Smart Helmet for Coal Mines Safety Monitoring and Alerting

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Abstract: Industrial safety is one of the main aspects of industry specially coal mine industry. Underground mining hazards include suffocation, gas poisoning, object fall, roof collapse and gas explosion. So air quality and hazardous event detection is very important factor in mining industry. This system provides a wireless sensor network for monitoring real time situation of underground mines from base station. It provides real time monitoring of harmful gases like CO, CH4 and LPG and also temperature. The main reason for death of miners is that, due to any reason miners falls down and loses consciousness also proper treatment is not provided them at that time. To overcome this problem the system provide emergency alert to the supervisor if person fall down by any reason. Some workers are not aware for safety and they are not wear helmet. A Limit switch was then used to successfully determine whether a miner has removed his helmet or not. The system uses Zigbee technology for transmission of data from underground mine to base station. There is alert switch at mines and base station for emergency purpose.

Keywords: Zigbee; helmet removal; real time monitoring; coal mine safety; air quality; person fall detection.

I. INTRODUCTION

Mining is the extraction of valuable minerals like solid, liquid and gas from the earth. The mining continue to supply all the basic resources like oil and gas used by modern civilization. The materials recovered by mining include aluminium, copper, lead, Zink, gold, silver, diamond, metal, coal etc. The large amount of coal required for electricity generation. Globally, coal resources have been estimated at over 861 billion tonne. While India accounts for 286 billion tonne of coal resources (as on 31 March 2011), other countries with major chunk of resources are USA, China, Australia, Indonesia, South Africa and Mozambique [1]. Coal meets around 30.3% of the global primary energy needs and generates 42% of the world's electricity [1]. India is the third largest coal producing country after China and USA. Coal is a prime source of energy in India. Coal is the key contributor to the Indian energy scenario 51% of the current total commercial energy needs is made by coal.

There are mainly two methods for extracting the coal from earth- surface mine and underground mine. Most of surface mines are open pit or open cast mine. The surface mine are entirely open and operated from the surface of the earth. The advantages of surface mines are high productivity, low operating cost and good safety condition. Most of the coal is extracted using surface method. In case coal is very deep from surface underground method is used. The underground mines are supported or unsupported mines. In supported method used artificial pillars for support of the opening. Supported mining methods are often used in mines with weak rock structure. The artificial supports are does not available for unsupported mining method. Unsupported methods are used in those areas where strong rock structure available. Underground coal mining involves a higher risk than surface mining due to the problems of ventilation and potential for collapse. The maximum accident occurs in underground mines.

In mining industry worker safety is very important issue. Every year, thousands of miners die in accidents and many more get injured, especially in the processes of coal mining and hard rock mining. The main reasons of accidents are gas or dust explosions, gas intoxications, improper use of explosives, electrical burn, fires, collapsing of mine structures, rock falls from roofs and side walls, flooding, workers stumbling/slipping/falling, or errors from malfunctioning or improperly used mining equipment. In coal mine use of personal protective equipment like helmet, shoes etc. are not proper and proper arrangements were not there to check if the person is wearing personal protective equipment or not [2]. The proper supervision for worker wear the protective equipment is very important factor for consideration. Underground mines are very dark so any miners are fall unconscious because of suffocation or falling of structure, supervisor don't known about her health condition and proper treatment is not provided her in time. The main reason for miner death is harmful gases explosions. In coal mines carbon monoxide, methane, LPG gases are existing and they are very harmful for human body.

The proper supervision and proper communication is very important requirement of mining industry. The smart helmet provides a real time monitoring of harmful gases, person fall detection and miner wear the helmet or not. The harmful

gases like carbon monoxide, LPG, Methane and also temperature are monitor using this system. The wired communication network is not so effective because when natural calamity or a roof fall occurred, wired network is damages, so it is very difficult and costly to reinstall the entire system. In wired network technology installation and maintenance cost is very high. The effective solution for communication from base station to underground mine is Zigbee wireless network. In Zigbee technology mesh topology provide a long distance wireless communication network.

