Personnel precise positioning system of coal mine underground based on UWB

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Abstract. For short positioning distance, low positioning accuracy and location data jumping of personnel positioning system of coal mine based on Bluetooth, WiFi, RFID, Zigbee and so on, a precise positioning system was proposed which is based on UWB technology. The principle of UWB positioning technology and symmetrical two-way two-way ranging (SDS-TWR) algorithm is analyzed and applied to the system. According to the characteristics of coal mine roadway, a single card reading substation can be used to independently network and realize one-dimensional accurate positioning of positioning card. The experimental results show that the UWB technology meets the positioning requirements of the system, the algorithm is flexible, the refresh rate is fast, the positioning error is not more than 0.3m, and the coverage reaches 400m.

1. Introduction

In the past two years, the state has paid more and more attention to the safety production and management of coal mines. As one of the "six systems", the personnel positioning system is becoming more and more important. At present, wireless communication technologies such as RFID, WiFi and Zigbee are commonly used in personnel positioning system in coal mine$^1$. RFID and WiFi technology have been used in underground personnel positioning system earlier, and can only provide regional positioning function; Zigbee technology is widely used in underground personnel positioning system with small power consumption, long communication distance and low cost, but its positioning error value is too large, anti multipath effect is poor, positioning position is easy to drift, and can only achieve one-way attendance management of underground personnel$^{2-4}$ . With the development of coal mine mechanization, informatization and intelligence, the above-mentioned system can not meet the growing demand of coal mine enterprises for high-precision positioning technology, and can not meet the demand of modern mine production management in the future$^5$.

In view of the above problems, in order to accurately grasp the real-time activity trajectory and accurate position of underground personnel, and meet the intelligent control of equipment, this paper proposes a coal mine accurate positioning system based on UWB (ultra wide band) Technology. The system makes use of the characteristics of UWB signal, such as strong anti multipath interference, high transmission rate, extremely wide bandwidth, high time resolution, low power consumption and high positioning accuracy. Combined with the algorithm of time of arrival ranging, the system realizes the
accurate positioning of mine personnel[6-7]. This ranging method has the advantages of no time synchronization problem, little environmental impact and high positioning and ranging accuracy.

2. Key technology and Research on algorithm

2.1. Positioning technology of UWB

UWB (ultra wide band) is a low-power radio communication technology was applied in the field of wireless communication. It does not use sinusoidal carrier, but uses nanosecond or sub nanosecond pulses to realize wireless communication[8]. UWB communication does not need the RF frequency conversion required by conventional narrowband modulation. After pulse forming, it can be directly sent to the antenna, and then the antenna transmits the data information. The relative bandwidth (i.e. the ratio of signal bandwidth to center frequency) of UWB signal is not less than 0.2 or the absolute bandwidth is not less than 500MHz, and it is applicable to the specified 3.1GHz-10.6GHz band signal[9].

UWB uses time hopping spread spectrum signal, so that the power spectral density of the transmitted signal can be very low, even lower than the electromagnetic interference and noise generated by various devices; the bandwidth of megahertz (GHz) corresponds to the resolution of nanoseconds (NS), so that UWB has low power consumption, strong anti multipath fading ability, strong penetration ability, low system complexity, good secrecy, low interception rate and good confidentiality And can provide accurate positioning accuracy[10].

2.2. Algorithm of TOF

The positioning methods of UWB include: signal intensity analysis (RSSI), arrival angle positioning (AOA), arrival time positioning (TOF), arrival time difference positioning (TDOA)[11-12]; in the coal mine positioning system, TOF and TDOA based on flight time are usually used to achieve ranging. In this study, based on TOF positioning method, the improved symmetric-double-sided two-way ranging (TWR) is used to analyze and design the positioning system. This method is to calculate the distance by measuring the time of electromagnetic wave propagation back and forth in the air.

