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Integrated Management System for Coal Mine Locomotive Transportation

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Abstract: Combined with the reconstruction project of underground locomotive transportation system in Guqiao Coal Mine of Huainan Mining Group, the dissertation studies the comprehensive management system of coal mine locomotive transportation. The accuracy of ZigBee wireless positioning technology is improved through Gaussian filtering to make it applicable to more complex underground coal mine environment. Frequency conversion control is used in the motor control circuit to realize real-time calculation of the running speed of the locomotive. By analyzing the control scheme of the turnout and traffic lights, the explosion isolation and essential safety control sub-station suitable for gas mine are designed. Communication platform construction of the system is realized through wireless base station of Benan mine and industrial network of coal mine. System relevant data can be uploaded to the ground dispatching center in real time, so that the scheduling staff can reasonably arrange the scheduling tasks in a timely manner. The optimized logistics management and storage management system makes the material dispatching and transportation more reasonable and scientific. Through the analysis of the running data, the construction and personnel management of the locomotives are realized.

Keywords: Coal Mine Locomotive Transportation; The Locomotive Position; The Locomotive Management; Logistics Management

1. Introduction

At present, the production scheduling and mine site management basically rely on artificial processing, locomotive transportation informatization system, relatively backward equipment aspect, and the domestic use of traditional letters decentralize management way. The closed system can only realize the locomotive regional location and calculate the average velocity, but is unable to realize real-time positioning and speeding. The control room and vehicles communicate only by crossing the traffic lights or roadway construction dispatching telephone to realize real-time control of the vehicle running. The ground control center can't load unloading situation of locomotive transporting materials and personnel, and is unable to do real-time voice communication with the driver in case of an emergency to realize remote control of locomotive. On March 25, 2016, the State Administration of Work Safety promulgated order No. 87 of the State Administration of Work Safety and formally issued the newly revised Coal Mine Safety Regulations[1], which further raised the requirements for the comprehensive locomotive transport management system and made the system upgrade imminent.

This topic is aimed at the design and research of the locomotive transport reform project of Guqiao Mine of Huainan Mining Group.

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The underground locomotive transportation system before the transformation is a traditional information collection and closing system. The length of the -648 horizontal transportation roadway is about 4,000 meters, and there are about 170 switches, all of which are pneumatic switches. Manual button boxes are equipped on site, and the reverse fork is controlled. The horizontal transport lane has a total of 8 rechargeable electric locomotives for transport, mainly for the transport of materials. Expanded as mine laneway, transportation, and often appearing because of unknown locomotive location, the driver and staff manual scheduling caused by unreasonable phenomenon such as locomotive matches, locomotive and communication system. Base station is used and leakage cannot be achieved due to limited bandwidth of video signal transmission, for example, the position of the locomotive signal is buried in the switch in advance to realize the orbit of shaft, so it's only through the shaft device of vehicle for display, but unable to realize accurate positioning. As the shaft marker is installed on rail sleepers, it has been squeezed by rails and locomotives for a long time, and the workers are washed by water when they clean the roadway, so the shaft marker is vulnerable to damage, which seriously affects transportation efficiency and brings hidden safety risks.

After the transformation, through the construction of locomotive transportation monitoring system[2], the card reader installed on the roadway wall is used to read the locomotive position in real time, so as to realize the accurate positioning of the vehicles. Through the communication between wireless base station and locomotive at all times, the unified integration of switch and signal lamp control, on-board voice communication, personnel positioning information, alarm linkage and comprehensive display are realized, and the intelligent and scientific monitoring system of locomotive transportation is established. Through the construction of locomotive transportation management system, the information management of the whole process of material and personnel transportation and the integrated control of vehicles, operators and performance appraisal is realized, and an efficient and safe locomotive transportation management system is established.

2. Framework of integrated management system for coal mine locomotive transport

The architecture of the integrated management system of coal mine locomotive transportation is mainly composed of coal mine locomotive transportation dispatching system and coal mine locomotive transportation management system. The transportation dispatching system of coal mine locomotives realizes the accurate positioning of underground vehicles, and carries on the comprehensive monitoring to the underground transportation locomotives with the help of mine industrial television system[3], and carries on the driving signal locking and interlocking on the basis of the accurate positioning information of the vehicles. The intelligent on-board terminal is used to realize the voice dispatching, task dispatching and instruction issuing of ground vehicle dispatching room and running vehicle. To manage alarm information such as speeding, running red lights, safe distance, illegal parking, hostile operation, etc.; the coal mine locomotive transportation management system realizes the whole process information management of transportation task from loading point to unloading point through the logistics management module. The vehicle life cycle management is realized through the vehicle management module. The management of personnel qualification[4], health and performance is realized through the personnel management module. It also includes security management, infrastructure management and warehouse management. On this basis, various operation analysis of the transport system is carried out, and the intelligent logistics and transport management are realized.

