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Design of UWB-based positioning system for rotary drill

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Abstract: *The rotary drill is one of the core equipment in large-scale open-pit mining drilling operations. Amidst the rapid development of the mining and construction industries, its heavy-duty drilling capabilities have shown indispensable importance in complex and ever-changing open-pit mines and large-scale engineering fields. Given the rugged terrain and dynamic environments of mines, traditional positioning methods often struggle to ensure drilling accuracy, thereby affecting mining efficiency and operational safety. High-precision Ultra-Wide band (UWB) positioning technology can significantly reduce ineffective drilling and repetitive operations, holding significant value for accelerating the construction of smart mines. This paper presents the design of a UWB-based, high-precision outdoor positioning system tailored for rotary drills in large-scale mines. This system can be applied in scenarios requiring high-precision outdoor drilling positioning and also meets the precision demands of driverless drill operations.*

Keywords: *Ultra-wide band positioning; High-precision positioning; Rotary drill; Outdoor positioning*

1. Introduction

In the mining operation of large open-pit mine, the excavation of the ground and slope affects the stability of mountains and slopes, leads to rock (soil) deformation, induces geological disasters such as collapse and landslide. It is of great practical significance to construct an intelligent perception system for safety production in open-pit mine by using cutting-edge technologies such as high-precision positioning. In the safety management of large open-pit mine, personnel and rig are two important factors. Dealing with the personnel and rig management problems can effectively reduce the occurrence of safety accidents. In order to avoid safety accidents between personnel drills, it is a key scheme to obtain real-time positioning information of roller drills and drilling holes in open pit mines through positioning system to replace traditional manual drilling position calibration.

Ultra-Wide Band (UWB) technology is a new type of wireless communication technology. The Federal Communications Commission of the United States has specified that the signal with a relative bandwidth of not less than 20% or an absolute bandwidth of not less than 500 MHz belongs to the category of UWB[1], which directly modulation the impulse pulse with a very steep rise and fall time, so that the signal has a bandwidth of the order of GHz. It has the advantages of insensitivity to channel fading, low power spectral density of the transmitted signal, low interception capability, low system complexity, and can provide positioning accuracy of several centimeters.

For the application scenario of this paper, roller drill drilling positioning and real-time drilling path planning require high refresh rate and high precision. Zigbee, RFID, ultrasonic, WIFI positioning technology commonly used in indoor is obviously not up to such requirements, and large open mine is generally located in the mountainous areas with rich mineral resources. GNSS positioning requires the establishment of expensive positioning base stations. In order to meet the needs of high-precision positioning and low-cost equipment at the same time, this paper designs a set of roller drill positioning system based on double-label UWB positioning, which can realize high-precision positioning of roller drill and drilling in large open-pit mine.

2. Research Status

Common positioning technologies mainly include GPS, Zigbee, UWB, RFID, ultrasonic, WIFI and other positioning technologies[2]. RFID positioning does not have the ability to communicate with each other, while WIFI positioning technology has high positioning accuracy in areas with dense Wi-Fi hotspots, which depends on the coverage and density of Wi-Fi hotspots, generally 1-20 meters, and may be affected by weather, buildings, vehicles, mountains and other factors. In contrast, equipment using UWB positioning technology has low energy consumption, high time resolution, strong signal penetration and high ranging accuracy, which are widely used in high-precision outdoor positioning[3]. UWB positioning technology has a wide range of application scenarios, such as indoor positioning[4], object tracking[5], industrial site personnel positioning[6], vehicle positioning[7], etc. Among them, the application of UWB positioning technology in complex scenes such as industry[8] has always attracted much attention.