![Figure 1. Schematic diagram of sds-twr ranging algorithm.](image)

The principle of SDS-TWR ranging algorithm is shown in Figure 1. According to the sending time interval of ranging message, the following decomposition steps can be obtained:

- The UWB node 1 first sends the ranging signal with time stamp at T1, and the node 2 receives the ranging signal at T2, reads and analyzes the data, and then sends the signal with label information to T1 at T3. At this time, the time period of T23 = T3-T2 is obtained.
- After node 2 sends the ranging message, node 1 turns on receiving at T4, receives the response message, and gets the time period of T14 = t4-t1.
- After receiving the response message at T4, point 1 sends the last message with time stamp at T5 after processing the corresponding response message. At this time, T45 = t5-t4 is obtained.
- After receiving the message from T5 at T6, node 2 completes the ranging of this cycle and prepares for the next test. At this time, the time period of T36 = T6-T3 is obtained.
- According to the above steps, T23 and T45 are not the flight time of ranging message. According to other variable time, the direct distance d between node 1 and node 2 is obtained d:
$$d = \frac{(T_{41} - T_{23}) + (T_{36} - T_{45})}{4} C$$

Where $C$ is the propagation rate of electromagnetic wave (equivalent to the speed of light), $C = 3.0 \times 10^8$ m/s.

TOF ranging does not depend on the time synchronization between two nodes, so there is no error caused by clock synchronization deviation. However, the time of ranging depends on the accuracy of clock crystal vibration. The clock offset caused by CPU in the process of data processing will bring error [13-14]. The SDS TWR method can reduce the clock offset between nodes by calculating the average flight time, thus improving the ranging accuracy. In this study, the author makes full use of the advantages of TOF algorithm and designs a mine personnel positioning system based on UWB technology according to the characteristics of high signal time resolution.

3. System design

3.1. System composition

The system consists of Positioning card, substation of card reading, network interface, server, system software platform, etc. the whole system structure is no more than 3 layers, as shown in Figure 2. In the design of the system, optical fiber or network port can be used to connect the UWB positioning substation and the network interface directly. The optical fiber communication design is also used between UWB positioning substations, which is installed in cascade mode to realize the real-time and fast transmission of positioning data.

![System Diagram](image)

Figure 2. composition of precise positioning system of coal mine underground.

3.2. Substation of Card reading

The substation of card reading is mainly composed of UWB ranging circuit board, SMA short feeder, SMA to n-head long feeder and omni-directional antenna. Its principle block diagram is shown in Figure 3. According to the characteristics of UWB signal, TOF algorithm and coal mine roadway, UWB ranging circuit board is designed with dual ranging RF module, which is composed of RF module 1, RF module 2 and control unit [15].
In this system, substation of card reading and positioning card was done one-dimensional positioning, and defines the RF module 1 as the main RF and the direction "front"; the RF module 2 as the auxiliary RF and the direction "behind". The long feeders are connected to the antennas on the RF modules, and the antennas are installed on both sides of the substation with a spacing of \( L=2m \). Using the SDS-TWR ranging algorithm, the positioning card sends out the positioning message, ranging with RF module 1 and RF module 2 respectively, and the final ranging values are \( d_1 \) and \( d_2 \) respectively. The direction is calculated according to the ranging values of different modules.

Because of the systematic ranging error, the positioning accuracy error is less than 30cm, so \( S=L-0.3 \), and \( S \) is defined as the reference value of direction judgment. For the determination of underground direction, the following definitions are made in the software: if \( d_1 - d_2 < S \), the positioning card is in front of the card reading substation; if \( d_1 - d_2 > S \), the positioning card is behind the card reader substation; \( d_1 < L \) and \( d_2 < L \), the positioning card is under the substation.

3.3. Working process of system and substation

- **Device registration.** Register the location card and card reading substation in the system software platform, fill in the card number of the location card, the corresponding information of person name, Department, type of work and authority level, and enter the card reading substation number and installation address.

- **Location card network broadcast.** Set the positioning card 3s to send a broadcast packet. If the card reading substation is working, RF module 1 and RF module 2 will immediately assign time slots to the positioning card after receiving the broadcast message, and reply to the ranging packet with time slots. The positioning card and the card reading substation will complete the communication registration.