3. Coal mine locomotive transportation dispatching system

The coal mine locomotive dispatching system is based on the accurate positioning information of the vehicle, and the vehicle intelligent terminal is used as a tool to assist the underground turnout and signal lamp control system, intelligent dispatching system, voice dispatching system and GIS geographic information system. Realize the whole process of control and real-time dispatching of the auxiliary system transportation vehicles and operators, make it scientific and intelligent, so as to achieve the purpose of efficient and safe operation of the locomotive transportation system. The system is

mainly composed of intelligent dispatching subsystem, vehicle terminal subsystem, dispatching communication subsystem, switch and signal lamp control subsystem, GIS mine geographic information subsystem, data transmission control subsystem and system interface subsystem.

3.1 System function design

3.1.1 Precise positioning of vehicle

At present, indoor positioning technology mainly includes UWB (Ultra Wide-band) technology, RFID technology, ZigBee technology, ultrasonic technology, inertial navigation technology, WiFi technology, geomagnetic technology and satellite positioning technology.

Because the locomotive under Guqiao Mine adopts track locomotive, the locomotive track width is smaller than the track length, and locomotive transportation can be regarded as one-dimensional linear space. The WiFi sub-station and positioning label are installed on the roadway wall, and the vehicle intelligent terminal is installed in the cab of the locomotive, which contains ZigBee wireless signal transmitting devices. The wireless signal is transmitted by the vehicle terminal, the intensity of the sensing signal of the positioning label is fed back to the position of the intelligent vehicle terminal, and the calculated position information is transmitted to the WiFi sub-station through the WiFi signal[5].

Compared with other vehicle transport positioning, the transport track of coal mine rail transport locomotive is very fixed, which can only run along the track and the track length is much longer than the track width. According to these characteristics, the motion of track transport locomotive on underground roadway can be simplified to the motion on the point line. The track arrangement diagram of Guqiao Mine transport locomotive is shown in **Figure 1.**

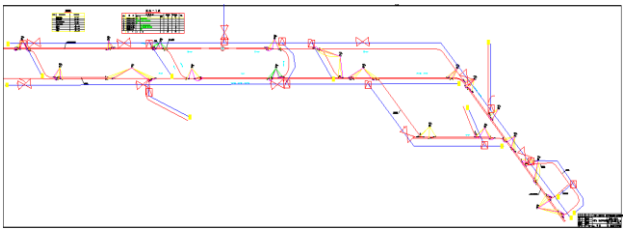

Figure 1. Guqiao Mine locomotive transportation track layout.

The RSSI algorithm is used for accurate positioning of the vehicle. The signal strength indicator received by RSSI is an optional part of the wireless transmission layer used to determine link quality and whether to increase broadcast strength. A positioning technique that measures the distance between a signal point and a receiving point by measuring the strength of the received signal calculates the distance based on the corresponding data[12]. In the transmission process of electromagnetic wave, there is an exponential attenuation relationship between the received signal strength index and the transmission distance, which can be expressed by formula (1):

$$P_r = \frac{P_t}{d^u} \tag{1}$$

In the formula, P_r is the received wireless signal power, P_t is the transmitted wireless signal power, d is the distance between the sent and received signals, and u is the attenuation coefficient of the wireless signals. According to the above formula, if the wireless signal power is transmitted by the base station, the attenuation coefficient of the wireless signal and the received power of the unknown node will be known, and the distance between the base station and the unknown node will be calculated. Since the transmitting power of the base station is not easy to be controlled or measured in practical work, a reference node is introduced to eliminate the transmitting power P_t of the base station. The calculation formula of the reference node is as follows:

$$P_{r0} = \frac{P_t}{d_0^u} \tag{2}$$

In the formula, P_{r0} is the wireless signal power received by the reference node. In unit W, d_0 is the distance between the transmitting base station and the reference node. Equation (1) and (2) can be expressed as:

