Design of anti-collision device of mine trackless rubber tire vehicle

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Abstract: For the problem of safety accident such as the collision between equipment or between person and equipment beneath the coal mine, after analyzing the advantages and disadvantages of active safety technology now, a high precision ranging system based on UWB has been designed. This system uses Symmetric Double Sided Two-Way Ranging algorithm which can reduce the influence of clock drift, improve the ranging accuracy of the system and reduce the false alarm rate of the system. The device has the functions of personnel intrusion alarm, vehicle approach alarm, automatic shutdown of the vehicle, and so on. The results show that the maximum ranging error of the system within 20 m is ±0.13 m, which can fully meet the requirements of vehicle active safety collision avoidance. Through the research and application of preventing intrusion and proximity alarm devices, the collision accidents between vehicles and personnel as well as those between vehicles and vehicles are effectively avoided. The safety of underground personnel is improved, and the efficiency of underground auxiliary transportation is also improved.

1. Introduction
At present, coal resources still occupy the primary position in China's primary energy consumption [1]. Along with coal resource conformity and large mine's construction, more and more auxiliary transportation equipment is used in the coal mine [2], especially on the moving face. Because of the large volume and widely visual blind area, accidents may happen easily and then cause severe personnel and property losses. According to the US Mine Safety and Health Administration (MSHA) technical report, since 1984 the use of remotely operated continuous shearer was popularized in the coal industry in the United States, there have been 33 deaths caused by shearer extrusion or impact in the coal industry in the United States and 12 deaths caused by shuttle cars till 2010. Other mobile devices such as bolter miner, roof bolter, and forklift also cause injuries or collisions to varying degrees. Australia's 2011 statistics show that there have been 4,633 injuries accidents in coal mine operations for 3 consecutive years, of which 2,149 are related to equipment, accounting for about 46% of the total [3].

Equipment safety accidents can be found in China: ① On June 2, 2001, a death accident was caused by extrusion between machine and miner in the Changcun coal mine. ② On November 7, 2011, because of the mistakenly operated, one miner of Liyazhuang Coal Mine was dead in the accident. ③ On May 16, 2015, a road-header accident occurred at the Xiangshan Mine of Pingmei Shenma Group in Pingdingshan, Henan Province, China, which resulted in the death of one person. ④ On January 13,
2016, a miner of Cuimu Coal Mine illegally entered the comprehensive excavation machine operation range, and then his legs were cut off by the head roll.

Now, the active safety anti-collision technologies used in underground equipment include ultrasonic radar technology [4], infrared ranging technology [5], laser ranging technology [6], millimeter wave radar technology [7], and machine vision technology [8], Received Signal Strength Indication (RSSI) technology [9], magnetic field area identification technology [10], wireless positioning technology [3], etc. However, influenced by the special environment of the coal mine, the actual effect of safety technology is not so good, the system is not stable and rate of false positive is high. Because of those disadvantages, it cannot play a promoting effect. On the contrary, it may affect the normal production, so a set of reliable anti-intrusion and dangerous proximity alarm devices is urgently needed to reduce the underground safety accident rate and ensure underground safety production.

2. System design

2.1. Principle of high precision ranging based on UWB technology

UWB (Ultra Wide Band) is a carrier-free communication technology that transmits data by sending and receiving extremely narrow pulses with nanoseconds or less and thus has bandwidth of GHz magnitude. The unique communication mode enables its ranging accuracy to reach the centimeter level, and it also has the characteristics of strong anti-multiparty interference ability, strong penetration ability, high temporal resolution and low power consumption which make it the best choice for high-precision wireless ranging and positioning [11].

Compared with the traditional ranging algorithm, the TWR (two-way rangefinder) algorithm can achieve accurate ranging between equipment without clock synchronization. Although the short ranging time and high real-time, the ranging results of simple SS-TWR (Single Sided two-way Ranging) are greatly affected by the clock drift. Considering the real-time and accuracy of ranging, this paper uses the SDS-TWR algorithm, which can minimize the error caused by clock drift. Compared with the SS-TWR algorithm, the SDS-TWR algorithm has errors due to clock drift Reduced by half, the ranging accuracy has improved a lot [12].

First of all, A sends a Poll Message packets to B and records the sending time, device B receives the poll message packet and records the receiving time, and then B sets the response message packet and records the sending time after delay processing time. Next, A sends a final message packet to B and records the sending time after delay processing time and B receives the final message packet and records the receiving time, thus complete A ranging task, as shown in figure 1.

The signal transmission time between A and B is shown in Equation (1):

\[ T_{prop} = \frac{(T_{roundA} - T_{replyA}) + (T_{roundB} - T_{replyB})}{4} \]  

(1)

There \( T_{roundA} \) is the time from the packet sending to receive of A; \( T_{roundB} \) is the time from the packet sending to the receiving of B, \( T_{replyA} \) is the set packet delay processing time for A previously, \( T_{replyB} \) is the set packet delay processing time for B previously.

Then the distance between A and B is shown in Equation (2):

\[ S = C \cdot T_{prop} \]  

(2)

There C is the propagation speed of electromagnetic wave in the medium.
2.2. System composition

The system mainly includes card reader, the enhanced Omnidirectional antenna, the sound-light alarm and personnel identification card, as shown in figure 2.

