Journal of Mines, Metals and Fuels, *70(9A) : 43-47; 2022. DOI: 10.18311/jmmf/2022/32248*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Design of Wireless Gas Monitoring Technology for Underground Coal Mines

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Abstract

The underground coal mines are well known for its hazardous environment where miners are supposed to work under the presence of many toxic and flammable gasses. The continuous monitoring of these gases is a major challenge for the safety of underground coal mining operation. Hence, continuous monitoring of the complex and hazardous underground mines environment is essential for ensuring safer coal production. In this regard, an attempt has been made to design a wireless sensor networks (WSNs) based gas monitoring system for underground coal mines. The developed gas monitoring system provides an aid in real time monitoring of different underground coal mines gasses. The developed WSNs based gas monitoring system is tested in the laboratory, under the controlled environmental conditions, for the measurement of carbon dioxide (CO_2), carbon monoxide (CO) and methane (CH_4) gases. The outcomes of this study help in introducing an innovation technique of gas measurements in underground coal mines so that its safety can be improved from preventive to predictive measure.

Keywords: *Underground coal mines, Wireless sensor networks, Methane, Carbon dioxide, Carbon monoxide*

1. Introduction

Underground coal mines are known for their difficult working conditions and hazardous working environment. There are several incidents happen in underground mines environment where severe accidents occurred that results of significant loss of properties and lives [1]. These incidents can be caused by a number of factors, including a rapid increase in toxicants like carbon monoxide (CO), hazardous combustible gases like methane (CH_4) or firedamp, and a lack of oxygen for miners to breathe [2]. The level of toxic gasses in mines generally increases due to the operation of heavy diesel operated machines whereas combustibles gasses are present in the coal seam and release during its excavation. The measurement of toxic and explosive gasses helps in improving the safety of miners and this makes an uninterrupted operation of underground mines. Thus, the developing technology and finding ways to make mines hazard-free is becoming very important for the efficient operation of underground coal mines. This is very necessary for coal mining industry's long-term growth and for the safety of miners. The introduction of innovative gas monitoring system helps in improving the safety of underground mines environment by shifting its safety features from preventive to predictive measures. There are few conventional gas monitoring methods namely flame safety lamp, multi-gas detector, hygrometer, kata-thermometer, air sampling and other

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methods which can be measured the underground mine environment condition [3]. But these methods are unable to provide the accurate information hazards prediction, further, there is always a risk of gas accumulation while working in underground coal mines.

Therefore, a proper continuous gas monitoring system is highly needed which can play a very crucial role in improving the safety of underground environment.

The introduction of wireless technology, for continuous gas monitoring of underground coal mines, is one of the innovative solutions that helps in improving the safety of miners and material while working in underground coal mines environment [4]. At present scenario, wireless sensor networks (WSNs) gained a significant attention in worldwide. The WSNs network establish a communication between transmitter and receiver port. A WSN consists of special feature sensors that record the physical conditions of the environment and forward the recorded data to the central node through wireless netwirk. In WSNs, sensors are distributed in an adhoc manner [5]. The adhoc network is a temporary type of local area network (LAN) that establishes a proper communication between sensors and central node without the use of an infrastructure device. This WSNs techniques provide an effective data collection with the optimum use of network resources [6].

Basically, in WSNs gas monitoring technique there are two types of nodes namely, sensor node and central node. The sensors nodes collect the information of environment and transmits to the central node where a proper decision can take place against the recorded data. In this technique any number of nodes can be increased or eliminated based on the requirement and no cables are involve in this method which makes it an easy installation to incorporate in the underground mine's atmosphere. Due to the computing ability and data storage capacity with fusion sensor node makes a suitable choice for the remote monitoring system. Therefore, the introduction of wireless sensor network for measuring the underground mines gasses can be considered an ideal choice that improve the safety operation by shifting towards the predictive measures. This paper provides an outline of designing a wireless gas monitoring technique for the underground coal mines and it consists of six different sections. The literature review and designing system are presented in second and third section of the paper. The fourth section includes the results and discussion which is follow by the conclusions in the fifth sections. This paper presents the design of the wireless gas monitoring system that explained the required hardware and software for the developments of wireless system. Thereafter, under the laboratory condition the developed model is tested so that the accuracy of the wireless system can be assessed.

