Ultra Wide Band Technology and Indoor Precise Positioning

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ABSTRACT: UWB technology is a wireless carrier communication technology that uses frequency bandwidth above 1GHz. This essay mainly focuses on the theory of UWB and one of its most important applications, which is indoor positioning. It will explore some possibilities of UWB in the field of precise positioning. Based on the literature, the theory of UWB and the algorithm of positioning will be shown in a relatively simple way. The result shows that Ultra Wide Band (UWB) technology has the advantages of low system complexity, low power spectral density of transmitted signal, and insensitivity to channel fading. The positioning system based on UWB can be used for the real-time location management of personnel, equipment, and vehicles, as well as to view the real-time location and distribution area of the target., such as nursing home elderly positioning monitoring, to prevent the elderly from getting lost, location management of chemical plant operators, security of dangerous areas, location management of vehicles and equipment, etc.

1. INTRODUCTION

UWB technology began in the 1960s with the rise of pulse communication technology. UWB technology uses ultra-wide baseband pulses with an extremely wide spectrum to communicate, so it is also called baseband communication technology and wireless carrier communication technology. It is mainly used in military radar, positioning and communication systems with a low interception rate/low detection rate. In February 2002, the FEDERAL Communications Commission issued preliminary rules for the use of spectrum and power for civilian UWB devices. Communication systems with a relative bandwidth of more than 0.2 or more than 500 MHz at any time of transmission are referred to as UWB systems in the regulation, and UWB technology is approved for use in civilian goods. Japan then opened up the UWB spectrum in August 2006. UWB technology has become the preferred technology for wireless personal local area network (WPAN) because of its high data transmission rate (up to 1Gbit/s), strong anti-multipath interference ability, low power consumption, low cost, strong penetration, low interception rate, and spectrum sharing with other existing wireless communication systems [1].

There are numerous studies on UWB in the academic world. Most of the research is related to the application of UWB. For example, UWB personnel positioning in coal mine. The intelligent construction of coal mine puts forward higher requirements for the accuracy and real-time of underground personnel positioning system. Based on infrared detection, ultrasonic compared to technology such as using nanosecond pulse signal to communicate, the UWB (Ultra Wide Band) technology can well reduce NLOS (Non Line of Sight) interference, better adapt to the underground complex environment, and realize cm-level accuracy positioning [2]. In addition, some research focus on the combination of UWB technology and other positioning technologies to obtain more accurate positioning algorithms: UWB and GPS fusion localization algorithm based on the Unscented Kalman Filter (UKF). By developing the system scheme, optimizing the data parsing algorithm of the UWB module, constructing the nonlinear fusion system model of UWB and GPS, analyzing the complexity of the algorithm, writing the algorithm into the controller for real-time filtering, and analyzing noise error and variance under different algorithms [3].

This article focuses on some basic algorithms of UWB positioning, and discusses relevant strengths and weaknesses and possible solutions. It can provide relevant theories for beginners who are interested in UWB, and compare the advantages and disadvantages of the UWB indoor positioning algorithm, which can provide reference for researchers studying indoor positioning.

2. DEFINITION

UWB technology is a wireless carrier communication technology that uses frequency bandwidth above 1GHz. Instead of using a sinusoidal carrier, it uses narrow pulses of non-sinusoidal waves at the nanosecond level to transmit data, so it covers a wide spectrum and can transmit data at rates of hundreds of megabits per second or more, despite wireless communication. UWB can transmit signals over a very wide bandwidth. According to the Federal Communications Commission (FCC), UWB occupies more than 500MHz of bandwidth in the 3.1-10.6 GHz band.

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3. THEORY

The FCC, UWB frequency band allocation is from 3.1 GHz to 10.6 GHz, a total of 7.5 GHz frequency band, limited by radiation power, far below the levels of BLE/WiFi, 41.3 dBm. In terms of spectrum, UWB is much wider.

