Positioning System of Underground Coal Mines Based on ZigBee Technology

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Abstract

The study introduces the man and machine positioning system of underground coal mines based on the ZigBee Wireless Communication Technology. It can realize the effective management of the precise positioning of machine and the workers. This article presents the composition of the system, the performance and management of content and network formation. The actual application shows that the underground man-machine positioning system based on ZigBee technology can play an important role in the underground personnel information and security management. So the system can meet the needs of the mine safety management and there has great application prospect.

Keywords: ZigBee technology, positioning system, information management, emergency adapting

1. Introduction

The main reason and the direct cause of accidents in mines are the person's unsafe behaviors and insecurity state of the management. The managers cannot exchange information timely with underground persons in real-time, real time distribution of the mine personnel and can't be obtained; precise positioning of the staff can't be gotten effectively. Especially in some unexpected accident, it is unable to determine the exact location of the mine personnel, thus lead to the increase number of casualties. Therefore, how to realize the personnel positioning in the underground mine has great significance in the safety management of the mine.

Underground Man-machine Positioning System, also known as the personnel positioning and underground work personnel management system, is generally composed by a recognition card, location monitoring station, power supply unit (With the integration of sub-station), transport interfaces, Host computer (including monitor), system software, server, printer, large-screen, UPS power supplies, remote terminal, network interfaces and cables and so on.

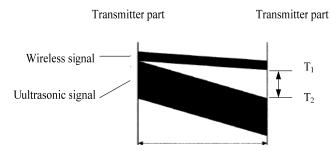## 2. Comparison of Different Positioning Methods
2.1. The Personnel Positioning Technology Based on RFID

The working principle of RFID (radio frequency identification devices) positioning technology its is putting a certain number of base stations in down hole, and each base station is connected with the ground controller through communication cable and data cable, each person have the identification of radio frequency card, when the people go into the underground, as long as the people pass or near the receiving stations, the base station will immediately receives the signal, and uploaded the information to the main control machine on the ground. The master machine can store the information through software platform; and put the information on the screen, and the every day information can be saved to the database of mine personnel management. The manager can check the total number of underground personnel in real time, personnel information nearby the base station, etc., it also can query the information according to the specific time, the name or number of the mine personnel needed.

2.2. TDOA Location Technology

The principle of TDOA (Time Difference of concatenated) positioning technology is that the radio frequency identification card launches two wireless signals with different propagation velocity, the wireless two kinds of signal transmission speed base stations can calculate the distance between the radio frequency identification card and WAP (Wireless Access Point) according to the difference of arrival time of the two signals. In the same way, the distance between two WAP and the radio frequency identification card can be measured through the three edge measuring method or maximum likelihood estimation method, thus the location of the radio frequency identification card can be determined. Usually radio frequency identification card emits radio frequency signal or the ultrasonic signals, T1, T2 are arrival time of two signals as shown in Figure 1.

Figure 1. Positioning Principle Diagram of TDOA

As radio frequency signal is known and the ultrasonic propagation speed is C_1 and C_2 so the distance between the AP and the radio frequency identification card is as (1).

$$d = T_1 - T_2 \times S \tag{1}$$

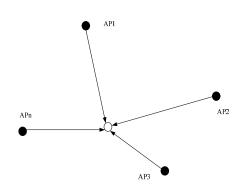Where, $S = C_1 \times C_2 / (C_1 - C_2)$

2.3. Positioning Technology Based on RSSI

RSSI (Received Signal Strength Indicator) is based on received signal strength, and the positioning technology receive the same signal of identification card at least three AP at the same time to, as shown in figure 2 and obtain the value of RSSI,. It can get relative distance of radio frequency identification card to each WAP through Eq (2) and (3), then merge with the absolute coordinates with WAP, and then through three edges measuring method or maximum likelihood estimation method personnel location information in the mine can be obtained. Computation formulas are as follows:

$$p(d) = p(d_0) + 10\eta \lg(\frac{d}{d_0}) + \varepsilon_0 \tag{2}$$

$$d = 10^{\frac{p(d) - p(d_0) - \varepsilon_0}{10\eta}} * d_0 \tag{3}$$

Where $p(d)$ 、 $p(d_0)$ respectively, represents the distance from the base station WAP for d, and the strength signal strength of d0, $p(d)$ is the actual received power, $p(d_0)$ is the received power at the reference distance d0, η is the path loss factor, ε_0 is Gaussian random variables of zero mean with standard deviation is δ.
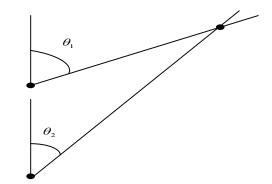
Figure 2. Positioning Principle Diagram of RSSI

Figure 3. Location Principle Diagram of AOA

2.4. Personnel Positioning Technology Based on AOA

AOA (angle of arrival) location technology is to get position directions through measuring angle between target and location node.When two locating node measure the same signals emitted from one target node at the same time, intersection of the two the AOA income goal is a direction location of the target, which is shown in the Figure 3 below.If make the hypothesis that signal arrival angle of localization node A and B are θ_1 , θ_2 respectively, the formula (4) can be obtained:

$$\tan(\theta_i) = \frac{x_0 - x_i}{y_0 - y_i} \quad i=1, 2 \tag{4}$$

The node location coordinates if (x_0, y_0) target can be obtained by solving the nonlinear equation.