2. Literature Review on Monitoring Technology

Many literatures are studied in order to understand the role of sensor and wireless technology in remote monitoring system. The literature includes the adequate information regarding sensor and sensing method used in various monitoring systems. The advancements in communication and tracking systems for underground mines can be efficient way to improve the safety precautions of the hazardous environment. In one study usage of oxygen sensors were explained in a variety of applications that have different performance characteristics. The ideal operation of a sensor is defined by three parameters namely sensitivity, selectivity, and reaction time [7]. A heart pulse sensor can be used to create a smart framework for a human heartbeat rate tracking device base on the internet of things. The heart pulse sensor, which is made up of components mounted on a breadboard and enclosed in a plastic shell, is worn on the user's fingertip [8]. Another work carried out in improving the gas sensor technology by looking at sensing components, signal processing, and pattern recognition methods. This study claims that, along with non-linearities and high sensitivity to humidity, drift correction is the most significant problem in the production of gas sensors [9]. In [10] the heart rate monitoring device was built and the pulse oximeter was used to detect the heartbeat by fingers. The reasoning that when the heart extends and contracts, the amount of blood within the fingertip changes and the amount of blood pulse in a fingertip is equal to the heart rate. One more study conducted a work on oxygen sensor research status progress and referred that by adjusting the air fuel ratio the combustion mechanism in an automotive engine can be controlled for an oxygen sensor [11]. One more work showed the tracking distance motion with ultrasonic sensors that are widely used as sample along with reliable presence trigger for alarms and automatic lighting systems. In this sensor, people position can be tracked in the environment and it would be one of the key sensors that can be used in underground mines for tracking the miners during roof fall accidents [12]. Still many research works is in progress to improve the applicability of sensor in monitoring areas. Underground coal mines are one of the areas where the application of gas sensor monitoring helps in enhancing the gas measurements techniques so as to improve the safety of miners.

3. Design of Wireless Gas Monitoring System

The system architecture of the monitoring system consists of five main units namely, sensors, microcontroller, transmitting, Zigbee interfacing and monitoring unit. The sensors units mainly consist of three types such as MQ4, MQ7 and MQ135 for analysing methane, carbon monoxide and carbon dioxide gases, respectively. The sensors unit is directly connected to the microcontroller (Arduino), which starts the operation of the sensor and receives the information about sensed gasses. The sensed gasses are converted into digital form and transmitted to the Zigbee interfacing device through wireless router Xbee Pro S2B. Thereafter the Zigbee interfacing board is transferred the recorded values of gasses to the monitoring points where it can be stored for future analysis. The complete block diagram of the wireless gas monitoring system is shown in Fig. 1. The gas sensing unit is a very important unit that is connected to Arduino where the threshold limit of gasses can be adjusted so that in the event of any abnormal conditions a preventive measure takes place. The flow chart of gas sensing unit is presented in Fig. 2.

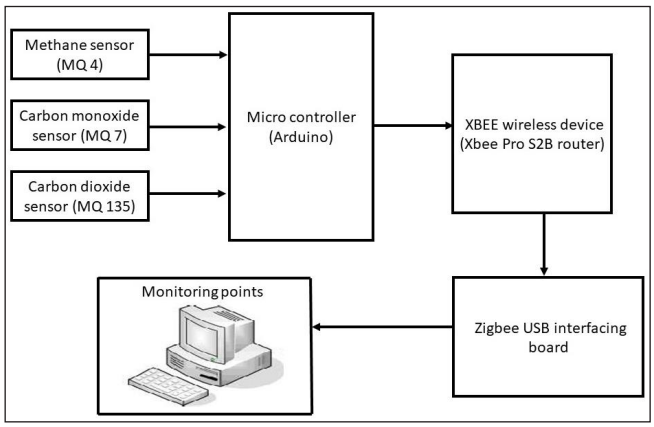

Fig. 1: Block diagram of wireless gas monitoring technique

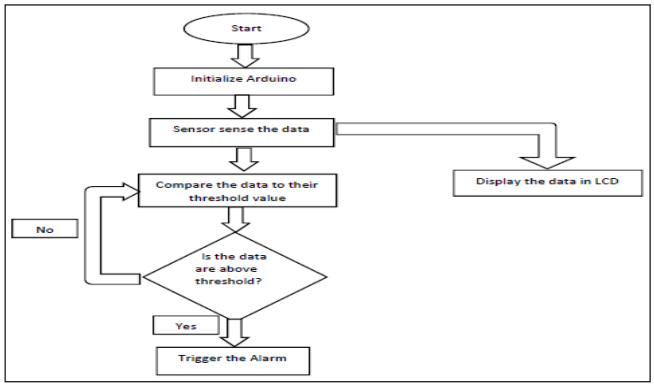

Fig. 2: Flowchart of sensor unit in WSNs gas monitoring

The hardware implementation of wireless gas monitoring system is performed on the prototype scale in the laboratory and its performance is measured under the laboratory environment. A breadboard is used to complete the electrical circuit diagram of whole monitoring system. The analog pins of the Arduino are connected to the sensor through breadboard and for the power supply VCC and GND pins of Arduino are used. The sensors transfer the data to the Arduino, which pass the data to the wireless router to transmit the recorded data to the monitoring points. The sensor senses the level of gasses and if it found above the threshold limit then it gives the trigger alarm signal through Arduino (where a proper programme is already set for this operation) and the same can be visualised on the display unit. The complete pictorial view of the WSNs gas monitoring system is shown in Fig. 3.

