An Automated Underground Space Monitoring and Communication System Based on Wireless Sensor Networks

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Abstract. In the challenging environment and Cutting-edge technology in mining industry, reliable and effective communication is a high-stake issue, along with the objectives of safe and efficient underground mining operations. Automation through remote and automatic systems has delivered improvements in workplace health and safety for employees, operational management, energy and cost-effectiveness, and real-time response to events. In this context, Wireless Sensor Networks (WSNs) have been widely employed in underground monitoring and communication systems for the purpose of environmental monitoring, the positioning of workers and equipment, operational monitoring and communication system. Considering the capabilities of WSNs, a ZigBee network is adopted in this study.

The aim of this study is to propose a reliable and effective monitoring and communication system in underground environments, using WSN nodes were developed to sense environmental attributes and texting emergency messages. A trigger action plan for monitored attributes above normal and threshold value limits is programmed in the surface GIS management server. The system will provide multi-users surface operation and 3D visualization for realistic understanding of underground environment and miners' conditions.

Keywords: Mine automation Safety Wireless Sensor Networks ZigBee GIS

1 Introduction

Underground excavation safety and health remain challenging issues in the mining industry. Death toll statistics in China's coal mines have gradually reduced from 5798 to 2631 between 2000 and 2009 [1] but fatality still occurs. The number of occupational mining fatalities in the United States' underground metal mines has fluctuated from 40 to 46 during the years 2001 to 2010. Most importantly, 33.8% of the deaths have resulted from ignitions and explosions of gas or dust [2] in underground mining. In April 2014, two men were killed when a wall collapsed in an underground coal mine in New South Wales, Australia. Figure 1 illustrates the death toll of underground mining in some countries such as USA, India and China between 2000 to 2013. It shows that the underground mining occupations remains one of the most dangerous activities. Human errors were concluded from reports as the most significant reasons for mining fatalities. Thus, safety is always a significant concern in mining and tunnels operation. Some studies have recently focused on improving the health for underground miners.

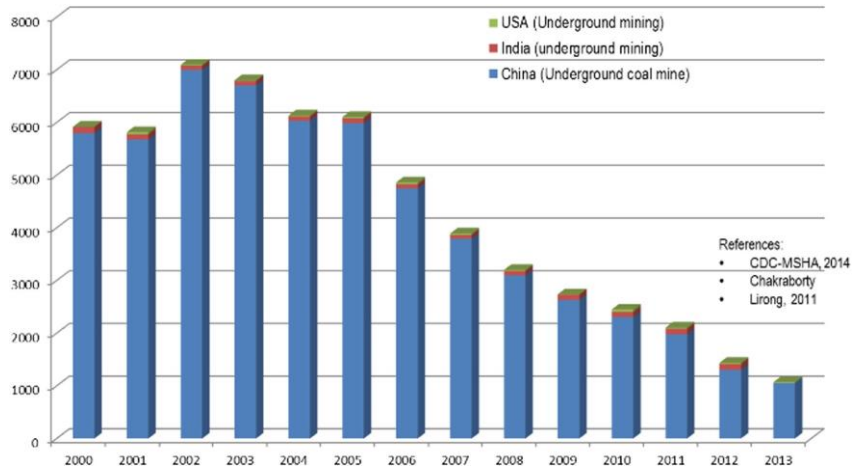

Fig. 1. Death toll of underground mining in some countries between 2000 to 2013

In this study underground safety and health concerns are significantly mitigated based on the system integration which incorporates ventilation management and emergency message texting. The applications of the ZigBee network for underground communication and monitoring is illustrated in Fig. 2. These applications considering sensor nodes' abilities are classified as follows:

(a) Safety and health approaches

- Air quality and quantity measurements
- The determination of workers' location
- Emergency and safety communications
- Gas detector and fire alarm
- Geotechnical monitoring

