ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202011_3(11).0034

Research and Analysis on UWB Indoor Positioning System

Xianyue Zou[1], Anhang Wang[1], Shiyu Li[1], Shuai Wang[1]

[1]Shandong University of science and technology, Tai'an 271000, China.

Abstract

GPS outdoor positioning technology has gradually entered people's lives, and there is still much room for the development of indoor positioning technology. This paper mainly analyzes the development status, technical characteristics and UWB positioning technology of UWB technology, and designs an indoor positioning system based on UWB. After testing, the indoor positioning accuracy of the system can reach 10cm.

Keywords

Indoor positioning; UWB; positioning accuracy.

1. Preface

Currently, the main positioning method in the world is wireless positioning technology. GPS outdoor positioning technology has been widely used, but it can only work within the visible range of GPS positioning satellites. GPS cannot achieve effective positioning indoors with many obstacles. In order to solve this problem, UWB is widely used due to its ultra-wideband and strong penetrability, which can accurately locate indoors and underground. [1]

2. Overview of UWB Positioning Technology

Since UWB technology was officially used in commercial activities, related academic research and industry have developed rapidly. UWB indoor positioning system mainly adopts TOA method and TDOA method to realize positioning. In theory, its maximum positioning accuracy can reach centimeter level. UWB technology has the advantages of large bandwidth, extremely low transmission power, strong penetration ability, no carrier, strong anti-multipath interference ability, and ultra-high time resolution. Its positioning error will not accumulate over time. This method can better integrate various complex indoor environment relationships, and is very suitable for the design of indoor positioning systems.

3. Development Status of UWB Positioning Technology at Home and Abroad

UWB technology is not a new technology. Since the birth of UWB signals, UWB positioning technology has a history of nearly 100 years. UWB technology in the sense of the establishment of the United States originated in 1965. At first, the research of UWB technology in the United States was only involved in the military, and the results were only applied to the direction of communication and military radar, resulting in slower development of UWB technology. In 2002, UWB technology was formally put into civilian use, and the definition of UWB was expanded to stipulate the bandwidth of UWB signals. From then on, UWB technology can go to the road of commercial development, which greatly promotes the development process of UWB technology. [2]

Benefiting from the extremely narrow pulse width and pulse frequency of UWB signals, UWB signals have ultra-large bandwidth, extremely low transmit power, high data transmission capabilities, strong penetration capabilities, ultra-high time resolution, no carrier, and good

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202011_3(11).0034

Anti-multipath interference ability, etc. In recent years, various developed countries have begun to pay attention to the development of UWB technology. Therefore, UWB positioning technology is developing rapidly and is gradually being used in positioning, communications, radar and other fields. Because UWB technology has high ranging accuracy, strong anti-interference ability, low power consumption and strong data transmission capabilities, UWB technology shines in the field of positioning, and its applications are very wide: indoor cargo management, automatic service robots, Disaster emergency rescue work and other aspects.

4. UWB Technical Characteristics

UWB communication adopts non-carrier communication method. Compared with traditional wireless communication technology, it has a simpler hardware structure, lower power consumption, high communication rate and better ability to suppress multipath fading. The specific advantages are:

(1) Simple structure, low power consumption

When UWB technology acts on a short distance range, the application of time-hopping spread spectrum technology enables the signal transmission power of UWB transmitters to be reduced to a very low level, generally lower than 1mW, and the UWB signal radio frequency width can even be higher than 1GHz. UWB signal is a non-sinusoidal narrow pulse signal ranging from nanosecond to picosecond. [3] It does not need sine wave modulation, so it does not need oscillator, mixer and up-down converter circuit structure. The complicated modulation and demodulation structure is omitted, so it can be small in size and low in power consumption.

(2) Good resistance to multipath fading

The ability to suppress multipath fading of UWB signals can be analyzed in the time domain and frequency domain. In the time domain, the UWB pulse signal has a short duration and a small signal duty cycle, so it has a strong time resolution. The path resolution is tens of centimeters, which can effectively distinguish multipath signals. In the frequency domain, because UWB signals have extremely wide signal bandwidth, radio signals only appear at certain frequency points in multipath fading. From time domain and frequency domain analysis, we know that the energy of multipath fading only accounts for a small part of the total signal energy, so it has a strong ability to resist multipath fading.