II. A RELATED WORK

Yongping Wu and Guo Feng implement coal mine monitoring using the Bluetooth wireless transmission system. As a standard of unified global short-range wireless communication, Bluetooth technology is to establish a common low-power, low-cost wireless air interface and controlling software opening system [3]. At the same time, the system uses CAN bus technology maturely, has realized the combination of wired and wireless data transmission system. The main difficulty of this system is that the Bluetooth is short distance wireless technology and use of cabling is difficult. When a natural calamity or a roof fall occurred, the cabling is damage. So the reliability and long life of conventional communication system is poor. Due to the harsh environment inside the mine, the installation and maintenance of the wired communication is very difficult. Jingjiang Song, Yingli Zhu proposed automatic monitoring system for coal mine safety based on wireless sensor network. The sensor groups of the system intensively monitor temperature, humidity and other parameters in the underground mine, parameters measured are sent to wireless communication module by the micro-controller. The collected information is sent to long-distance monitoring centre by cable [4]. The problem of this implementation is that hardware is placed inside the coal mines, when a natural calamity or a roof fall occurred, the system is damage. So the reliability and long life of conventional communication system is poor. The another problem is that the working condition of coal mine is very noisy and if the distance of miner and system is long, miner not get proper message. Pranjal Hazarika presents implementation of safety helmet for coal mine workers. This helmet is equipped with methane and carbon monoxide gas sensor. This sensor sense the gas and the data is transmitted to the control room wirelessly, through a wireless module called Zigbee connected with the helmet [5]. This system does not detecting fall down of the person and whether the miner's wear the helmet or not.

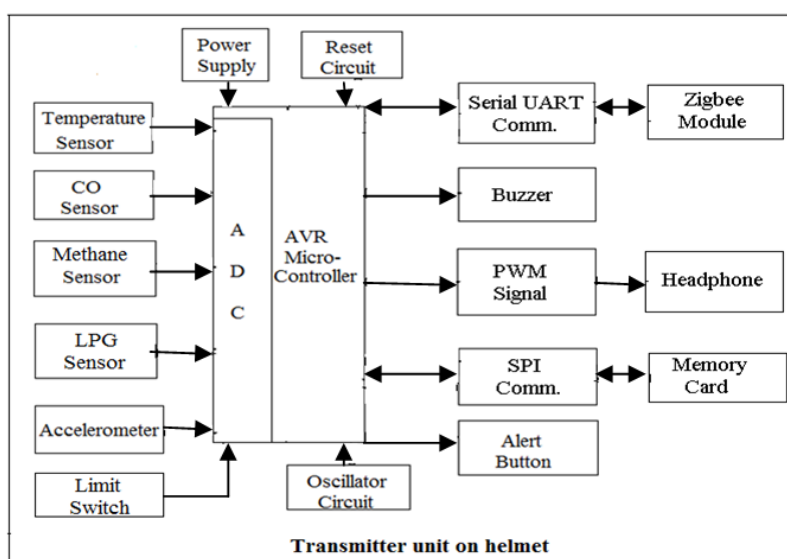## III. PROPOSED SYSTEM

A. Block diagram of proposed system:

Fig.1 Block diagram of Transmitter unit on helmet

Fig 1 shows the block diagram of transmitter side placed on miner helmet. The system provides real time monitoring of mines from base station. The transmitter unit is placed on helmet of worker and receiver unit placed on the base station. The Zigbee wireless technology is used for data transmission from coal mines to the base station. The Zigbee communication network provide two way communication means from base station to mines and from mines to base station. The transmitter unit consists of air quality sensor, helmet removal sensor and person fall detection sensor. The air quality sensors monitor the level of harmful gases like LPG, Methane, Carbon monoxide and also temperature.
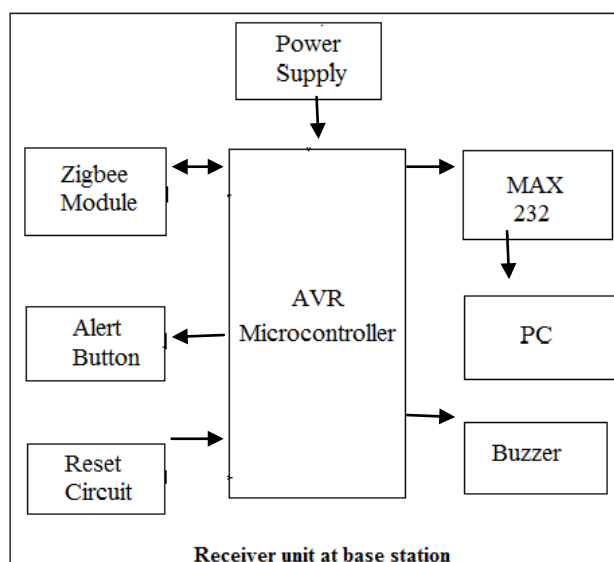
Fig. 2 Block diagram of receiver unit at base station

