Forecast and Prewarning of Coal Mining Safety Risks Based on the Internet of Things Technology and the Big Data Technology

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ABSTRACT

Major accidents, such as coal and gas outbursts and rock bursts, are of unclear occurrence mechanisms and difficult to forecast and pre-warn. Through the Internet of Things ("IoT") in a mine, the mine surface geographical information, the underground geological information and the mine production system are monitored in a real-time manner; in combination with the big data technology, the massive collected data are processed and mined to develop the mine disaster forecast and pre-warning system.

KEYWORDS: Internet of Things ("IoT"), big data, safe mining, disaster forecast and pre-warning system.

INTRODUCTION

Coal is China's principal energy source. According to 2014 National Economic and Social Development Statistical Bulletin, China's coal consumption in 2014 accounted for 66.0% of the total energy consumption. According to the Study of the Strategies for the Medium and Long-term (2030, 2050) Development of China's Energy, from 2030 to 2050, China's primary energy structure will be undergoing a significant change, but coal will still be the basis of the energy system and account for half of the energy consumption. Coal plays an irreplaceable role in promoting economic growth and ensuring energy security. But coal development and use also cause ecological damage, environmental pollution and other problems.

Currently, China's coal industry faces a very severe situation. Affected by the overall economic situation, a large number of coal enterprises make losses because of weak demands of the downstream industry and because of such enterprises' excessive production capacity, high inventory, disorderly development, environmental pollution and other problems. More pressingly, in China, coal is mainly produced through underground mining. Therefore, coal production is threatened by major accidents such as gas outbursts, rock outbursts and water permeation. In particular, in small and medium-sized coal mines have low productivity and frequent safety accidents.

The emerging IoT technology and big data technology provide new technical means and guarantee for the safe production by coal enterprises. In combination with their own characteristics, coal enterprises give full play to the advantages of mines in IoT and big data technology and establish the mine disaster forecast and pre-warning system to effectively improve the capacity of safe production.

ABOUT THE MINE IOT TECHNOLOGY AND BIG DATA TECHNOLOGY

Study of Coal IoT

IoT derives from the radio frequency identification ("RFID") system proposed by the Auto-ID Labs of Massachusetts Institute of Technology. It results from the rapid development of communication, embedded technology and microelectronics technology. The inception and development of IoT is deemed as a major reform and opportunity in the information field [1, 2]. Zhu Hongbo et al. [3] interpret IoT as a form of the application of the ubiquitous network, rather than a network in the traditional sense. In the opinion of Sun Qibo et al.[2] , the IoT in the narrow sense refers to a network connecting a thing to another thing for the intelligent identification and management of things; the IoT in the broad sense can be deemed to integrate the information space and the physical space, digitalize and network all things to achieve the efficient information interaction between things, between things and people, and between people and the physical environment, integrate various information technologies with social behavior in a new service mode, and elevate the application of informatization to a higher level.

Mine IoT is the specific application of the IoT technology in coal mines. In China, 90% of the coal resources are only suitable for underground mining [4]. Owing to the special environment of underground mining, coal production is threatened by major accidents such as gas outbursts, rock outbursts and water permeation. Underground mining involves special and complex geological conditions, and enormous production and transportation systems. In particular, the narrow mining space and many uncertainties raise higher requirements for mine IoT. A mine IoT is made up of the perception layer, the transmission layer, the analysis layer and the application layer. The basic need is to integrate the information collected by the coal monitoring system to the architecture of the coal IoT, and use a unified and standard network to achieve monitoring, control and management[1, 5-13]. After the systematic study of the application of the IoT technology in coal mines, Zhang Shen et al. [11, 12] identified a number of characteristics of the coal IoT: comprehensive business services of the perception layer, mobile agent and service discovery, compatibility of dynamic and static contents, uniform data description methods, and unified data warehouse platform.

In practical application, Jiahe Coal Mine under Xuzhou Coal Mining Group developed China's first perception mine demonstration project, and achieved the architectural design and application of the mine IoT. In the light of the special geological conditions of coal mines, Jiahe Coal Mine IoT was developed with 1000-MB explosion-proof industrial ethernet, made up of optical fibers and switches, and supplemented by the wireless network based on the WiFi technology. In Jiahe Coal Mine IoT, there are the personnel environmental perception system, the device health perception system, the mine disaster pre-warning system, the GIS management system and the virtual reality 3D demonstration platform, forming a new mode of the application of the IoT technology to mines [13].