2.5. ZigBee Technology

Due to short-range, low-complexity, low-power, low data rate, and low-cost, ZigBee technology has been recognized as the main technical support of the wireless sensor network. Zigbee structure is composed of the application layer, network layer, application support layer, data link layer, the media access and physical layers,etc. The network layer protocol is developed by the ZigBee Alliance. The physical layer, media access layer, and the data link layer use the IEEE 802.15.4 standard. The physical layer of IEEE 802.15.4 simply adopts bit technology, symbol-to-symbol mapping conversion technology to the chip sequence, offset quadrate phase shift keying (OQPSK) modulation techniques, algorithms of channel coding, etc.; media access layer uses carrier sense multiple address collision avoidance technology, support sleep mode. Based on the IEEE 802.15.4 protocol, ZigBee technology adopts the global free-band in communication. Global band 2.400 ~ 2.484GHz, in Europe, the band is from 868.0 to 868.6MHz, the United States has adopted the band 902 ~ 928MHz, the transfer rate is from 250 kbit/s to 20 kbit/s and 40 kbit/s ,and its theoretical value of communication distance is about 10 ~ 75m, the specific module parameters as shown in Table 1.

Table 1. ZigBee Module Parameters

	Small power module ZICM2410P0	High-power module ZICM2410P2
Real-Time Measuring of transmission distance (5dbi antenna/m)	500	1500
Antenna power output/dBm	6	20
Receiver sensitivity/dBm	-97	-103.5

The design of the entire protocol makes ZigBee technology has the characters of low data transfer rates, low power consumption, low cost, huge network capacity, low propagation delay, safe, small effective range, flexible working band and etc. It is very suitable in the appliances of industrial monitoring and control system, the wireless detection, remote control systems, security and defense systems.

3. Underground Man-machine Positioning System Based on ZigBee Technology

Underground man-machine positioning system based on ZigBee technology is composed by the information processing servers, communication links, wireless base stations, identity card, power Adapter.

3.1. The Main Performance of Composed Parts

a) The information processing servers

It is primarily responsible for information storage of issued by the network wireless base station, and to analysis, process and display the received information, while allow other authorized users to access information in the form of network.

b) Wireless base station

It can realize the data acquisition of subscriber identity module card, and send the information to the information processing server through both wired and wireless, and also carry other wireless base station data relaying functions.

c) Identification card

It mainly sends a signal timely to the system for registering, in order to obtain the positioning of personnel functions.

d) Optical transceiver converter

The data transmission channel is between information processing server and underground radio base station; this module can convert the electrical signal to an optical signal.

e) Power supply adapter

The power supply adapter can convert high-voltage into low-voltage direct current, which is the need of underground safe systems. It also can automatically convert for battery charging in the case of power failure under normal circumstances.

3.2. Management of Underground Man-machine Positioning

The orientation system of mining personnel is a comprehensive system, which combines the underground man-machine positioning, attendance of the mining personnel with the emergency rescue and daily management.

Monitor the real-time location of the mining personnel through the permeated readers in the mine and the manager could master the trajectory of mine personnel and mobile devices in the management. Once an accident occurs, the rescue workers could take appropriate actions and provide immediate help according to the data and graphics that provided by the system. It could improve the efficiency of the emergency rescue work.

With different logos, analog graphics or different color, data, dynamics the system could display of the status and distribution of the down hole categories of personnel and scrapers and transport vehicles in real-time, and it can dynamic display the simulation of activities trajectory of underground man-machine, then realize the interaction of the scheduling command center with underground management personnel. It will provide the warning with automatic audible and visual alarm once the personnel underground work overtime, display the danger zone or key protection area and when the working face have accidents and the underground personnel in case of emergency.