3. Systematic Design

3.1. Scheme Design

The base station and label are composed of STM32F103C8T6 master chip + DWM1000 + USB serial port + power supply + Lora module + peripheral circuit. The block diagram of the base station is shown in *Figure 1*, where the functional core of the module is the master control chip and DWM1000. The function of the master chip is to control the work flow of the whole system, including the control of DWM1000 to receive and send UWB signals, output information to the serial port and external pins. DWM1000 is a module which integrates UWB RF chip, peripheral circuit and antenna, and is used to receive and transmit UWB signals. The USB serial port is responsible for outputting the serial port signal and receiving the external serial port signal. It can not only be wired with the host computer, but also realize the wireless control and writing configuration of the host computer through the designed Lora module. At the same time, USB serial port also has the function of power supply. The power part is responsible for powering the module. The external pins include TTL serial port and module burning program pins, 5V power supply pins and GND. When the module is positioned to work, the basic power supply must be available. There are two power sources: one is the USB port to provide 5V voltage, and the other is the 5V pin in the external pin to access the power supply. When the power supply is normal, taking the main base station as an example, the master control chip controls DWM1000 to receive and send UWB signals, and reads the information needed for positioning from the DWM1000 module for processing. Finally, the position information and ranging information of the tag are calculated, which will be transmitted to the host computer through the USB serial port and Lora module.

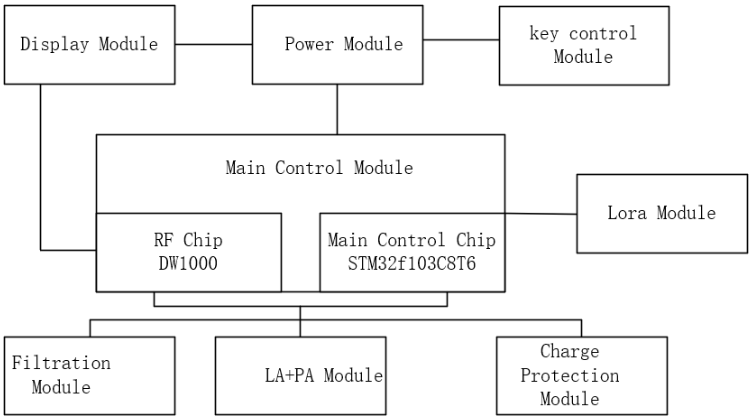

Figure 1: Block diagram of the base station

3.2. Hardware Design

STM32F103C8T6 chip has rich functions, built-in CAN controller, serial port and other communication controllers, which is responsible for the control and management of the whole system, and realizes the functions of data acquisition, processing, storage and transmission. In order to realize the lightweight of the system and the high-speed signal transmission, the base station is constructed by PCB board, facing the complex outdoor environment of the mine. We designed a waterproof housing on the outside of the PCB board. In the design process, we adopted a double-layer board design, which can better manage signal integrity and power distribution and reduce cross-layer interference by separating the signal and power layers on different layers. The double-layer plate design allows for better control of

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differential and single-ended impedances, as well as optimized output of signal frequencies. The overall physical drawing is shown in *Figure 2*.

Figure 2: The realistic view of the base station

3.3. Data Flow Design

Modbus protocol is a network communication protocol for industrial control, a format specification for data and information transmission between machines, as shown in *Figure 3*. The protocol also follows the master-slave protocol, which supports a single host and multiple slaves with a maximum of 247 slave devices. Moreover, there is only one host in the same communication line, and all the communication processes are initiated by the host. After the slave receives the request from the host, it will respond to the request. The slave does not take the initiative to send data, and there is no communication process between the slave.

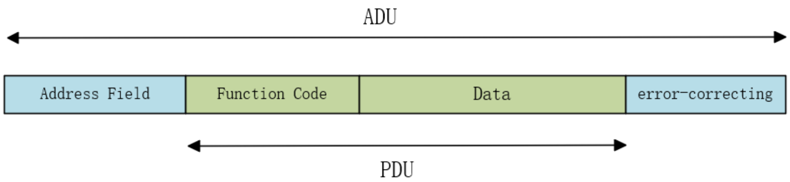

Figure 3: Generic Modbus frames

We designed four ranging modes as follows:

Single positioning, the host computer needs to send the corresponding instructions to obtain the ranging/positioning data.

Continuous positioning, the host computer needs to send corresponding instructions to obtain ranging/positioning data.

Single positioning after the automatic output of the host computer

Automatic output after continuous positioning

The format of the automatic output of the main base station can be changed by changing the data of the 114th register in the Modbus register table. The corresponding bit in the register data is 1 for enabling output, otherwise it is not output. The selection information is output in *Table 1* as follows.