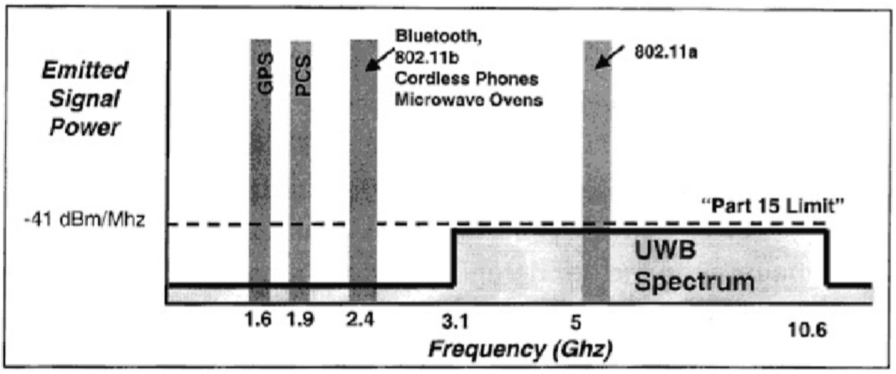

Figure 1 Power limitation

The characteristics of UWB determine that it is perfect for precise positioning.

(1) Strong ability to resist multipath: the wider the bandwidth, the stronger the multi-path resolution and the higher the position resolution. As shown in the figure below, the path loss of UWB is ~ ~7dBs less than that of narrowband communication under the worst path.

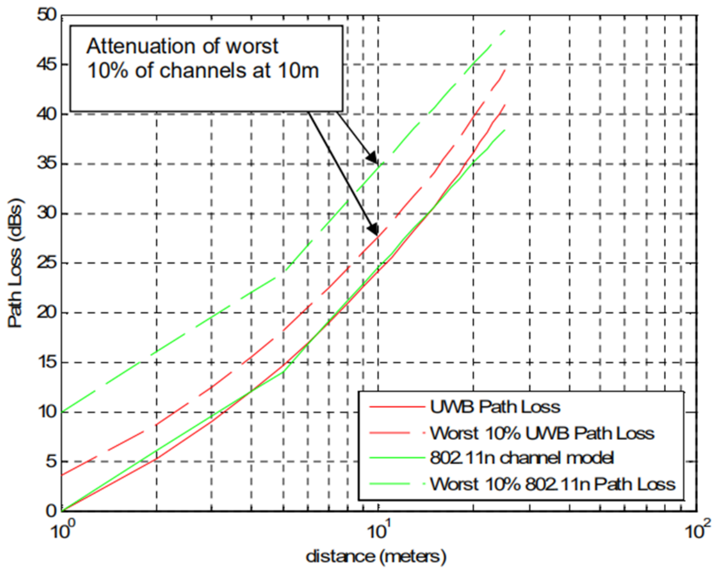

Figure 2 UWB path loss versus distance diagram

(2) High temporal resolution: generally in the nanosecond UWB signal transmission is complete, V (velocity) * T (time) = distance, and high precision time resolution support higher precision positioning.

(3) Energy efficiency is high. The energy curves of UWB and narrowband signals are as follows. It can be seen that the EER of UWB narrowband is much higher, which enables UWB to further transmit distance under relatively low transmission power.