Figure 1. SDS-TWR ranging model

The card reader is type of mine encapsulation and intrinsically safe which is installed in center of the equipment and DC24V power is used to supply energy to it. The intrinsically safe power module and output isolation module in the card reader realize the isolation between intrinsically safe signals and non-intrinsically safe signals. It uses encapsulation type which can advantageous for the direct connection between the card reader and the equipment electric cabinet and the electric power supply. At the same time, the output control signal can control the control circuit to stop or halt the equipment electrical cabinet. The core control module in the card reader uses the design of intrinsically safe circuit, which can not only realize the accurate distance measurement between the card reader and the identification card and set the alarm range of the equipment, but also directly drive the sound-light alarm to send out the alarm signal.

The enhanced omnidirectional antenna is a passive simple element with the characteristics of flame retardant and anti-static, strong and compact. It can meet the requirements of underground coal mine and cover the horizontal range of 360° range at the same time.

The sound-light alarm is mine intrinsically safe type connected with the card reader through the cable. There are two input signal interface of switch quantity driven by the sound-light alarm unit in the card reader. This alarm can realize the sound alarm, also can realize the light alarm.

Personnel identification card is a mine intrinsically safe type using lithium manganese acid battery power to supply, with the function of power supply indication, low power reminder, vibration alarm and rechargeable. The internal integrated RFID radio frequency chip and induction coil can store personal information as the identification card of the access control system. In consideration of the convenience and the using habit, personnel identification cards are divided into lab-type identification card, wristband identification card and helmet identification card.
2.3. System operating principle

UWB technology is adopted between the card reader and the identification card to achieve high precision ranging. The parameter of the card reader is set by computers, it mainly includes alarm range setting, double alarm zone setting, ring alarm zone setting, output signal mode setting, alarm free identification card setting and identification card management.

When a staff wearing an identity card into the alarm area (larger radius of protection area), ID card can vibrate the alarm, the sound-light alarm corresponds light and sound alarm signals (such as flashing yellow lights and accompanied by the alarm sound of "personnel near notice") , at the same time, the output isolation module can output the corresponding switch contact signal to control the equipment of the corresponding mechanism to stop operation, such as vehicle deceleration. When a staff wearing identity card into the outage area (smaller radius of protection area), ID card can vibration alarm, sound-light alarm module corresponding light and sound alarm signal (such as flashing red lights and accompanied by the alarm sound of "personnel risk please stop"), meanwhile, the output isolation module can output the corresponding switch contact signal to control equipment to stop running (such as vehicle brake), as shown in figure 3.

![Figure 3. Alarm diagram of personnel approaching equipment](image)

When two equipments are close to each other, the two card readers are ranging each other. Determine whether the other party's device enters its own alarm zone according to the range of the alarm zone and the shutdown zone set by each. If it enters the stop area, the acoustic-optic signals corresponding alarm sound and light alarm, if they entering the stop area, the acousto-optic alarm signals corresponding alarm and stops equipment at the same time. Meanwhile, the ranging information is fed back to the main controller of the equipment, which can realize the linkage control of the equipment.

3. System test

In order to verify the actual using effect, the device was installed on the WC75E bracket truck for a actual test. The card reader was installed on the top of the cab to avoid the surrounding shielding as far as possible and ensure the visibility between the card reader and the identification card. The sound-light alarm was installed in an obvious place in the driving room to ensure that the driver can receive the alarm signal indirectly at the first time, as shown in figure 4.

According to the size of the bracket carrier and the maximum speed of the vehicle, the radius of the parking area of the vehicle was set to be 13 m and the radius of the alarm area was set to be 20 m. The anti-collision device can give a reliable alarm when the person wearing a safety helmet identification card approached the vehicle from any direction around the vehicle. The actual distances between the card reader and the identification card when the alarm signal and stop signal are triggered, as shown in table 1.
Figure 4. Installation drawing of anti-collision device on the equipment

Table 1. A real data table of alarm distance and shutdown distance

| Direction   | Actual alarm distance (m) | Alarm distance error (m) | Actual stopping distance (m) | Stop distance error (m) |
|-------------|---------------------------|--------------------------|----------------------------|------------------------|
| Front       | 19.95                     | -0.05                    | 12.92                      | -0.08                  |
| Back        | 19.90                     | -0.10                    | 12.89                      | -0.11                  |
| Left        | 20.10                     | +0.10                    | 13.04                      | +0.04                  |
| Right       | 19.89                     | -0.11                    | 12.95                      | -0.05                  |
| Left-front  | 19.90                     | -0.10                    | 12.90                      | -0.10                  |
| Right-front | 20.13                     | +0.13                    | 13.11                      | +0.11                  |
| Left-back   | 19.98                     | -0.02                    | 12.96                      | -0.04                  |
| Right-back  | 20.09                     | +0.09                    | 13.07                      | +0.07                  |

According to the test results in table 1, it can be concluded that the alarm distance error of the device on the WC75E bracket truck was ±0.13m, and the stopping distance error was ±0.11m, which fully meets the operating requirements.

4. Conclusion

Compared with the collision device which based on wireless positioning technology, the anti-collision device designed in this paper which adopts UWB high precision ranging technology, is not only easy to install, but also has high ranging accuracy and high alarm accuracy.

The device adopts hierarchical alarm system, which not only realizes the alarm of personnel intrusion, but also realizes the alarm of close proximity between equipment. At the same time, the device also has the function of no alarm. Comprehensively considering the production process of underground coal mine, the system fully meets the requirements of underground operation.

This system, compared with the traditional active safety warning device, has the advantage of high ranging accuracy, strong anti-interference ability and distinct system stability. However, it can only give early warning to the person who wears identification cards, others without identification cards still have security risks. In the subsequent design, a multi-technology integration should be adopted to improve the alarm accuracy, the target coverage and the work environment adaptability.

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