Table 1: Selecting output data

1	2	3	4
Locator Data	Ranging Data	Receive Information	Timestamp information
If the corresponding data bit is 1, data output is enabled. Otherwise, data output is disabled.			

3.4. DS-TWR and Positioning Principle

UWB signal has a very wide bandwidth, so it has a high Time resolution. TOA (Time of Arrival) method is more suitable for UWB positioning. The accuracy of TOA method depends on the measurement of time, so the time between the base station and the tag is required to be completely

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synchronized, but it is difficult to achieve complete synchronization in practical applications, so we adopt DS-TWR (Double-sided two-way ranging) method. Two round-trip time measurements are used and combined to give the time-of-flight result, device A initiates the first round-trip measurement with timestamp, device B responds, after which device B initiates the second round-trip measurement with timestamp, device A responds to complete the DS-TWR exchange. Each device is precisely marked with the transmission and reception times of information. DS-TWR ranging technology has become a popular scheme in the field of modern ranging because of its high accuracy and strong robustness. The ranging principle is as follows *Figure 4*:

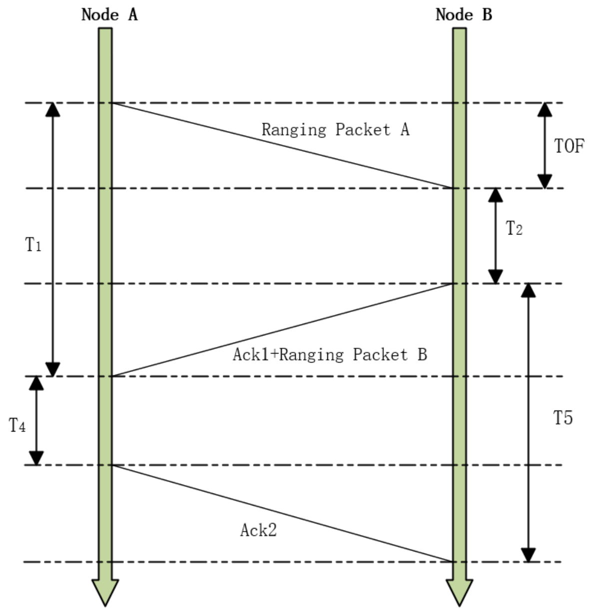

Figure 4: Principle of DS-TWR

The formula to calculate the signal flight time is as follows.

$$T1 = 2 \times TOF + T2 \quad (1)$$

$$T5 = 2 \times TOF + T4 \quad (2)$$

$$T1 + T4 = T2 + T5 \quad (3)$$

$$TOF = \frac{T_1 \times T_5 - T_2 \times T_4}{T_1 + T_2 + T_4 + T_5} \quad (4)$$

Principle of trilateral distance dead reckoning algorithm: There are three non-collinear base stations 1, 2, 3 and a label X on the plane, and the distances between the three base stations and the label X have been measured as r1, r2 and r3, respectively. Then three intersecting circles can be drawn by taking the coordinates of the three base stations as the center of the circle and the distances from the three base stations to the unknown terminal as the radius, as shown in *Figure 5* below, and the coordinates of the labels are the intersection points of the three circles. Due to the existence of environmental interference or ranging errors in reality, it is unlikely to fully satisfy the situation that the distances measured by three base stations intersect at a point. In more cases, such as the following figure, the error can be reduced by using the least squares solution. The total centroid algorithm is to find the centroid of the triangle formed by the intersection of three circles a, b and c as the coordinate point of the label. The calculated solutions are all real number solutions, which have high accuracy and robustness.

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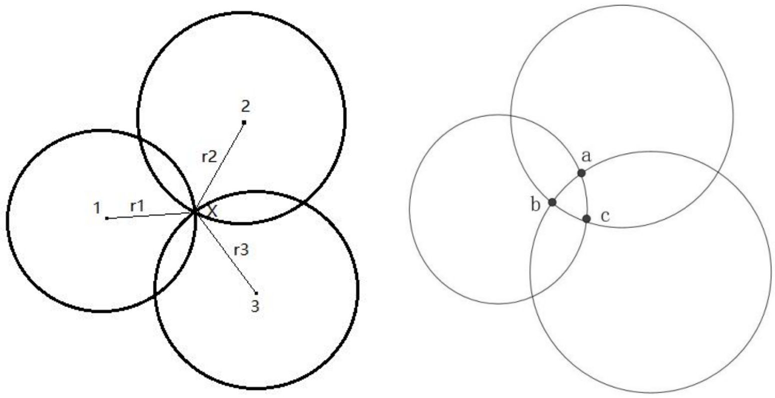