(3) High security

Compared with other communication technologies, the interference caused by UWB signals can be regarded as white noise. UWB signals can hide in the noise of the surrounding environment and are difficult to find. This is because the defined UWB signal transmission power spectral density must be lower than its set value, which is -41.3 dBmmMHz. Therefore, the UWB signal generation system can coexist with the narrowband signal system in the same frequency band, and the system has little impact on other systems. In addition, the hidden nature of UWB signals may make it difficult to intercept and possess strong confidentiality. The extremely high channel bandwidth and extremely low transmit power spectral density of UWB signals make these signals hidden in other signals and noise, so the possibility of being detected and captured is very low. In addition, UWB technology also uses time-hopping spread spectrum technology, the receiver needs to know the spreading code of the transmitter in advance to demodulate the transmitted signal, and the security of communication is very high.

(4) High-precision positioning

The positioning accuracy of ultra-wideband is higher than that of GPS, and its positioning accuracy can be accurate to centimeters. It has a wide range of technical uses and can be used for positioning in indoor or underground environments. However, GPS positioning is mainly used in outdoor environments and the positioning accuracy can only reach meters. The pulse

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202011_3(11).0034

of UWB signal is very short, and the pulse is used to obtain higher positioning accuracy. The characteristic of UWB signal determines its strong ability to resist multipath interference. The duration of the pulse signal is much smaller than the delay caused by multipath propagation, so it is very suitable for wireless ranging. In addition, the extremely wide signal bandwidth of UWB signals also makes the range resolution higher. UWB technology can be used to achieve high-precision ranging and indoor positioning functions.

(5) Wide coverage and good real-time performance

UWB positioning technology is mainly used in medium and short distance situations, such as positioning in indoor environments. With the development of technology, the maximum distance between UWB signal transceivers in the positioning system can reach 70m. In addition, each UWB signal transceiver module can cover an area of approximately 420 square meters. Compared with other traditional positioning technologies, UWB positioning technology also has an important advantage that positioning technology has good real-time performance.

(6) Strong penetrating ability

Ultra-wideband signals have strong penetrating capabilities and can directly penetrate various obstacles, making them very suitable for indoor and underground positioning. The military detection equipment used to search for dangerous explosives on the battlefield uses the characteristics of UWB signal penetration capabilities. UWB-based detection equipment can also be designed for civilian detection of underground objects.

(7) High portability

When the UWB signal generator works normally, it mostly uses baseband transmission, and the radio frequency modulation technology and radio frequency adjustment technology do not need to be used. Because of this feature, UWB equipment can have a very small size, and the equipment also has the advantages of low power consumption, low cost, and simple structure.

Traditional wireless communication lacks many advantages of UWB technology. The research value and application scenarios of UWB technology are very extensive, and it has become the main research hotspot in the communications industry.

5. Principles of UWB Positioning Technology

Wireless positioning algorithms can be divided into two types: positioning algorithms based on ranging and positioning algorithms that have nothing to do with ranging. The positioning method based on ranging information needs to obtain the distance information between the node to be measured and the reference base station at a known location, and then obtain several distance equations based on the position and distance information of multiple reference base stations, and solve the equation set to obtain the position coordinates of the target node. The positioning principle that is not based on ranging information is to use the connectivity between the communication networks to determine the approximate location of the node by determining the signal strength of the connection between the node under test and the reference base station or the number of connected hops. This method is easy to implement, but its positioning The accuracy is low, not suitable for indoor high-precision positioning. [4] Therefore, UWB positioning generally uses a ranging-based positioning method.

The UWB ranging method usually uses a time-of-flight (TOF) ranging method. In the positioning algorithm based on ranging, it can be divided into time of arrival (TOA) method and time difference of arrival (TDOA) method.