(b) Operations management and control

- Real-time monitoring underground mine operations from surface control centre
- Improving the underground operation cycles (scheduling)
- Traffic control (Signals) and Ventilation on Demand (VOD)

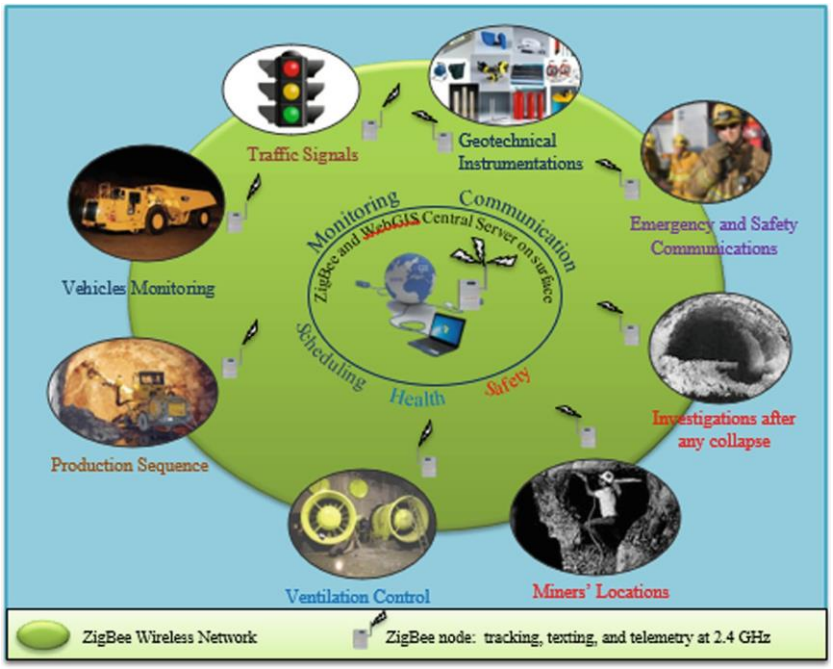

Fig. 2. Applications of WSNs for underground communication and monitoring

2 Underground WSN Data Management

In response to these challenges, mine automation by new technologies such as wireless sensor network (WSN) assisted with geographic information system (GIS) has been widely utilised in underground environments to enhance safety and health, productivity and reduce operational costs. GIS is new technology used for spatial data analysis in order to capture, store, analyze, manage, and present data that is linked to locations [3]. GIS allows users to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. Web-GIS is an inevitable trend which helps solve the problems of spatial information integration and sharing in technical aspect of web media [4]. The architecture of underground monitoring and communication for the system integration is illustrated in Fig. 3. Temporal ZigBee data including messages and environmental attribute readings such as temperature, humidity and gases

concentration are transferred to GIS management server in the surface control centre. The transmitted data is received and stored by ZigBee program then provided for manipulation in the control centre. Risk situations are immediately identified and responded through a logical process of data analysis in the GIS management server before reaching dangerous (unsafe) levels and accidents occurring. The ventilation system management is also used for the workplace health and safety compliance and the optimisation of mine site power usage.

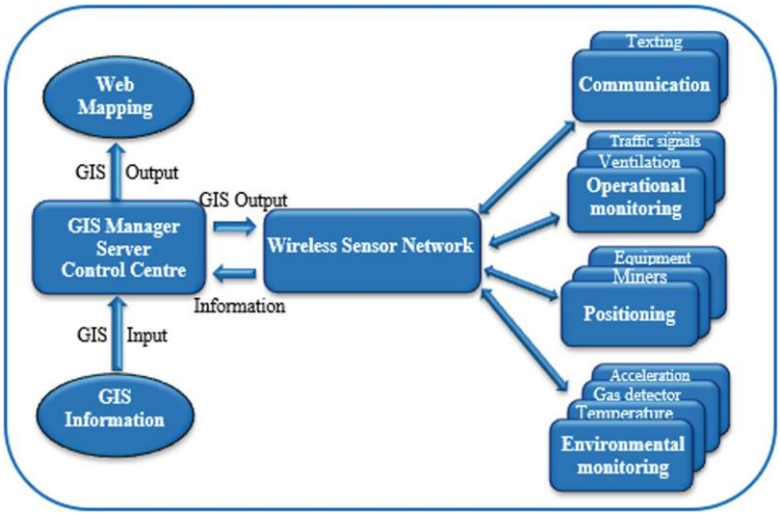

Fig. 3. Architecture of a WSN monitoring and communication system in underground mines