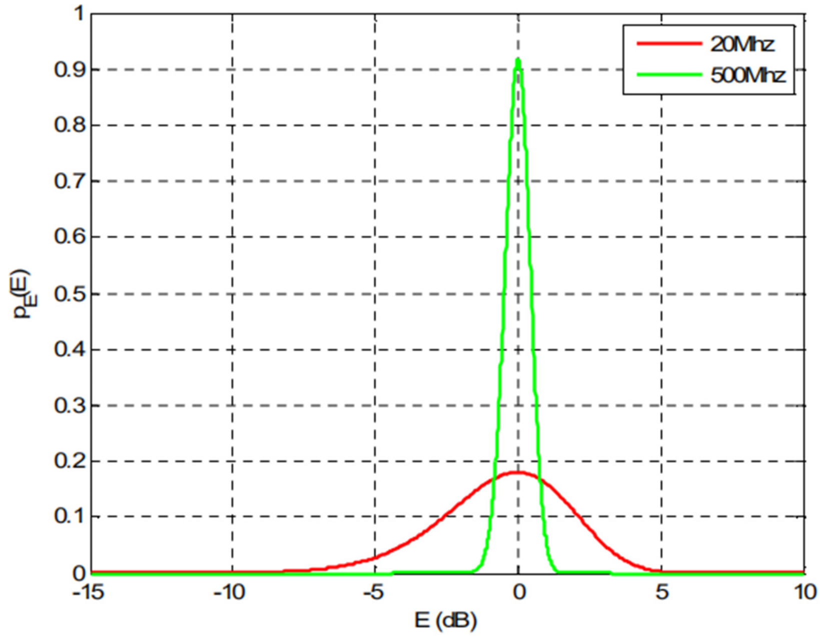

Figure 3 UWB and narrowband signal energy curves

(4) Anti-interference: UWB can transmit signals at low signal-to-noise ratio.

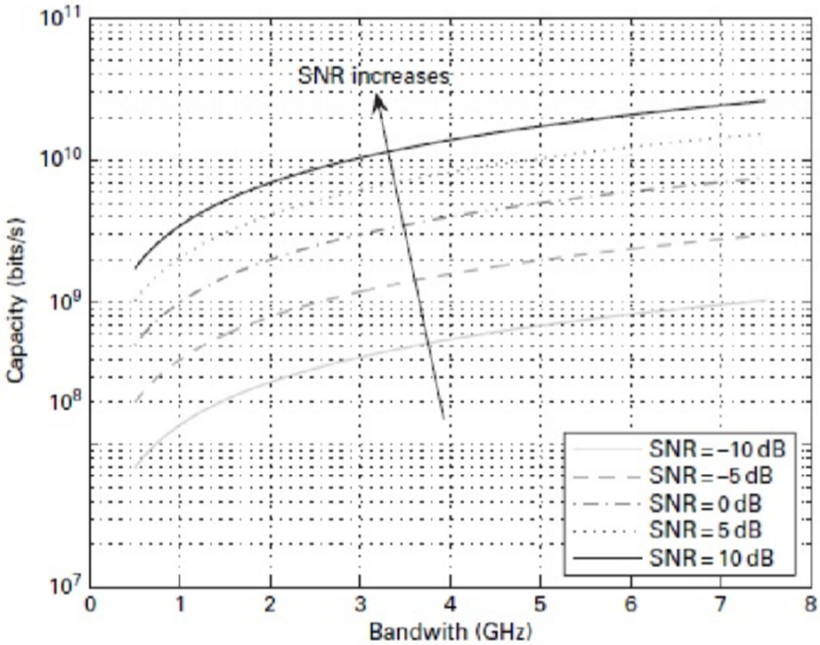

Figure 4 Capacity, bandwidth and SNR

4. INDOOR POSITIONING TECHNOLOGY

The very short time domain pulses of UWB systems make them ideal candidates for combined communication and positioning. The duration of the pulse is inversely proportional to the bandwidth of the transmitted signal. If the known uncertainty of the arrival time of the pulse is very small, it is possible to accurately estimate the distance from the pulse to the source. A simple triangulation technique can be used to estimate the position of the source by combining the distance estimates of multiple receivers.

For UWB systems with a potential bandwidth of 7.5 GHz, the maximum time resolution of pulses is 133 picoseconds. Therefore, when the pulse arrives, the “flight time” of the pulse can be known in 133 picoseconds. This time uncertainty is equivalent to 4cm of spatial uncertainty. For the medium 500 MHz bandwidth, the corresponding time resolution is 2 nanoseconds, equivalent to about 60 cm of spatial uncertainty. Therefore, for any UWB signal, as long as the temporal and spatial uncertainty can be combined from multiple sources without significant loss, it is possible to achieve sub-meter positioning accuracy. The corresponding position estimation will be affected by the cumulative error of each distance estimation and any uncertainty or error introduced by the positioning technology itself. There are different technologies to determine the location according to the arrival time or flight time estimation, and each technology has its advantages and disadvantages [4]. There are many types of location estimation techniques that have different uses in different situations. Signal strength, Angle of arrival (AOA), and time measurements (TOA, time-of-flight and time-of-arrival difference (TDOA)) can all be used for position estimation. The following example is a cellular system. The next part will show these methods and their algorithms.