3.3. Distribution of Underground Man-machine Positioning

The drawn mine development and mining area layout according to the actual situation of the wellbore, the roadway, and the mining area, and shows the person's number of various regions of current panel in the figure. These figures are dynamic, as the underground man-machine is mobile, the figures will be updated at any time. Click on the graph with a mouse, it can display the selected area of man and machine's list, it also can display a selected whereabouts when the man-machine going down; if enter any man-machine name and number,

graphically area of it can be immediately displayed. It can also have the display function of current position of multiple staff and mobile devices.
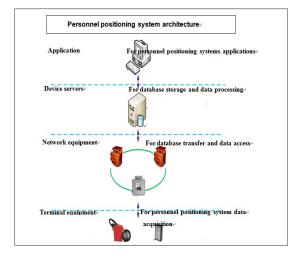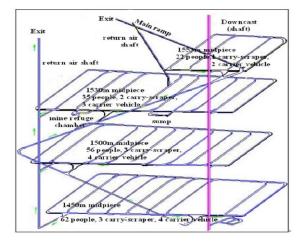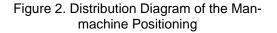

Figure 1. Personnel Positioning System Architecture

Figure 2. Distribution Diagram of the Man-machine Positioning

3.5. Information Management of the Mining Personnel
The system is capable to statistics the entrance time and rise time of the staff in real-time. Monitor and classify statistics of the number of classes, trips, late, leave early, etc. in each unit.

The data could be queried with real-time. The situation of the separate staff, team, and mine leadership can be checked at any time. Data can be kept for at least two years. The system also can provide two years of data summary statistics. The personnel information management can be carried out summary statistics, query, print according to the demand at any time.

4. The Network of the System
Currently most of the system's networking mode is adopted bus method, as this mode will affect the communication speed and distance of multi-base station, the number of base stations of network-attached and the communication distance are limited. With the development of Internet technology, it becomes mainstream media of the industrial data transmission with its unique features of low-cost, high effectiveness, high scalability and high intelligence. The man and machine positioning system in the study is based on the Industrial Ethernet with using ZigBee communication technologies. Its establishment of communication link in the link layer protocol has been guaranteed.

The system of physical layer adopts frequency of 2.4GHz in communications, this technology can realize more far communications distance, and its anti-interference capacity is strong, but signal of penetrating force and diffraction capacity is not enough. The well roadway is narrow, and environment is very complex, all regional are unable to be visual in line, the occurred faults in communications node may led to a regional interruption of communications; according to this problem, the system take the wire combined with wireless communication method in order to improve system reliability.

5. Z-NET System
Mine safety production is a dynamic, complex, and systematic process. In order to realize the mine safety, digitized method should put into consideration systematic and comprehensively, it also should make the whole system efficiently and collaborative, each

subsystem can run independent, and also can run in collaboration to protect scheduling commanding the unobstructed high speed. Like the underground positioning and communication system, they can be a unified system integration platform, the effective integration of these independent subsystems; can be used in the actual analysis and management.

The industrial network construction is the base of the systems' engineering. The network infrastructure is built under the guidance of the core idea of the integrated communications platform, its target is to achieve high-speed, open, and secure, reliable mine public network transmission platform and network switching system. integrated application of 54 MB broadband wireless, RS485 and ZigBee sensor wireless transmission cam realize safe production scheduling, personnel positioning, the monitoring and control network communications platform can be shared by multiple applications.

On the base of the Industrial Ethernet, the multi-play mine Z-NET communications management platform which is integrated the data, voice and image, is the first full-intrinsically safe, precise positioning, broadband, complex underground information system platform. It can provide the strong IT assurance for the six major systems implementation and digitized mine construction.
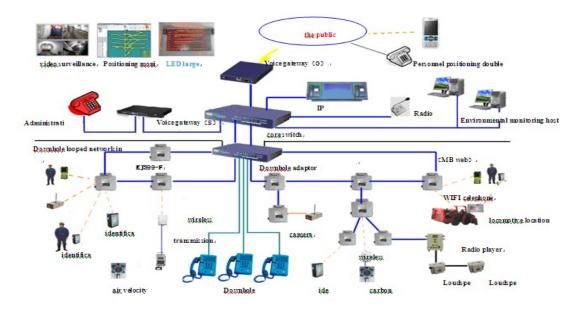

Figure 3. Z-NET System Application Diagram

6. Conclusion

By applying the advanced wireless communication technology in man and machine positioning system of underground coal mines, the realization of zone positioning and management of man and machine underground can be performed. The underground positioning base stations can collect the signal of the identity cards held by each worker and scrapers, and upload the signals to the central server on the ground. Through the analysis of the collected data, it can show the distribution of personnel and vehicles underground, running track, and other information in time, indirect, visual indication. All this can improve the daily management of the mine personnel, vehicles, and scheduling. This also avoids the occurrence of work passing phenomenon, and improves the working efficiency. Underground man-machine positioning and information management is not only important for effective rescue work when accident happens, but also it is important to improve the level of modern management of mine enterprises. Furthermore it can prevent the ultra-capacity production and prevents personnel to enter hazardous areas. It can reduce the accident hazards degree by comprehensive management measures and prevent serious accidents. Meanwhile, it also provides strong technical support and IT assurance to digitized mine construction.

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