The MQ4, MQ5, MQ7 are used to monitor the level of Methane, LPG, CO resp. and LM35 is used for monitoring temperature. These are semiconductor type sensor. The sensor sense the particular level of gases and transmitted real time data to the controller, the controller receive the data processing on it and transmitted to the base station using Zigbee. At the same time if gases level is increases above threshold, alert voice message is provided to the worker using headphone.

The limit switch is used for detection of helmet removal condition. The limit switch placed inside the helmet. If helmet is wear, the switch is pressed and this data is transmitted to the base station using Zigbee. If helmet is removed, the switch is not pressed and then buzzer is ON, at the same time this data is transmitted to the base station. At the base station message of worker wear her helmet or not is display on PC.

The accelerometer is used for detection of worker fall down. The accelerometer sensor placed on the centre of worker helmet. If any object or sides are fall on the worker and worker are fall down or get unconscious, the accelerometer sensor detect the angle of helmet and ground and send to the base station. If angle exceed its threshold level the flashing light is ON. The flashing light is placed on helmet for detection of worker fall down. Same condition is applicable for miner get unconscious and fall down because of suffocation. Underground mines are very dark so if any miner fall down or get unconscious, other worker or supervisor doesn't know her health condition and her location so flashing light is use for find the miner location and alert other worker. There is alert button at transmitter side for emergency purpose. Any emergency arrive in mines the worker can press the button and transmits the emergency message to the base station.

At the transmitter side alerting devices like flashing light, buzzer and headphone are used for alerting to the worker. The flashing light used for detection of person fall down, buzzer is used for detection of helmet is removed and headphone for level of gases exceeds above threshold. The real time data of gases are transmitted to the controller, the controller processing on given data and if gases level exceeds its threshold value controller retrieve the data from memory card and voice message are listen in worker hear through headphone.

Fig 2. Shows receiver block diagram. All real time data are received from helmet to the base station through Zigbee and display on PC. At the receiver side buzzer is used for abnormal condition. The buzzer is ON when gas sensor exceeds above threshold or miner removed her helmet or person fall down. This system provides an alert button at base station so that control room can directly convey the emergency message to the miners.

B. Hardware component:

1. Person Fall Detection (ADXL 335)
The ADXL 335 is MEMS (micro electro mechanical system) based accelerometer, used for tilt sensing. It is a 3-axis (X, Y, Z axis) sensing device. It has low power requirement, excellent temperature stability and bandwidth adjustment capability.

It is applicable in -40^0c to 85^0c temperature range and 10000g shock survival. The output of ADXL 335 is in analog form. It is very small in size and low weight. The accelerometer can measure the static acceleration of gravity in tilt-sensing applications as well as dynamic acceleration resulting from motion, shock, or vibration. ADXL 335 accelerometer contains micro machined three axis sensor along with signal conditioning circuit. The sensor is made up of spring loaded, macro machine structure, mounted on silicon base [6]. The ADXL 335 have inbuilt amplifier and demodulator. The strength of demodulator output is increases using output amplifier and get three axis output at output pins X_{OUT}, Y_{OUT}, and Z_{OUT}. The approximate sensitivity of each axis depends on the type of accelerometer.

2. Air Quality Sensor (MOS Sensor):
There are main three types of gas detector sensor: Biometric sensor, electrochemical sensor and metal oxide semiconductor (MOS) sensor. The metal oxide semiconductor sensor is better because of its advantages of reliability, quick response, low power and long life span. The semiconductor sensor consists of metal oxide and heating element. The type of metal oxide being used depends on the detection of target gas.