$$\frac{P_r}{P_{r0}} = \frac{d_0^u}{d^u} \tag{3}$$

By logarithmic transformation on both sides of

equation (3), the received signal strength indicator model can be obtained:

$$P_R(d)=P_{R0}-10u\lg\left(\frac{d}{d_0}\right) \quad (4)$$

In the above equation, P_R is the wireless signal power received by the unknown node, which is taken dBm as unit; $P_{R0}$is the power of the wireless signal received by the reference node relative to the transmitting base station, also in dBm; d_0 is the relative distance between the reference node and the transmitting base station, in m. In order to facilitate the calculation and to consider the effectiveness, d_0 generally takes 1 meter; u is the attenuation coefficient of the wireless signal. In different environments, the attenuation coefficient of wireless signals will vary. In the actual site of underground coal mine, we take it as 2. In the case of obstacles, the attenuation coefficient of wireless signals will increase correspondingly. In practical application, the value of the attenuation coefficient of wireless signals is obtained through unitary linear regression. In calculation, it is necessary to know the locations of unknown nodes at different distances from the base station, and set the location of the base station and the wireless signal receiving power P_R of the unknown nodes acquired. Formula (4) can be represented by matrix, and the results are as follows:

$$P=uL \quad (5)$$

In the formula, $P=[P_R(1)-P_0,P_R(2)-P_0,\cdots,P_R(n)-P_0]^T$,$L=[-10\lg\left(\frac{d_1}{d_0}\right),-10\lg\left(\frac{d_2}{d_0}\right),\cdots,-10\lg\left(\frac{d_n}{d_0}\right)]^T$, the attenuation coefficient of the wireless signal can be obtained by using the least square method:

$$u=\frac{P^T}{L^T} \quad (6)$$

The ranging formula of the received signal strength index can be expressed as:

$$d=10\left(\frac{P_{R0}-P_R}{10u}\right) \quad (7)$$

As can be seen from the above equation, the distance between the base station and the unknown node can be calculated by measuring the wireless signal receiving power P_R of the unknown node. In addition, if the base station location is already determined, then the precise location of the underground transport locomotive in the roadway will be determined.

In practical application and field environment, hardware design problems, obstacles and other problems will have an unavoidable impact on the wireless signal receiving power P_R, resulting in certain deviation of the value of the wireless signal receiving power. In order to get the correct received power value of wireless signal, Gaussian filter is used to filter the received power value of wireless signal.

Gaussian filter is a kind of linear smoothing filter, which is suitable for eliminating Gaussian noise. The geometric mean P_{Ra} of the received power value of the wireless signal at the unknown node is calculated from these values, which can exclude some of the received power values of the wireless signal with less probability and stronger interference, greatly improving the accuracy of positioning. The probability density function of wireless signal receiving power is:

$$f(P_R)=\frac{1}{\sigma\sqrt{2\pi}}e^{\left(-\frac{(P_R-\mu)^2}{2\sigma^2}\right)} \quad (8)$$

In the formula, μ is the true mean of the received power of a wireless signal, and σ is the true standard deviation of the received power of a wireless signal, both of which are constant. If the sample mean is $\overline{X}$, the standard deviation of the sample is S, and the confidence level of μ is 0.6, the high probability interval $\overline{X}-0.845\frac{S}{\sqrt{n}}\le P_R(j)\le\overline{X}+0.845\frac{S}{\sqrt{n}}$ can be obtained, and through this formula, the high probability interval $P_R(j)$ can be obtained, and then the geometric mean $P_{Ra}=\frac{1}{K}\sum_{j=1}^{k}P_R(j)$ can be calculated. Finally, it is concluded that the distance between the unknown node and the known transmitting base station is $d=10\left(\frac{P_{R0}-P_{Ra}}{10u}\right)$.

The system realizes accurate positioning of vehicles and real-time monitoring of downhole/well transport vehicle location information. According to the position information of the vehicle to carry out the interlocking control of driving signal, guide the vehicle to drive and avoid. In case of overspeed, illegal parking or illegal intrusion, the system will give an alarm and record the alarm information. At the same time, the tracking management of the vehicle transportation task will be carried out according to the vehicle position information to form the basis of the closed-loop task and data statistics, so as to realize the query and playback of the running track.