Application of the Big Data Technology to the Exploitation of Coal Resources

So far, there has been no uniform and definite definition of big data, but the three widely recognized three characteristics of big data are volume, variety and velocity. Some people deem that big data have an additional characteristic: value [14, 15]. At the No. 462 Fragrant Hill Meeting held in May 2013, Shi Yong et al. [14] define big data as below: big data are enormous and complex data sets

of diverse sources and types and with potential value, but difficult to process and analyze in the expected time.

According to the definition of big data, data not only include the routine data prepared by humans and website clickstream data, but also include the real-time data generated by the IoT technology, mainly including the data generated by RFID tags and reader/writers, cameras, GPS, sensors, terminals, the sensor network and other devices. So to say, IoT is an important source of big data.

Some scholars studied the relationship between the mine big data and the mine IoT. In the opinion of Ma Xiaoping et al. [16], the IoT technology is applied to the system development of mines and the technological support for interconnection, the system interconnection generates big data, and big data are used for disaster pre-warning. In the author's opinion, through the perception of mining equipment, mining environment and mining personnel, the mine IoT obtains the big data about mines, and through the cleaning, classification, mining and analysis with the big data technology, the data are used for the safe, efficient and intelligent production in mines.

The big data about coal mines are mainly studied in two aspects [17].

Firstly, for the mines currently with relatively higher degree of informatization, a large number of monitoring data, mainly the data generated by sensors and the sensor network, are generated in the production process. Such data mainly include the values of voltages, currents and powers at switches of aboveground and underground power substations, the monitoring data of tapping machines and other transportation equipment, the monitoring data of water supply and drainage equipment, the personnel positioning data, the data about the gas content and the working surface temperature, the monitoring data of the underground ventilation rates, and roof and floor stress and strain data. Such data have the obvious characteristics of big data: large data, many types, high velocity, high value and complex processing process.

In addition, many people are injured or killed in mine accidents. People have not fully identified the law of the occurrence of highly damaging major accidents, such as coal, gas and rock outbursts. Therefore, it is difficult to develop the effective and timely accident forecast and pre-warning mechanism. In the current application of the big data technology, the relationships among accidents are analyzed through the study of a large number of data, but the cause and effect relationship is ignored. This philosophy has been widely applied in e-commerce, finance, logistics and other fields. Before rock outbursts, there are changes and fluctuations of mine pressure, electromagnetic radiation, infrared radiation, temperatures and other data. Similarly, before coal and gas outbursts, there are fluctuations in gas emission quantity, temperature, electromagnetic radiation and other data. Similarly, there are relevant pre-warning indicators before water inrush accidents, roof accidents and fires.

When the mechanisms of occurrence of rock outbursts, coal and gas outbursts, and other accidents are fully understood, the IoT technology is fully used and the monitoring and testing devices are deployed in combination with the big data technology to mine and analyze the massive monitoring and testing data, to identify the law of data changes before the occurrence of accidents, and to establish the effective coal mine accident pre-warning mechanism.

STUDY OF THE MODE OF SCIENTIFIC MINING BASED ON THE IOT TECHNOLOGY AND THE BIG DATA TECHNOLOGY

Data Collection System in the Mine IoT

A scientific mining monitoring system has been established to form the self-quantification mechanism for scientific mining. The modern Internet technology and the fiber bragg grating technology are used to collect the mine data in an automatic and real-time manner, such as mine gas content, working surface temperature, the stope and tunnel roof and bottom displacement, and pressure. The real-time positioning system is used to collect personnel position data and working conditions. Data are automatically processed on the system platform, and the mine's scientific mining indicators are updated in a real-time manner, so that the data of the whole mine are monitored, collected and processed in a real-time manner.

The mine IoT mainly addresses the imperfection of the existing production, monitoring and management systems, the singleness of means, the lack of interaction between monitoring systems and the inability to recall and use monitoring data. In this way, the mine IoT provides a unified network platform and unified data standards for coal enterprises. The ultimate purpose is to perceive the mine information in a real-time, accurate and comprehensive manner by with various sensing technologies, transmit the perceived information in a fast, efficient and reliable manner with network technologies, improve the information-based and automatic management of mines from the perspective of production process and safety decision-making, and provide technical support for the decision-making by mining enterprises, so that mines' production, management and decision-making can truly meet enterprises' actual needs and development.

According to the functions in networking, IoT devices can be classified into terminal nodes, routing nodes and coordinator nodes. Data collection nodes, namely, terminal nodes, are installed at different positions in line with the types of the collected data. Data collection nodes are made up of various sensors, including displacement sensors and temperature sensors. Such connection nodes set the collection time intervals according to people's needs, for example, collecting data once every 5 seconds. The collected data are sent to the coordinator nodes in the ZIGBEE network via the routers, the coordinator nodes are transmitted to the ethernet gateway via the underground CAN bus, so that the host computer can achieve recall data in a real-time manner to achieve real-time monitoring.

