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THE RESEARCH ON DEVELOPMENT OF UNDERGROUND MINE SAFETY MONITORING SYSTEM OF COAL MINE BASED SPATIAL DATA MINING

D.CHANDRASEKAR, SK.SAMEER PASHA, N.SRI CHANDRAHAS

Department of Mining Engineering, Malla Reddy Engineering College (Autonomous)

ABSTRACT

Based on the characteristics of Coal Mine safety information activity, dynamic changes, closely related to the space, this paper puts forward the project about the Safety Monitoring System of Coal Mine Based on Spatial Data Mining, and builds a coal mine Safety Monitoring System model based on Spatial Data Mining and GIS technology. The Safety Monitoring System of Coal Mine will fundamentally reduce the occurrence of coal mine disasters, and improve the level of coal mine safety management. Frequent accidents have occurred in coal mine enterprises; therefore, raising the technological level of coal mine safety monitoring systems is an urgent problem. Wireless sensor networks (WSN), as a new field of research, have broad application prospects. This paper proposes a Web of Things- (WoT-) based remote monitoring system that takes full advantage of wireless sensor networks in combination with the CAN bus communication technique that abstracts the underground sensor data and capabilities into WoT resources to offer services using representational state transfer (REST) style. We also present three different implemented scenarios for WoT-based remote monitoring systems for coal mine safety, for which the system performance has been measured and analyzed. Finally, we describe our conclusions and future work.

INTRODUCTION

Coal is the main energy source in China. According to 2016 National Economic and Social Development Statistical Bulletin, the coal consumption in 2015 is about 64% of total energy consumption. So the government of China is paying more and more attessntion to safety production and proposing to use WSN, big data, IOT, and AI technologies to build “digital coal mine” so as to improve the safety level of coal mine industry. In China, most of the coal mining has happened underground, so it is very complicated about the environment in the coal mine. Some gases such as CH4 and CO are easy to gather in the coal mine tunnels; it is the main reason causing explosion accident; many workers lose their life. Since 2010, all of the coal mine industries were asked to install the monitoring system to prevent the happening of the accident. The monitoring system is working 24 hours a day without interruption. It means there are lots of monitoring data produced in the monitoring system every day. These data mainly include the state of equipment, the concertation of gas, the pressure of roof, the speed of the wind, and so on. These data have the characteristics of big data: large data, many types, high velocity, high value, and complex processing process. Taking the data obtained by monitoring system by the State Administration of Work Safety in 2015 as an example, the cumulative information exceeds 5 million and the space occupied is 10TB. We can use these data to build the suitable prewarning model and decrease the accident. It is meaningful to society.

The traditional communication method of the monitoring system is burying mine communication cable underground, but it is difficult to do at some places such as coal working face because the coal working face always changes with the digging process. With the development of WSN, its characteristics were proved to easily be used in industry. For these reasons, many scholars proposed using WSN to replace the mine communication cable of the monitoring system. Obviously, the features of coal mine industry are much different with other fields when we use WSN; the coal mine tunnels are very long and narrow. For example, in the mines of the Nanyang Coal Industry Co., Ltd., Hengyang, China, the main haulage roadway is approximately 12,000 m long, and most return airways have lengths of more than 1000 m, but the width is only several meters (Figure 1 shows part of the main haulage roadway). If we want to use WSN in the monitoring system in the coal mine industry, we should solve some problems. The big problem is how to extend the lifetime because it is difficult to change the battery of sensor.

Although MS technology has conspicuous advantages for monitoring coal and gas outburst, is also has the following shortcomings:

1. The results for the regional stress field detected by seismic wave tomography are only relative: the absolute stress value in the region is not obtained. Therefore, using seismic wave tomography to determine the degree of coal and gas outburst danger has some limitations. However, it is undeniable that the distribution of the regional relative stress field can determine the relative magnitude of coal and gas outburst risk in different positions, and this is of great significance for identifying the key danger areas so as to prevent and control coal and gas outburst.
2. Both coal and gas outburst and rock outburst are typical dynamic coal-rock disasters in coal mines, and their occurrence mechanism and characteristics have many similarities. MS monitoring technology has been successfully applied many times in the field of rock burst monitoring and early warning. However, the coal seam and its roof or floor are usually stronger in a rock outburst-prone seam than in a coal and gas outburst-prone seam. This is because the energy release in a rock outburst-prone seam is larger than in a coal and gas outburst-prone seam. Therefore, the accuracy of early warnings of coal and gas outburst from MS monitoring technology should be further discussed.