2.1 Data Management Server Using GIS

In the challenging environment and changing topology of a mine, reliable and simplified communication is a high-stake issue with the objectives of safe and efficient mining operations. In response to these challenges, integration of technologies has a significant role in underground mining automation. According to WSNs' specific features of high reliability and multi-hop networking, ZigBee can create an integrated wireless network between nodes in the underground mine tunnels and the surface gateway. In this study, ZigBee's capability of monitoring underground environmental attributes is combined with geographic information to provide potential applications in communication, operational and environmental monitoring systems of underground mining.

In order to achieve such smart underground mine system, integrating maps information and spatio-temporal data from ZigBee nodes into a database at a control centre is required [5]. Figure 4 illustrates flow chart of data processing in the integrated system.

The network demanded in an underground mine must be capable of providing bilateral communications between the surface control centre and all underground wireless nodes interactively. According to the threshold limit values for the different variable parameters (V1, V2, ..., Vn) of underground mine environment, the conditions of safe, transient and unsafe were set. Thus, the remote or automatic countermeasures in a GIS management server were arranged in order to control ventilation fans and send alert or alarm messages to relevant authorities. Additionally, immediate texting messages are bilaterally communicated between underground personnel and the surface operator in emergency conditions [6].

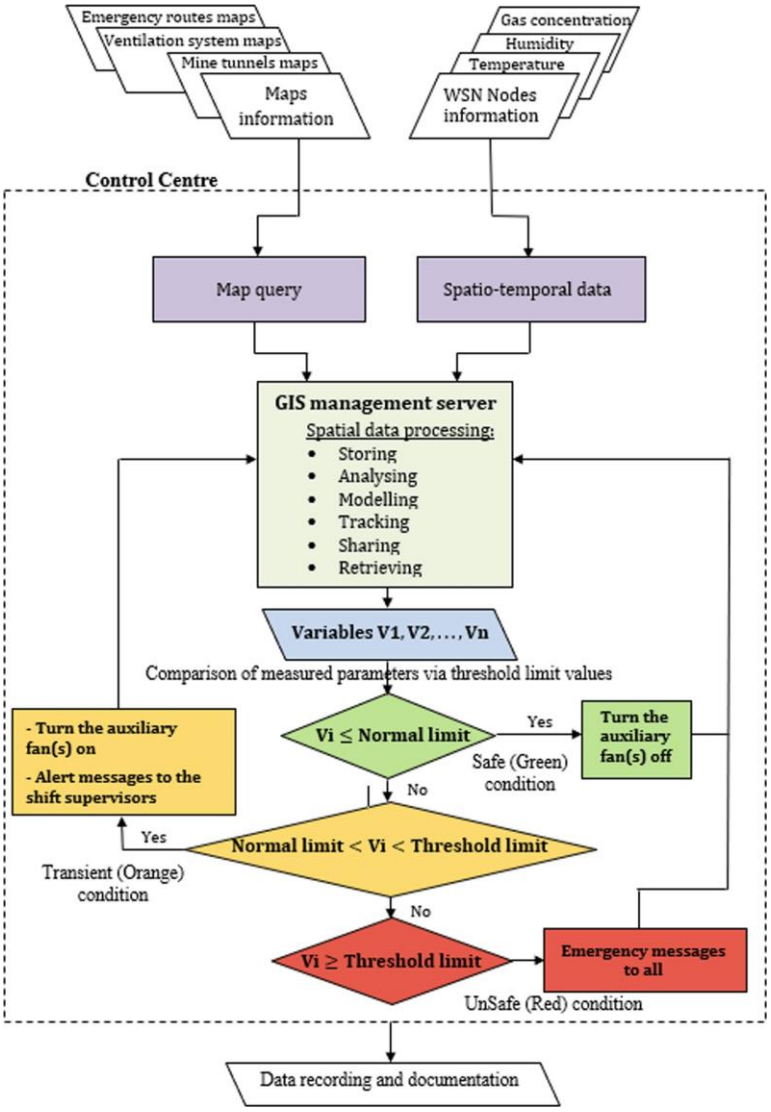

Fig. 4. Flow chart of data processing in the integrated system

Based on this system, near real-time monitoring data, remote and automatic controls, and communication by texting messages have achieved the required safety and health outcomes and improving underground mining operations.

2.2 System Outputs