3.1.2 Accurate personnel positioning system

ZigBee wireless communication technology is also used in the design of personnel positioning system[6], and the precise location of personnel is obtained through RSSI algorithm and Gaussian filtering. LED display screen is installed in the waiting room to display the number of passengers, so as to inform the passing people and drivers that there are people waiting for the bus. At the same time, it can display the timetable of passengers and cars and the situation of coming passengers and car drivers, to show whether there are empty seats and other information. The system can not only realize accurate positioning within 5m for the personnel entering the well, but also meet the general requirements of the personnel positioning system such as real-time display of the total number of persons entering and leaving the well, time of entering and leaving the well, length of entering and leaving the well, information statistics, operation trajectory, overtime alarm and restricted area alarm. In the test process, 40 test points of transport locomotive and 20 test points of personnel positioning were selected. For a total of 60 measured values, the mean error E=3.6 m was obtained through equation 9.

$$E = \frac{1}{n}\sum_{j=1}^{n}(X_J - U) \tag{9}$$

In the formula, X_J is the measured value of the measurement point j, and U is the actual position of the measured object.

The system greatly improves the positioning accuracy, and effectively solves the problem that the memory axis can't realize real-time accurate positioning. Due to the use of positioning, wireless base stations and car terminal are installed on the wall of roadway and locomotive driving indoor, and the using environment is good, greatly reducing the system failure rate and maintenance cost, and effectively solving the shaft device positioning system's problem of high failure rate and high operational cost.

3.1.3 Switch and signal control

The system controls the turnout according to the vehicle position information obtained by monitoring and the transport task of the vehicle, and links the signal light to show the direction of the turnout, and the dispatching center commands the vehicle operation remotely. Turnout control is automatically controlled with reference to vehicle position, number, type, roadway conditions and other information, or can be manually controlled by the drivers; the system can flexibly configure and remotely manage the control parameters. The system monitors the alarm when the driver runs the red light and records the alarm information.

A total of 170 sets of electric switches are designed for the -618 level with local control and remote control interface. The switch control box is connected to the flameproof and inherently secures sub-station[7], and the control box feeds back the positive, negative and not in position state information of the switch to the switch control box. Explosion-proof and intrinsically safe control sub-stations are set up in places with dense signals and control equipment[8,9], which are used to control measurement and equipment such as each measurement and control point of the roadway, subordinate signal machine, point machine and various sensors. The sub-station is equipped with switching power supply, intrinsic power supply, and PLC[10].

3.1.4 The vehicle speed

At present, the locomotive used in Guqiao Mine is the accumulator traction track locomotive, and the driving motor used by the locomotive is the variable frequency asynchronous motor. In order to satisfy the system's accurate control and conversion of locomotive speed, the original asynchronous motor of electric locomotive is replaced by permanent magnet synchronous motor. The permanent magnet synchronous motor uses frequency conversion control. The power supply of the electric locomotive is the on-board battery, with a capacity of 560AH and a voltage of 192V. The permanent magnet synchronous motor of electric locomotive adopts frequency conversion control, which has good speed regulation and energy saving effect. It not only realizes stepless speed change, but also keeps constant torque when the motor runs at different frequencies due to the V/F control. Compared with the traditional resistance voltage regulation control method which causes energy waste frequency conversion control greatly improves the electric energy utilization rate of electric locomotive battery. As the power supply of electric locomotive is directly provided by the DC battery, there is no need to design the rectifier circuit. Just invert the battery DC power supply to AC power supply[11].

3.1.5 Voice dispatching

Based on the development trend of communication technology and the current situation of the use of each

system, combined with the actual conditions of Guqiao Mine, this scheme uses wireless and VOIP technology based mine wireless communication system for networking[12]. The whole system takes the mine industrial ethernet ring network as the main transmission platform and WiFi wireless network and TCP/IP protocol as the basic architecture to form the combination of wired backbone and wireless terminal, covering part and all the related areas of roadway and ground in the mine, and finally realizing the wireless communication of the coal mine.

3.1.6 Alarm management

Alarm management mainly refers to the management of alarm information such as overspeed alarm, running red lights, safe distance between transport locomotives or between transport locomotives and underground personnel, illegal parking of transport locomotives, hostile operation, insufficient storage of batteries and so on. Alarm information can be linked with large-screen system, SMS system, industrial TV system and on-board intelligent terminal system, and it is also the basis for performance assessment of vehicles and drivers.