5. ALGORITHMS OF INDOOR POSITIONING TECHNOLOGY

5.1. TOA: Time of arrival

Arrival localization algorithm, also known as the TOA localization algorithm, directly calculates the distance between the measured point (tag) and the reference point (base station) according to the signal propagation time. In this algorithm, the label sends signals to at least three base stations, and the system obtains the distance between the label and the base station by measuring the time when the signals reach each base station. Then, the distance obtained from each base station is the radius of the circle, and the intersection of each circle is the reference position of the destination node [5].

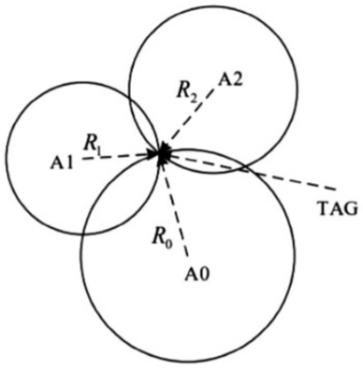

Figure 5 TOA positioning schematic diagram

The figure above shows the traditional TOA algorithm, which is based on record labels with unidirectional signal propagation time between the three stations.

Figures (A1, A2, and A3) for Scenario Three Base Station, multiplying the time by the propagation velocity of electromagnetic waves in the air, measuring point label and three linear distances between the base stations, and remembering Ro, R1, and R2. Ao, A1 and A2 represent the circle's center, Ro, R1 and R2 represent the radius of a circle, and the intersection of three circles represents the coordinate of observation points. Set by measuring point label coordinates (x, y), Ao coordinates (xo, yukio okamoto,), A1 coordinates (x1, y1), A2 coordinates (x2, y2), which can be calculated as follows:[6]

$$\begin{cases} (x_0 - x)^2 + (y_0 - y)^2 = R_0^2 \\ (x_1 - x)^2 + (y_1 - y)^2 = R_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 = R_2^2 \end{cases}$$

TOA can be used in designing the garage intelligent navigation system. In this system, the user enters the garage when receiving the vehicle entry card. The card has a built-in UWB positioning label, according to the base station of parking lots can locate the vehicle location. Based on the intelligent navigation guide, drivers drive to recommend free parking space, also can look for parking spaces. Driving away from the vehicle into the underground parking lot, users can see the position of the vehicle on the mobile phone APP and it is easy to look for when picking up the vehicle [7].

5.2. TDOA: Time difference of arrival

Both TOA and TODA depend on Signal propagation time to make measurement and calculation. But in TODA, the time used for the process is not absolute time but Signal arrival time difference. It only needs time synchronization of each base station and are not required to be measuring point in time also can achieve synchronization [8]. To locate the target, each value of TDOA measurement corresponds to two base stations as the focus of hyperbola [6]. The core formula is as follows:

$$\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} = C(t_i\text{-}t_0),\ \text{i=1,2,3}$$

(x, y, z) and (xi, yi, zi) relatively stand for target position and reference position. t0 means the time that target sends signal. ti means the time that signal arrives reference position. Then a time difference would be calculated. After several calculations, the position errors of target position and reference point caused by non synchronization can be reduced to achieve the positioning effect [6].

TDOA can be applied in coal mine. The overall level of coal mine safety technology and equipment technology in China is not high, there are many coal mine accidents and poor disaster capacity, which highlights the necessity, urgency and feasibility of establishing and improving advanced safety monitoring system. For many years, the coal industry's technical problems have been unsolved. the research and development of underground moving target positioning and tracking technology in improving the production efficiency, guaranteeing the safety of the mine personnel, and post-disaster self-rescue has very important significance.