The metal oxide sensor material (typically SnO_2) is heated at high temperature at 400^0C, free electron flow through the conjoined part of thin dioxide crystal. In clean air, oxygen is absorbed on the metal oxide surface, absorbed oxygen attracts free electron inside the metal oxide and forming the potential barrier. This potential barrier prevents electrons flow and increases sensor resistance in clean air. In the presence of combustible gas or reducing gas like as carbon monoxide, oxidation reaction of such gas and oxygen occur at the surface of tin dioxide. As a result, the density of absorbed oxygen decreases, width of potential barrier is reduces and sensor resistance is decreases so electrons easily flow through the potential barrier. In MOS type sensor gas concentration in air can be detected by measuring the changes of resistance.

The air pollution from coal mines is mainly due to emission of particulate matter and gases like carbon monoxide, LPG and methane. The CO is produced by incomplete combustion of natural gas, coal etc. These gases are very harmful for human bodies. The MQ4, MQ5, MQ7 are used to monitor the level of Methane, LPG, CO resp. These are semiconductor type gas sensor. When threshold level of particular gas increases, the voice message alert to worker using headphone.

3. Helmet Removal Detection (Limit switch):
The limit switch is used for detection of miner remove the helmet or not. The removal of helmet is also detected by using IR sensor. The IR Sensor sends infra red light through IR-LEDs, which is then reflected by any object in front of the sensor[7]. To use another IR-LED, to detect the IR light that was emitted from another led of the exact same type, but the infra red light is harmful for human and large amount of false alarm. So the limit switch is better.

The limit switch is small in size, low weight and low cost device. It is very precise in terms of accuracy and repeatability. It Consume little electrical energy. When object come into contact with a actuator, the device operates the contacts to make or break an electrical connection. It can determine the presence and absence of an object. If switch is pressed, miner wears the helmet and this data transmitted to the base station. If switch was not press, miner removes her helmet and buzzer is ON, at same time data is transmitted to the base station.

4. Wireless transmission device (Zigbee):
Zigbee is used for transmission of data from coal mine to base station. Comparing to Bluetooth and Wi-Fi Zigbee is better because Zigbee signal penetrate wall and work very well in mines. Zigbee module is more useful for creating large network than Bluetooth. Wi-Fi need cabling throughout the mines to routers, cabling is not effective in mines. The major advantage of Zigbee over Bluetooth and Wi-Fi is its support up to 6500 nodes in network and support multi hopping technique. Zigbee device can transmit data over long distance by passing data through a mesh network of intermediate devices to reach more distance ones. It was not required infrastructure network. It requires low cost, low maintenance and low power. Zigbee has low data rate i.e. 250Kbps operating on 2.4GHz ISM band.

5. AVR Microcontroller (Atmega328):
Atmega is subfamily of AVR Microcontroller. AVR microcontroller is selected because their fast responses speed. AVR reach 20MIPS at 20MHz clock where PIC16FS only reach 5MIPS at 20 MHz due to 4 clock instruction architecture. AVR is better in terms because of processing power.