5.1. Time of Arrival (TOA) Method

TOA positioning requires one target node and at least three reference base stations. The target node sends the signal to at least three reference base station receivers. If the signal transmission time from each reference base station to the target node is t in the TOA

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202011_3(11).0034

measurement, then d = v * t obtains the distance from the target node to each reference base station, and v is the signal speed. [5] The value of the radius of each circle is Ri, with the reference base station (xi, yi) as the center of the circle, so that the equation of the circle can be obtained, and the intersection of the three circles is used to approximate the target node Position coordinates.

According to the geometric principle, the equation (1) is obtained:

$$\begin{cases}(x_1-x_0)^2+(y_1-y_0)^2=R_1^2\\(x_2-x_0)^2+(y_2-y_0)^2=R_2^2\\(x_3-x_0)^2+(y_3-y_0)^2=R_3^2\end{cases} \quad (1)$$

Solve the equations (1), find the coordinate position of the positioning node (x_0, y_0). The premise of this method is that the location of the reference base station needs to be known. The advantage is that the approximate position of the target node can be obtained by solving simple equations, and the method is simple. The disadvantage is that the clock synchronization of the system requires higher precision. If the reference base station and the target node cannot achieve precise clock synchronization, the measured signal arrival time will be wrong, resulting in a deviation in the distance between the target node and the reference base station, so that the three circles cannot intersect or intersect. A point is an area, which leads to positioning errors.

5.2. Time Difference of Arrival (TDOA) Method

Because the clock synchronization requirements between the reference base station and the target node in the TOA positioning method are very strict, and the hardware cost needs to be increased, the time difference of arrival method is adopted. TDOA is currently the most popular positioning scheme. TDOA positioning is similar to TOA positioning. TDOA positioning algorithm is also called hyperbolic positioning algorithm, which is a positioning method based on time difference of arrival. TDOA positioning method does not require strict time synchronization, relatively simplifies the positioning system, and is more widely used. [6]

The TDOA method is usually implemented in two ways. One is that the sending node sends two wireless signals with different propagation speeds at the same time, and the receiving node calculates the distance between the target node and the reference base station according to the known propagation speed and arrival time of the two signals. By calculating the distance between the target node and at least three reference base stations, and using the three-circle intersection method to determine the coordinate position of the node to be determined. In another more commonly used implementation method, the reference base station is used as a fixed focal point, and the three focal points can have two pairs of hyperbolas. Therefore, the position coordinates of the target node can be obtained from the three reference base stations. The target node (x0, y0) simultaneously sends a signal to each reference base station (xi, yi). Because the distance between the target node and each reference base station is different, the known signal propagation speed v and the signal received by each reference base station multiplied by the time difference Δt can determine that the target node is located on the hyperbola with two reference base stations as the focus and The distance difference v*Δt. By measuring the signal arrival time difference between the three reference base stations, a set of hyperbolic equations about the coordinates of the target node are formed. Solving the hyperbolic equation can obtain a more accurate position of the target node.

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202011_3(11).0034

$$\begin{cases} \sqrt{(x_2-x_0)^2-(y_2-y_0)^2}-\sqrt{(x_1-x_0)^2+(y_1-y_0)^2}=v\cdot\Delta t_{21} \\ \sqrt{(x_3-x_0)^2+(y_3-y_0)^2}-\sqrt{(x_1-x_0)^2+(y_1-y_0)^2}=v\cdot\Delta t_{31} \end{cases} \tag{2}$$

In the formula, Δt_{21}, $\Delta t_{31}$is the time difference between the signal of the target node and the signals of the two reference nodes. These equations are nonlinear. In order to obtain the best solution, the least square estimation method is needed to solve the equation. The TDOA method is an optimization method based on the TOA method. It does not require strict clock synchronization between the target node and the reference base station, only the clock synchronization between the reference base stations, and the measured value is no longer the reference base station and the target node In addition, the TDOA positioning method is easier to implement than the TOA positioning method. This method can not only better integrate various complex indoor environment relationships, but also provide higher The positioning accuracy.