The TDOA method can realize target node positioning. The TOA ranging method uses the signal propagation time delay due to the mobile terminal and the receiver's strict synchronization, so there is a synchronization error. This system is relatively simple, the cost is low, but the consumed power is higher because the signal is two-way communication. Possibility in the actual implementation of the technology compared with TOA is much higher. This is because it does not require the clock line between the base station and the target under test, but only needs clock synchronization between each base station to get the required value, and in the process of reducing the arrival time difference, the positioning accuracy can be relatively increased. According to the above analysis, in practice, each location method can't be used in a variety of complex changes of channel environments to achieve ideal location accuracy. However, TDOA in these positioning ways has higher positioning accuracy and good practicability, so in this article, the positioning method used is the TDOA location method.

5.3. AOA: Angel of arrival

It uses the radial line between the base station and tag to determine both the Angle of the relationship.

6. PROBLEMS AND POSSIBLE SOLUTIONS

The part above shows some popular algorithms for UWB indoor positioning, but there are flaws exists. The following part will discuss their flaws and possible solution.

6.1. TOA

This algorithm is simple to apply, but the requirements for base and tag should strictly synchronize time, otherwise the accuracy of position cannot be guaranteed.

Possible solution: using the least square locating algorithm to process the original TOA ranging values, and seeking the best function matching of the data by minimizing the sum of error squares, so as to minimize the sum of error squares between the obtained data and the actual data [6].

6.2. TDOA

There is divergence, especially in the case of low signal-to-noise ratio, resulting in reduced accuracy.

Possible solution: Cheng Wen put forward that using a simple choose generation least-square algorithm [10]. Firstly, the algorithm transforms the TDOA equation from Pythagoras theorem to the standard form of least square method, plus the unknown in the equality constraint relationship, and calculates the position coordinates according to the selected generation idea. The method is verified by Monte Carlo simulation experiment to have more convergent positioning results.

6.3. AOA

The Antenna layout would affect accuracy. What’s more, Non-line-of-sight error and background noise are problems.

Possible solution: Ma Yi put forward a kind of AOA location algorithm based on refactoring. Assuming that the algorithm is transmitted wave measuring point distribution in D by measuring point as the center of the circle radius of the disk, the transmitted wave scattering wave travels via a uniform distribution of scattering body (S) to reach the base station. Select the strongest path for the waveform path of reconstruction thought, because the strongest path with waveform with the most effective information, and the best path in the non line-of-sight environment characteristics. Through geometric derivation, the coordinates of the measuring points can be obtained. The algorithm in the circular radius is larger. The greater the number of multi-path, the higher the positioning accuracy. Compared to the traditional AOA algorithms, the algorithm of positioning precision is improved [11].

7. DISCUSSION

Although UWB has strong resistance to multipath, high temporal resolution, high energy efficiency, and interference advantages, from a market standpoint, the positioning of the UWB represents demand still has certain forward-looking, and it is still a pain point for the industry at this stage. The process of certain industry applications, such as forklifts, although the location is very good, can’t support the size of the entire industry.

Also, UWB positioning system needs to include the UWB positioning base station, tag, engine and application system. WIFI, bluetooth, positioning technology such as RFID, compared to the base station positioning and orientation of the label price on UWB has an obvious landslide price differential.

UWB positioning technology is basic. It is using DW1000 chip. This chip integration algorithm are very few, actually is to send a pulse signal. The main localization algorithms are needed to do the integration of the vendor to their own research and optimization, which leads to the difficulty of the development being high, the investment of manpower, and the accident of positioning error being larger.

Although the UWB positioning technology has the above problems, but it has the biggest advantage of all in UWB positioning, precision. The orientation of WIFI and Bluetooth compared to this dispensable to use technology, UWB positioning precision straight after laser positioning. The combination of UWB technology and the Internet of things, the use of UWB technology in robot, and UWB technology in the application of 4.0 T industry will eventually put the technology requirements in the position to find their proper coordinates. The cost of continuous excavating is decreasing as new industry applications for continuous excavating are developed, and UWB ubiquity is just around the corner.

8. CONCLUSION

After the research shown above, conclusion can be drawn. UWB will be the mainstream accurate positioning method in the future, and the basic algorithm used in different scenes will be different. Each algorithm has its own advantages and disadvantages. However, this paper is still lacking in the introduction and examples of more positioning algorithms, and supplementary discussions will be made in the future based on new algorithms and learning.

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