More and more big data come from sensor nodes. Reference proposed a greenhouse gas sensor network located throughout California where it collects a large number of real-time data about greenhouse gases and their behavior. The project embedded about 200 sensor nodes on the bridge to monitor the state of the bridge. Tis monitoring system collects a variety of data including temperature and the pressure of the bridge's concrete reaction to any change. Sensor nodes can collect information in the natural disaster situation in order to optimally utilize the resource and manage supply chains. The challenges in big data mainly include two categories: engineering and semantic. The Jet Propulsion Laboratory (JPL) has identified a number of major challenges in big data; it includes the energy problem especially for the sensor nodes because there are more and more big data coming from sensor nodes in the future. As to the problem of energy, data aggregation is an efficient method to decrease energy consumption and prolong the lifetime of WSN. To reduce the amount of communication data in WSN, a lot of correlation-based data aggregation methods have been proposed. The traditional data aggregation methods which are used in WSN mainly include two categories, the first type is based on least square method, Bayesian estimation method, D-S evidence theory, and so on; the other is based on artificial intelligence theory of artificial neural network method, fuzzy reasoning method, and rough set method. Reference introduced the data density correlation degree to decrease the amount of data conveyed to sink node, so it can help save more energy.

For coal mine monitoring systems, data communication technology is the key to achieving the intellectualization and network of such systems and is also an important link to achieving a high-speed information platform for coal mines. Currently, the common communication modes that can be operated in the coal mine industry include the modulation and demodulation-based analog transmission mode, the distributed control system- (DCS-) based RS485 serial communication mode, the fieldbus control system (FCS) structure-based intelligent sensor transmission mode, and the wireless transmission mode. The fieldbus technique has been widely used in the industrial fields of various industries and can be used in either the master-slave mode or the multitasker mode as needed. The multitasker mode allows data exchanges among monitoring devices in different locations to be more flexible and direct. Due to its extremely high reliability and unique design, as well as its transmission characteristics (high speed, long distance), the fieldbus technique is especially suitable for use in the interconnection between field monitoring devices.

Analyzing the field test results from MS monitoring in Jinjia mine indicates that MS technology is capable of effectively detecting the distribution of regional stress in a coal and gas outburst-prone coal seam. At the same time, it can dynamically monitor the intensity of mining disturbance and the distribution of geological structures. Deep analysis of MS region prediction results in Jinjia mine, compared with traditional coal and gas outburst monitoring and forecasting methods such as drill cutting ΔH_2, K_1, q, artificial neural network and fault tree analysis models, multi-factor pattern recognition, etc., MS monitoring technology has conspicuous advantages.

1. Continuous monitoring. Artificial neural network and fault tree analysis models, multi-factor pattern recognition, traditional coal and gas outburst monitoring and forecasting methods, etc. all using coal seam property parameters or gas parameters to evaluate the risk of coal seam outburst. The gas desorption indexes (i.e., ΔH_2, K_1, q) are used to evaluate the risk of coal and gas outburst. None of these can realize continuous monitoring. As shown in Table 4 below, it is the result of predicting the risk of coal and gas outburst by K_1 value method during period of 7/8/2017 to1/20/2018 in Jinjia Mine. The prediction of K_1 value method is measured once every 7 meters, which cannot realize continuous monitoring. However, MS monitoring can realize continuous monitoring of mining disturbance information and regional stress field, which can be used to predict the risk of coal and gas outburst.

2. Regional dynamic monitoring. Unlike with the traditional monitoring and prediction methods, MS monitoring technology realizes continuous dynamic exploration of the stress field and geological structure in outburst-prone coal seams. These factors are the key to prediction of coal and gas outburst occurrence. By the end of February 2019, the MS monitoring system of outburst risk in Jinjia mine has been continuously monitoring for nearly 20 months.

3. Accurate location of the position of the disturbance source. Dynamic load disturbance and static stress concentration are two of the main factors in coal and gas outburst. Without mining disturbance, coal and gas outburst accidents will not occur. Therefore, dynamic monitoring of mining disturbance and its intensity is of great significance for monitoring and giving early warning of coal and gas outburst.