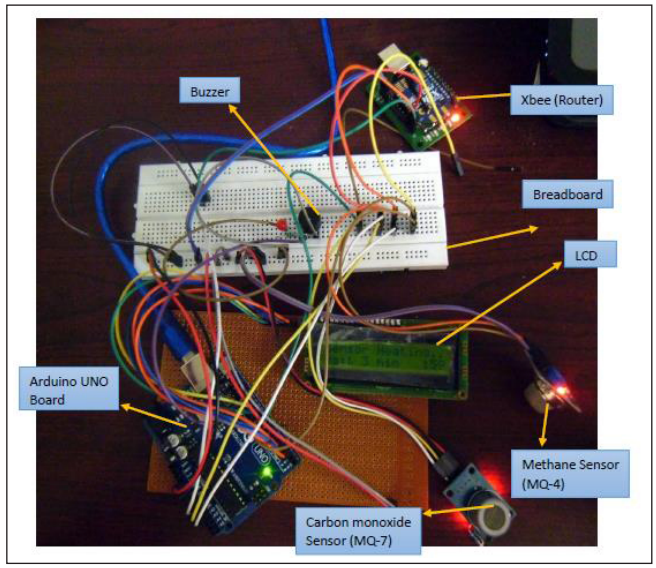

Fig. 3: Photographic view of wireless gas monitoring system

4. Results and Discussion

The developed wireless gas monitoring system is tested under laboratory conditions. The developed system is tested for the measurement of three different gasses such as methane, carbon monoxide and carbon dioxide. The developed gas monitoring system is tested in a laboratory, in a closed chamber, under the controlled environmental conditions where temperature and humidity are considered to be constant. As stated earlier, MQ4, MQ7, MQ135 sensors were used for detection of methane, carbon monoxide and carbon dioxide gases. The measurements of gasses are carried out in the laboratory during the February month of 2021. For methane gas, readily available liquid

petroleum gas (LPG) is utilised and diesel engines was used to generate carbon monoxide and carbon dioxide gases. The measured values of gasses are presented in Tables 1 and 2. As depicted in Table 2 the level of carbon dioxide increases as the level of carbon monoxide reduces and this is mainly due to the complete combustion in the operation of diesel engine. The concentration of above said gases were also measured using digital multi gas detector (Model: MSA ALTAIR 4XR). The readings obtained by the gas monitoring system and multi gas detector are presented in Tables 1 to 3, for their comparison.

Table 1. Measured values of methane gas by WSNs system

	Date	Time	As obtained by WSNs gas monitoring (PPM)	As obtained by multi gas detector (PPM)
1	2021-02-13	13:01:10	196	190
2	2021-02-13	13:02:04	203	205
3	2021-02-13	13:02:57	199	201
5	2021-02-13	13:03:49	197	190
5	2021-02-13	13:04:45	212	220
6	2021-02-13	13:05:43	207	211
7	2021-02-13	13:45:58	193	185
8	2021-02-13	13:48:01	213	220
9	2021-02-13	13:49:08	190	185
10	2021-02-13	13:50:03	190	180

Table 2. Measured values of carbon monoxide gas by WSNs system

	Date	Time	As obtained by WSNs gas monitoring (PPM)	As obtained by multi gas detector (PPM)
1	2021-02-13	14:01:28	350	345
2	2021-02-13	14:02:15	368	355
3	2021-02-13	14:02:57	315	305
5	2021-02-13	14:03:49	374	385
5	2021-02-13	14:04:25	117	120
6	2021-02-13	14:05:20	112	105
7	2021-02-13	14:50:15	106	110
8	2021-02-13	14:41:45	103	110

Table 3. Measured values of carbon dioxide gas by WSNs system

	Date	Time	As obtained by WSNs gas monitoring (PPM)	As obtained by multi gas detector (PPM)
1	2021-02-13	14:01:28	102	95
2	2021-02-13	14:02:15	105	110
3	2021-02-13	14:02:57	107	105
5	2021-02-13	14:03:49	110	110
5	2021-02-13	14:04:25	112	115
6	2021-02-13	14:05:20	118	120
7	2021-02-13	14:50:15	117	115
8	2021-02-13	14:41:45	121	120

5. Conclusions

The safety of man, material and machine are greatly affected by the environmental conditions of underground coal mines. Therefore, a continuous gas monitoring of underground coal mines environment is essential for ensuring the safety of miners and mining operations. At the present time, wireless sensor networks (WSNs) technique are widely used for monitoring of workplace environment and having a tremendous potential for assessing the other aspects of underground coal mines so that a safe environment can be maintained throughout the working period. This paper presents an attempt for designing the wireless based gas monitoring techniques for measuring the underground coal mines gasses. The developed model is tested in the laboratory for the measurement of three main hazardous mines gasses namely, methane, carbon monoxide and carbon dioxide. The measurement shows the maximum value of 212 ppm of methane concentration in the laboratory and 374 ppm of highest carbon monoxide. The highest value of 121 ppm of carbon dioxide was obtained by the developed WSNs gas monitoring system. During the experimental study, the measured gasses by WSNs gas monitoring system is well compared to the multi-gas detector, under the same controlled environmental conditions. The compared values showed a very minute deviation between two different measurement technique.

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