Mine safety and health were improved by intelligent maps supporting spatio–temporal data and coordinate of ZigBee nodes in this experiment. The final outputs of GIS management server are comprised of 3D visualization monitoring of underground mine tunnels and messages texting for alert and alarm conditions. The web-GIS is another application supporting the GIS management server to promote the underground monitoring and communication system.

3 Prospects of Underground ZigBee Applications

The Prospect of proposed ZigBee communications system is illustrated in Fig. 5. This system enables for real-time communication between surface operators and underground miners and applications. In other words, it can join all sensors' data with different duties such as geotechnical instrument data, miners, trucks and other equipment locations, ventilation system control to minimise wastage of electrical energy caused by running vent fans at their

full capacity at all times, and traffic signal management from the surface. It will be an essential tool for underground mine automation to improve project management in an era of economic, operation, health and safety optimization.

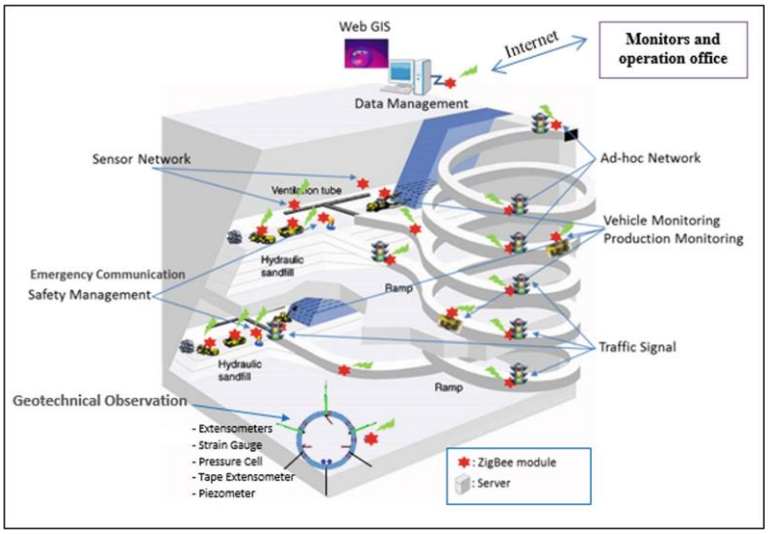

Fig. 5. Prospect of proposed automated underground mine monitoring and communication system based on WSNs

4 Conclusion

In this research it was shown that underground wireless networks could significantly improve the efficiency of environmental monitoring, workers and equipment locations, operational readings and communication system. In this research was shown that an integrated system based on the WSNs and GIS was introduced to automate underground mine monitoring and communication. The system is equipped with an automatic or remote trigger action plan for monitored attributes above normal and threshold value limits programmed in the surface GIS management server. The system also provides multi-users surface operation and 3D visualization for realistic understanding of underground environment and miners' conditions, and it could be a useful approach for high-tech underground mining.

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