The IoT perception mine model is undoubtedly closely related to the digital mine model and the comprehensive automatic mine model. The application model of the IoT perception mine is shown as below. This is a model of three-layer structure. The overall aims of the perception mine have been well reflected in the model.

Perception and control layer. In the light of the characteristics of mining operation, this layer is made up of two networks: the backbone transmission network and the perception layer network.

Information integration and MES layer. The information integration and MES layer is made up of two parts: the information integration network system, and MES (manufacturing execution system) based on information integration.

Management decision-making and application layer. The management decision-making and application layer mainly consists of software application modules.

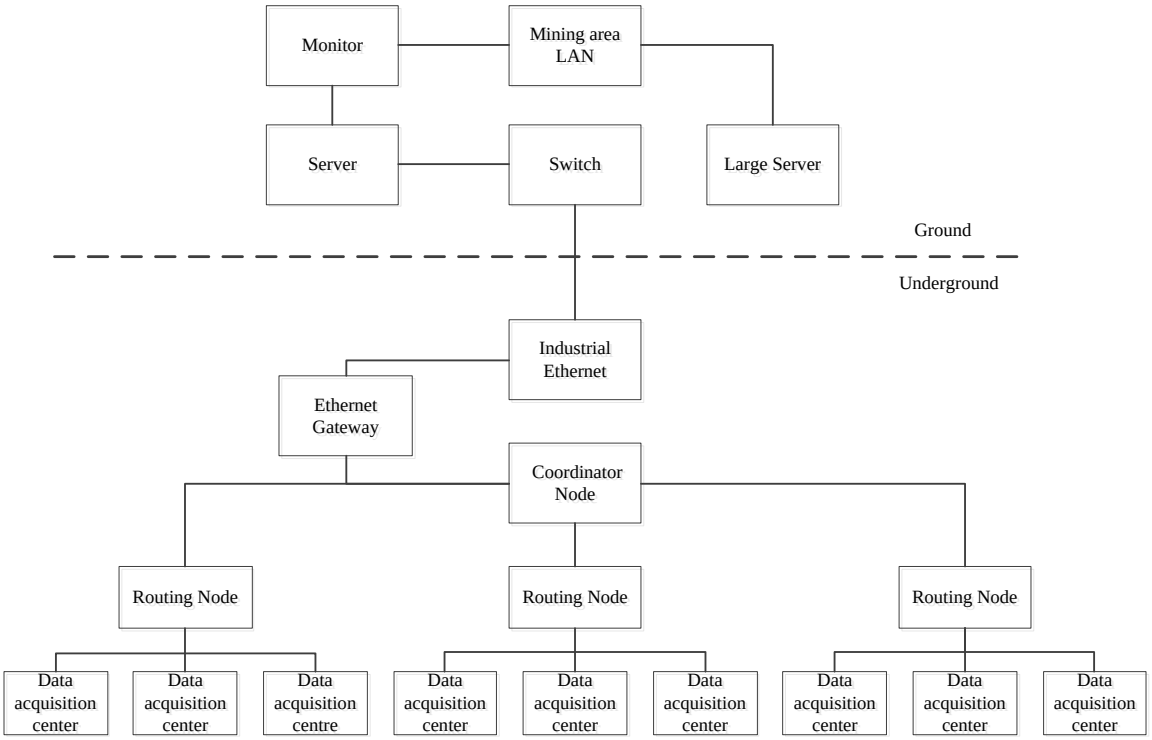

Figure 1: Data Collection System in the Mine IoT

Study of the Disaster Pre-warning System Based on the IoT Technology and the Big Data Technology

With the efforts of mining engineering experts and mine researchers, China's coal exploitation technologies have experienced great progress. For example, significant breakthroughs have been made in the R&D and application of the technology for the rapid construction of mines more than 1000 meters deep with thick alluvium and the R&D and application of outfits, the R&D and application of the quick tunneling technology, and the technology for the efficient mining of super-high seams; and great progress has been made in the R&D of intelligent fully-mechanized mining equipment. A series of breakthroughs have been made in the scientific theories involved in coal mining, such as the mine pressure and strata control theory, the gas seepage theory, and the coal and gas co-mining theory.