4. Ascertaining the area of stress concentration. As discussed in Section 3.4, the stress distribution in the coal seam obtained by seismic wave tomography technology is basically the same as the theoretical distribution.

One interesting thing about the term "spatial data mining" is that it is generally used to talk about finding useful and non-trivial patterns in data. In other words, just setting up a visual map of geographic data may not be considered spatial data mining by experts. The core goal of a spatial data mining project is to distinguish the information in order to build real, actionable patterns to present, excluding things like statistical coincidence, randomized spatial modeling or irrelevant results. One way analysts may do this is by combing through data looking for "same-object" or "object-equivalent" models to provide accurate comparisons of different geographic locations.

METHODOLOGY

The principle of MS monitoring and positioning technology is to arrange several seismic sensors around the monitoring area, then pick up the waveform produced by seismic activity and transmitted through the coal and rock mass.

According to the arrival time (t_i) of the seismic wave at each pickup sensor, the travel time residuals (Δt_i) of the waves can be calculated using the specific model

$$\Delta t_i = \frac{\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2}}{v} - (t_i - t_0)$$

where (x_i, y_i, z_i) is the 3D coordinate of the #i pickup sensor, (x_0, y_0, z_0, t_0) is the 3D coordinate and the arrival time of the vibration; v is the propagation velocity of shock waves in the rock mass.

The objective function based on Δt_i is presented below.

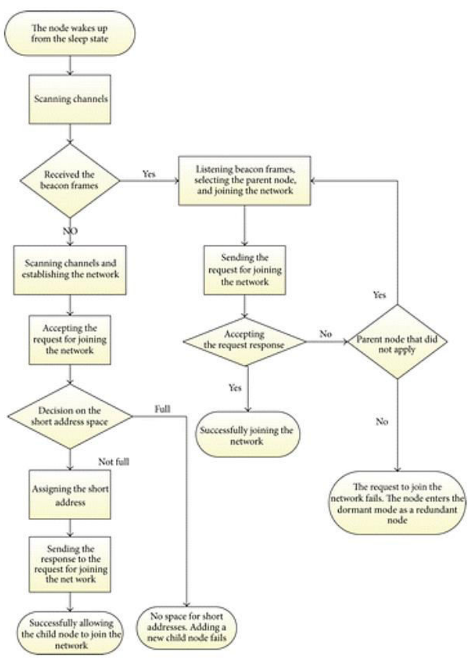
$$F(x_0, y_0, z_0, t_0) = \sum_{i=1}^{n} W_i \cdot |\Delta t_i|^p$$

$$V = L/T \quad L = VT$$

$$T_i = \int_{L_i} \frac{dL}{v(x, y, z)} = \int_{L_i} s(x, y, z) dL$$

$$T_i = \sum_{j=1}^{M} d_{ij} \cdot S_j (i = 1, \ldots, n)$$

FLOW CHART



Network process setup process.

Step1: Find available information for sensor devices from device description table. The STATUS field can equal 1, which means the device is available, or zero, which means the device is unavailable.

Step2: Extract the serial port COM_ID from the matched sensor devices, which indicates which serial port ID should be used for the sensor devices.

Step3: Judge whether the serial port COM_ID can be used, which can be determined based on the COM_ID from the serial port description table. If there are no matched items, or if there is a matched item but the STATUS field is equal to zero, which means this serial port is unavailable, then return an error message.

Step4: Extract the protocol information for the devices and extract the DEVICE_PROTOCOL from the matched device items.

Step5: Search the protocols from the protocol management module for the DEVICE_PROTOCOL protocol. If there is no matching protocol item, then return an error message.

Step6: Encapsulate the data packet based on the protocol specification.

Step7: Judge whether the serial port COM_ID is opened after the protocol data packet is encapsulated.

Step8: Open the serial port, and if the serial port COM_ID is not opened, then open this serial port.

Step9: Send the protocol data packets, and once the data channel is established when the serial port is opened, receive the data packet from the devices.

CONCLUSION

The Safety Monitoring System of Coal Mine based on Spatial Data Mining can provide relevant underground dynamically operating information, adopt different mining tools for information processing in order to provide good information for decision-making, and send the information to monitoring center through network. Spatial data mining provides intelligent management for space data processing and interpretation during the coal mine safety monitoring, and with the aim that the system excavates previously unknown, potentially useful knowledge from mass of data, in order to provide safety guarantee for coal mining.

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