6. UWB Indoor Positioning System Design

6.1. System Overall Design

The UWB-based indoor positioning system is mainly composed of UWB wireless positioning module and the display software of the upper computer. The hardware part of the system is a UWB positioning module composed of DWM1000 communication module and STM32F103C8T6 microcontroller, including reference base station and target node, and the role of the module in the system (reference base station or target node) is defined by the software. The formed UWB positioning module can accurately measure the time when UWB signals are received and sent. Each reference base station uses UWB communication function to send distance data to the target node, and the target node sends the distance data to the host computer through WiFi wireless communication for data calculation.

6.2. System Hardware Design

In this system, STM32 is used as the master device, using SPI to read and write the internal registers and random access memory of the slave device DW1000 chip, and communicate with each other to exchange information and send commands. SPI controls communication by using a clock signal generated by STM32. The main device STM32 drives the main chip as the WiFi module of the ESP8266, which realizes data transmission between the microcontroller and the WiFi module through serial communication, and transmits and receives data with the host through the built-in wireless network protocol of the ESP8266.

6.3. System Software Design

Embedded system software development uses Keil MDK5 of Keil, uses C language as programming language, uses J-Link to debug and burns the program online, realize embedded development simply and efficiently. The embedded program burned in MUC mainly completes the distance measurement from the reference base station to the target node TDOA, and sends the obtained information to the host.

Embedded software uses serial processing to process information. The single-wire structure can complete the required functions, including STM32 reset module, clock configuration module, SPI reading module, serial port configuration module, timer configuration module, DWM1000 transceiver configuration module, upper layer The application program initializes the module and interrupt handler. When the DWM1000 chip receives or sends a data frame, it will send an interrupt request to the MUC. The interrupt program mainly generates the type of

ISSN: 2637-6067 DOI: 10.6918/IJOSSER.202011_3(11).0034

interrupt, determines whether the interrupt position is correct, reads the source address of the data receiving frame, reads the type of data receiving frame, reads the TDOA information, encapsulates the read information and sends it to the host.

7. UWB Indoor Positioning System Test

In the 14m×8m×4m single-chip electronic design laboratory of Shandong University of Science and Technology, the laboratory can be approximated as an idealized environment, and UWB signal itself has the advantage of strong anti-interference ability, so the interference to UWB signal can be ignored. In order to reduce the error caused by manual measurement of the real distance, the laboratory is divided into 8 blocks, the points that are convenient for measurement are selected as the position of the target node in the laboratory, and the method of taking the average of multiple measurements is adopted.

Select 10 points at special locations in the block, collect 1000 data for each point, and analyze the experimental data by using the root mean square error. Finally, when the target node is stationary, the positioning accuracy can be controlled within 10cm, and when the target node is moving at a speed of 1mms, the positioning accuracy can be controlled within 20cm.

8. Conclusion

This paper analyzes the development status of UWB technology at home and abroad, comprehensively studies the characteristics of UWB signals and UWB positioning technology, expounds the design methods and theories of UWB technology on positioning systems, and conducts related tests on positioning systems. This design scheme gives certain ideas in high-precision indoor positioning and has certain reference value.

References

[1] Liao Lingjun. Research on AGV indoor wireless positioning system based on ultra-wideband[D]. Shenzhen University, 2018.

[2] Yuan Shuai. Research on Intelligent Car Positioning and Path Planning Technology Based on Ultra-wideband [D]. Xidian University, 2018.

[3] Yang Junjie. The design of indoor positioning system based on UWB [D]. Harbin Engineering University, 2018.

[4] Zhang Fan, Chen Diancheng, Yang Jie. Analysis on the principle and application of indoor positioning [J]. Mobile Communications, 2013, 37(Z1): 88-93.

[5] Li Zhenzhen, Zeng Liansun. Research on key technologies of indoor positioning based on UWB[J]. Information Technology, 2011, 35(11): 96-98.

[6] Chen Lijun. Research on communication technology in the integrated system of ultra-wideband communication and positioning [D]. Xidian University, 2010.