- **The location card sends the ranging message.** After receiving the time slot message successfully, the location card carries out ranging with the base station, and packages the ranging value, location card number and other information to the card reading substation to complete the ranging process of SDS-TWR algorithm. The time slot resource released by the positioning card after the ranging is completed is ready for the next ranging.

- **Ranging processing and data transmission of card reading substation.** According to the principle of SDS-TWR algorithm, the card reading substation receives the last ranging message from the positioning card. After receiving the ranging message, RF module 1 and RF module 2 perform distance calculation in the local card reading substation to get two ranging values, and judge the direction according to the distance value. According to the calculation results, the CPU packages the ranging data and substation ID and pushes them to the system software platform.
reading substation completes one ranging and opens the receiving channel to receive the next ranging calculation.

- Platform communication data processing. After receiving the data packet, the system platform software analyzes the data packet, separates the ID number of the substation and the ranging value, and uses the filtering algorithm and the secondary operation method to process the data again, so as to improve the effectiveness and accuracy of the ranging value. After the completion of the secondary calculation, the platform software writes the data into the database to save, but realizes the system B/S architecture data retrieval.

### 4. System testing

#### 4.1. Test process

The underground horizontal roadway (6m high and 5m wide) is selected as the experimental site. Test the positioning accuracy and the farthest coverage of the system. A card reading substation, a 100m meter ruler, a laser rangefinder and 15 positioning cards are used for the test. A total of 8 test points of 10m, 50m, 100m, 155m, 200m, 300m, 358m and 420m are set respectively. A 1.2m high bracket is placed at each test point, and the positioning card is placed on the bracket. 20 positioning error tests are conducted for each test point. After obtaining the test results, after each group of data removes a maximum value and a minimum value, the remaining data takes the average error, and the absolute value of the difference between the maximum ranging value and the actual value is the accuracy error.16

| Positioning card number | Positioning test value (m) | average error |
|-------------------------|---------------------------|---------------|
|                         | 10 | 50 | 100 | 155 | 200 | 300 | 358 | 420 |
| 101                     | 10.15 | 50.17 | 100.26 | 155.27 | 200.27 | 300.16 | 358.05 | 420.27 | 0.2 |
| 102                     | 10.23 | 50.26 | 100.18 | 155.15 | 200.21 | 300.26 | 357.95 | 420.25 | 0.198 |
| 103                     | 10.21 | 50.19 | 100.20 | 155.05 | 200.22 | 300.23 | 358.17 | 420.26 | 0.19 |
| 106                     | 10.15 | 50.18 | 100.13 | 155.24 | 200.19 | 300.21 | 358.13 | 420.27 | 0.187 |
| 110                     | 10.18 | 50.23 | 100.25 | 155.13 | 200.25 | 300.18 | 357.86 | 420.22 | 0.198 |
| 113                     | 10.24 | 50.21 | 100.27 | 155.19 | 200.16 | 300.22 | 357.91 | 420.25 | 0.2 |

#### 4.2. Test results and analysis

See Table 1 for test data, select data of 6 positioning cards for analysis, and the values in the table are the maximum values in the array. According to the test results, the ranging values of the positioning card are within the error range, the positioning accuracy of the system is less than 30cm, and the farthest coverage distance is more than 400m. In conclusion, the positioning accuracy of the underground positioning system based on UWB technology is high, the coverage distance is long, the ranging value is stable, and there is no fluctuation of the ranging value, which can meet the requirements of accurate positioning of personnel, vehicles and objects in the coal mine environment.

### 5. Conclusion

Through the study of UWB technology and the principle of SDS-TWR algorithm, UWB technology can be well applied to the coal mine precise positioning system. The experiment shows that the positioning error of UWB based coal mine precise positioning system is less than 30cm, covering a long distance, which meets the requirements of underground personnel precise positioning, and meets the requirements of Shandong coal mine personnel precise positioning system technical requirements (Trial). With the continuous development of technology and the improvement of intelligent level of coal mine, the system
will gradually play a greater role in accurate rescue of coal mine, intelligent control of shearer and accurate movement of mobile substation.

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