However, there are many theoretical research challenges posed to the scientific exploitation of China's coal resources. For example, the fundamental mechanisms of the occurrence of major dynamic disasters such as coal and gas outbursts, rock outbursts, water inrush and water permeation have been fully identified. Some achievements have been made in the application of IT to the monitoring and testing of underground production, ventilation, water supply and drainage equipment, but there is still a large gap from intelligent production and decision-making in mines. Therefore, the development of the mine accident forecast and pre-warning system based on the IoT technology and the big data technology can make up for the deficiencies in the current study of the disaster control theory. The mine surface geographical information is collected and monitored; the underground geological information, in particular, the stress and strain data, are monitored; the gas geological conditions are monitored in a real-time manner, and the hydro geological conditions are monitored in

a real-time manner. In this way, massive data are collected. Through data cleaning, classification, structuring and other processing and through the application of the data mining technology, the relevant disaster pre-warning information is extracted, and the monitoring results are published in a real-time manner.

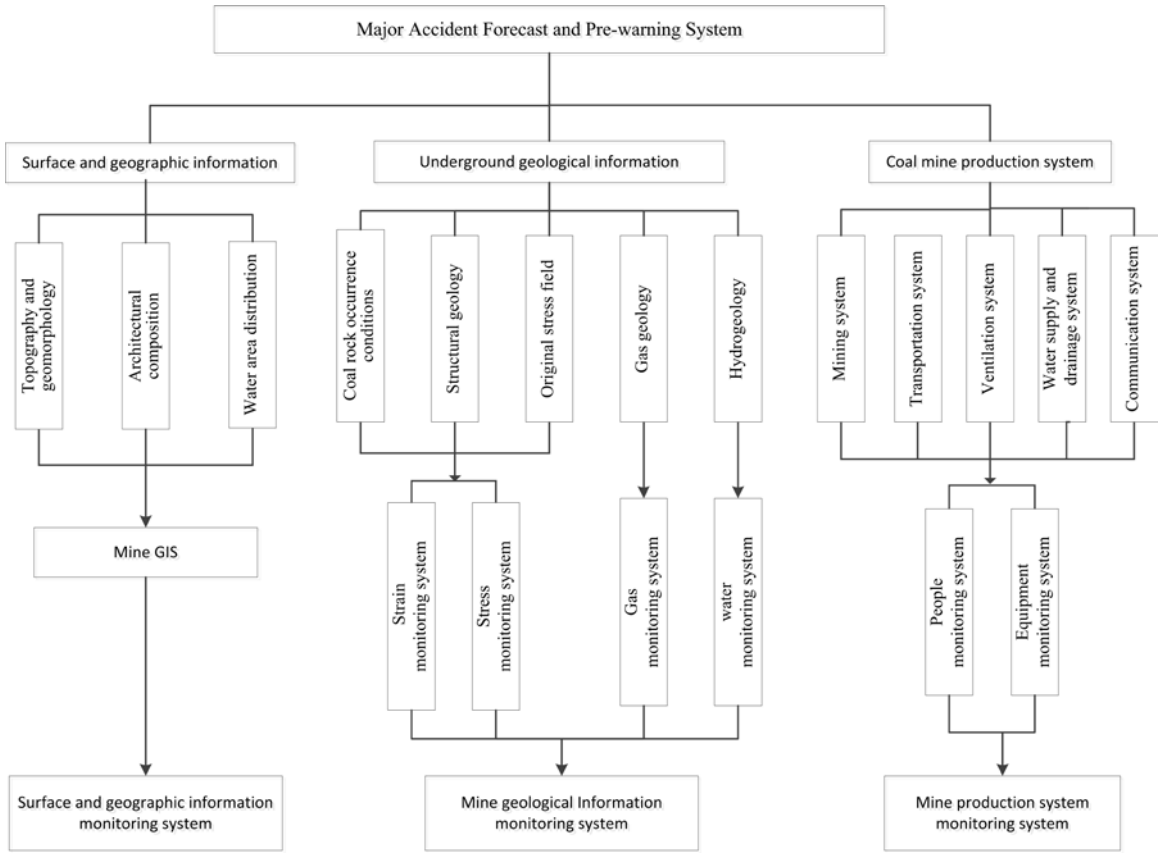

Figure 2: Major Accident Forecast and Pre-warning System

As shown in Figure 2, through the application of the IoT technology, the mine surface geographical information, the underground geological information and the coal production system information is collected for the respective development of the mine GIS system, the mine geological information monitoring system, the mine production system and the mine monitoring system. On this basis, the data analysis platform is established and the data mining technology is used to establish the mine accident forecast and pre-warning system.

CONCLUSION

In short, in the exploitation of coal resources, the advantages in the mine IoT technology and the big data technology are brought into full play to achieve the real-time monitoring of the mine surface geographical information, the underground geological information and the mine production system, and the collected data are processed and mined to establish the mine accident forecast and pre-warning system, which is an important channel for the scientific exploitation of coal resources and an innovation of the coal resource exploitation mode.

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