Figure 5: Schematic diagram of the localization algorithm

4. Positioning scheme Design

In the face of the open-pit mine where the large roller drill is located, a multi-base station positioning scheme (the number of positioning base stations needs to be greater than 3) is adopted in the open area. The location of the receiver is determined by measuring the distance or time difference between the tag and the base station by multiple base stations at the same time, as shown in *Figure 6* below. The red circle is the UWB ranging circle of the base station, and the radius of the circle represents the distance from the base station to the roller rig. According to the actual test, the roller rig label error is reduced to within 10cm.

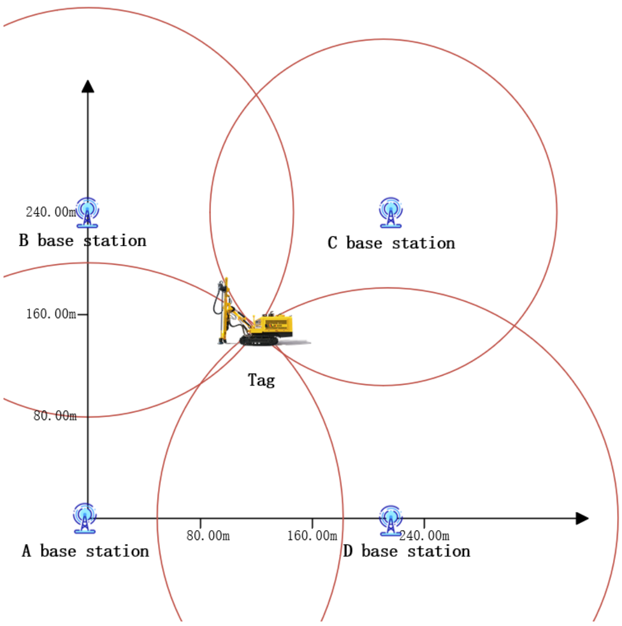

Figure 6: Base station and tag placement

Regarding accuracy, the following three accuracies are mainly involved.

The accuracy of ranging, ranging accuracy, the main factors have two, one is the used ranging algorithm, the other is the clock accuracy used. Ranging algorithm: mainly based on the time difference of arrival ranging, as far as possible to eliminate the error caused by the clock deviation; Clock accuracy: In the ranging process, you can choose to use a 0.5PPM clock TCXO, which brings better accuracy. The ranging accuracy can be controlled within 10 cm. The accuracy can be improved by adopting the TCXO (Temperature Compensate X'tal (crystal) Oscillator) method.

Time synchronization accuracy In outdoor UWB positioning system, TOA and TDOA (Time Difference Of Arrival) are supported. In TDOA, all positioning base stations need to be synchronized by wireless means. Compared with the wired synchronous method, the system is greatly simplified, and the system can be extended without limit, and will not be controlled by the wired distance. It also simplifies

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the difficulty of project implementation.

5. Conclusions

This paper mainly studies the high-precision positioning system of roller drill based on UWB. On the basis of UWB wireless communication theory, the UWB signal and characteristics are analyzed, and the UWB positioning base station and tag are designed. On this basis, the DS-TWR algorithm is designed, which provides the algorithm basis for the system. Finally, the frame diagram of the whole system is proposed, the system frame diagram is analyzed, the hardware circuit of the tag and the base station is designed, the description of the hardware module is given, and the positioning base station and the tag are tested, and the test error is reduced within 10 cm. There are still some problems that need to be further studied in this paper, as follows:

The performance of the localization algorithm is ideal in the case of no NLOS error, but the performance of the localization algorithm is not very stable in the case of NLOS error. How to reduce the influence of line of sight error on the localization results is the focus of the next work.

This paper mainly analyzes and tests the hardware composition of the base station and the tag of the system, but the positioning platform of the system has not been completed, and the complete realization of the positioning platform and the whole system is the focus of the later work.

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