and UWB fusion positioning system in non-visual range environment [J]. Radio Engineering, 2022, 52(06): 932-939.*
*[6] Luo Bo. Research and implementation of TDOA localization algorithm based on UWB technology [D]. Hainan University, 2017.*
*[7] Zhang Shuai. Research on indoor positioning algorithm based on ultra-wideband [D]. Zhejiang University of Technology and Industry, 2020. DOI:10.27462/d.cnki.ghzhc. 2020. 000221.*
*[8] Hu W-L, Zhou Y-F, Song Q-J, et al. Research on indoor positioning algorithm based on UWB and IMU information fusion [J]. Manufacturing Automation, 2023, 45(02): 193-197+213.*
*[9] Liu M. F., Wang D., Liu F. Y., et al. Research on high accuracy UWB/SINS combined indoor positioning system [J]. Journal of Navigation and Positioning, 2016, 4(02): 53-56+86. DOI: 10. 16547/j. cnki. 10-1096. 20160211.*
*[10] Wu C. The Research of Coal Mine Location Technology Based on the Ultra-wideband Wireless Sensor Networks[C]// International Conference on Intelligent Computation Technology & Automation. IEEE Computer Society, 2010.*
*[11] Yang J, Liu Y, Mu X. The Algorithm Research of Indoor Location Based on Ultra Wideband[C]// 2017 2nd International Conference on Civil, Transportation and Environmental Engineering (ICCTE 2017). 2017.*
*[12] Xiang Zheng. Research on non-visual range reduction hybrid localization algorithm based on TOA/AOA [D]. Nanjing University of Posts and Telecommunications, 2016.*
*[13] Li X. C., Yang S. Y., Zhang Y. C., Sun H. Y. UWB indoor localization algorithm for NLOS error reduction [J]. Journal of Chongqing University of Posts and Telecommunications (Natural Science Edition), 2022, 34(05): 758-765.*
*[14] Chen S, Guan W, Tan Z, et al. High accuracy and error analysis of indoor visible light positioning algorithm based on image sensor[J]. 2019.*