3.1.7 GIS block diagram management

In this design, GIS mine geographic information system[13] is used to realize three-dimensional modeling of underground roadway, tunnel, turnout and signal lights. The accurate distribution and operation information of downhole vehicles are presented, which provides an intuitive basis for scheduling decision.

The information of mine transport vehicles, switches, signals and relevant operators will be displayed in the GIS system in real time. Through modeling and management of relevant locations on and under ground, the GIS system can display the number, location and distribution of vehicles on and under ground. The position of each vehicle at any time, the activity track of each time period and the real-time transport task of the transport vehicle can be obtained, which provides a visual basis for the efficient, safe and scientific operation of the vehicles.

3.1.8 Wireless video surveillance system

Wireless video surveillance system is mainly composed of underground wireless base station, mobile video terminal, security camera and explosion-proof computer. The system uses wireless WiFi technology[14] to solve the problems of wiring difficulty and transmission attenuation in the complex transportation environment of long distance, changeable slope and large dip angle.

Two mine cameras are installed on each electric locomotive device. The camera is powered by 24V intrinsic ampere power provided by the transport locomotive and has the function of wireless signal transmission. The wireless base station installed along the -648 horizontal roadway has a coverage radius of 300 meters, which is not only used for precise positioning of transportation vehicles and personnel, but also for receiving wireless signals from wireless cameras. The wireless signals are processed and converted, and connected to the industrial ring network switch of Guqiao Mine nearby by optical fiber. Through ring will signal will eventually image information in the dispatching station underground explosion-proof computers and ground scheduling shown on the screen, ensure that operators can real-time dispatching center, clear and intuitive view transport along the site condition, adopt corresponding operation according to the on-site real-time status to increase the locomotive running safety.

3.1.9 Ground control center screen display

The ground dispatching center of the coal mine locomotive transportation integrated management system is built in the transportation work area of Guqiao Mine[15], and the large-screen display system is established to provide powerful processing and display functions for all kinds of information by applying large-screen digital Mosaic wall technology. The large-screen display system can display real-time downhole video pictures, analog operation pictures of electric locomotives, operation status and transportation tasks of each locomotive, etc. Dispatchers can realize centralized control and supervision of the operation of electric locomotives according to the information provided by the pictures, so as to realize visual monitoring function of electric locomotives.

4. Coal mine locomotive transport management system

Coal mine locomotive transportation management system is used to solve the problem of coal mine locomotive transportation, transportation task, transport vehicles and personnel work aspects such as material distribution application and approval, the driver and seconded, material to send and receive delivery vehicles such as the

whole process of comprehensive control, and to carry out the vehicle operations, driver management, market assessment, measurement information management and the overall goals to achieve the safe transportation of the mine haulage system, efficient scheduling. The design idea of the system: the coal mine locomotive transport management business is as the main, and transport equipment, personnel, transport materials, transport infrastructure and related events are as the basic data of the system; take lean management as management mode, plan, execute, check and optimize as means; process design and real-time information transfer as the main body of system application requirements; make full use of the existing system, network and other information resources to build the coal mine locomotive transport management system with integrated and innovative ideas. It mainly includes: personnel management, vehicle management, logistics and transportation management, security management, infrastructure management, warehouse management and operation analysis.

5. Conclusion

Through coal mine locomotive transportation construction project integrated management system, digital coal mine locomotive transportation control and intelligent management, and the traditional coal mine locomotive transportation management system causes of "fake" phenomenon can be fully realized, the locomotive positioning and the interval average speed measuring problems can be solved, and the traditional sensor system and the problem of high maintenance cost of the easily damaged can be solved. By realizing the remote control of the locomotive, the problem that the traditional system can only monitor the locomotive violation and cannot be controlled remotely can be effectively solved. It solves the problem that the communication bandwidth of traditional system is too narrow to realize the synchronous transmission of locomotive video. Through the locomotive management to solve the past locomotive maintenance, management is not in place, and put an end to the locomotive "with disease" on duty, greatly reducing sporadic accidents. Through the warehouse management and logistics management, the inventory is greatly saved, through the construction of the video system, the visualization of the transportation task is realized, and through the comprehensive management, the utilization of the transport locomotive and car is improved. The safety, efficiency and reliability of coal mine locomotive transportation system are greatly improved through the construction of coal mine locomotive transportation integrated management system.

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