The Atmega328 chip has an inbuilt ADC. It convert analog signal to digital value, with Vref value being a reference for which digital values are low or high. Atmega328 has 28 pins. It has 14 digital I/O pins, of which 6 can be used as PWM output, 6 analog input pins and 2 for crystal oscillator.
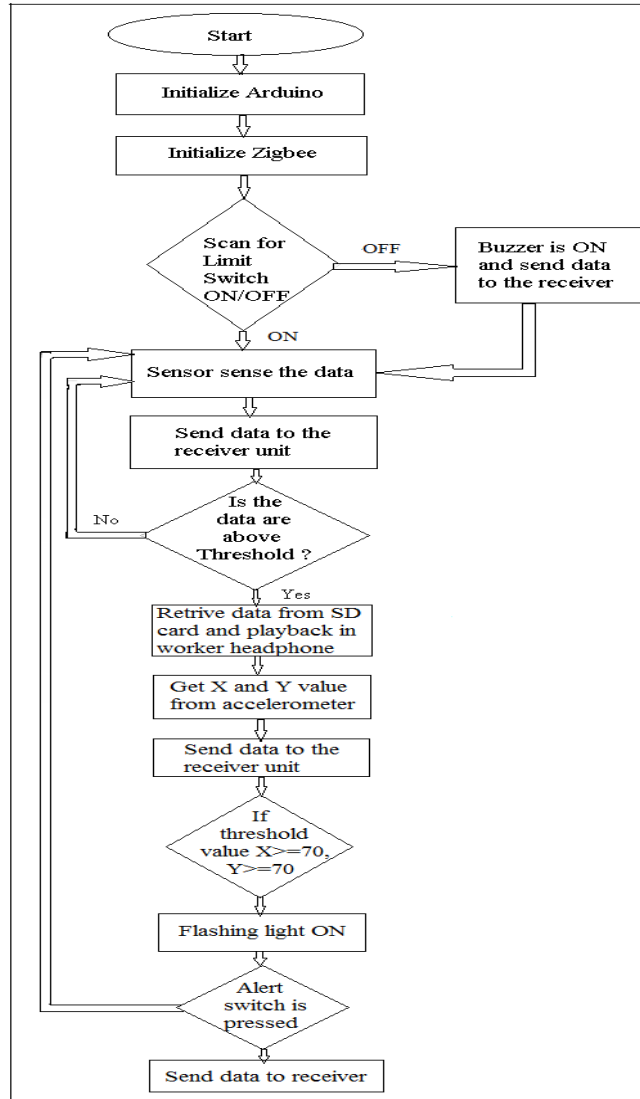
C. Flowchart:

Fig. 3 Flowchart of proposed system
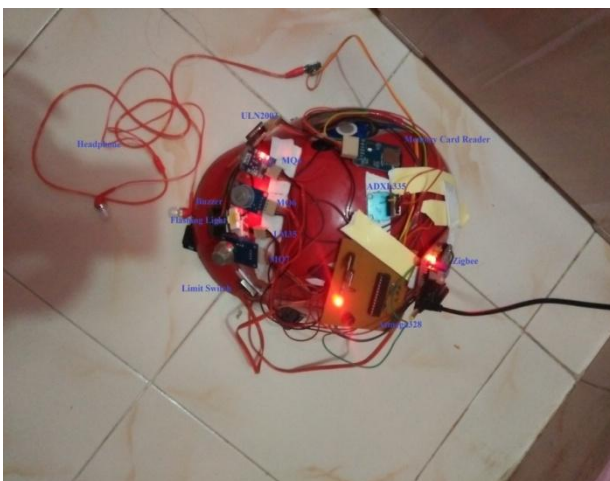
IV. EXPERIMENTAL RESULT

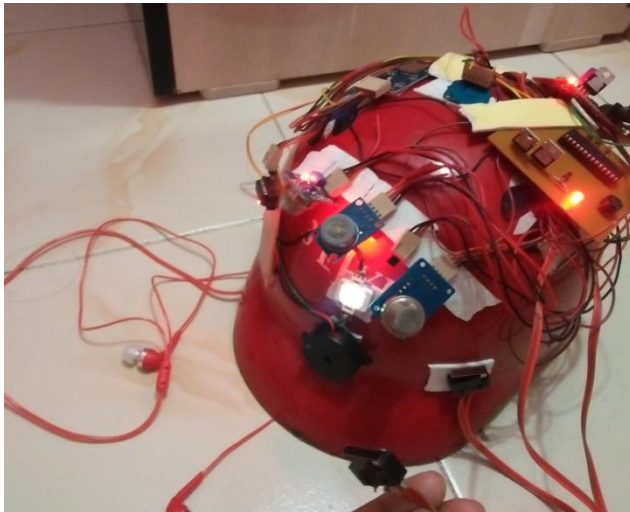Fig 4. Experimental setup of helmet   Fig 5. Person fall detection test (angle is $<70^0$)

Fig 6. Helmet removal test (switch is not press)

Fig 7. Experimental setup at base station

1. Air Quality Test:

In air quality testing process, concentration level of Carbon Monoxide, LPG, and Methane are measured. The threshold level of CO, LPG and CH4 are set as 400PPM, 1000PPM and 1000PPM respectively, if gases crosses this limit these are harmful for human. The MQ4, MQ5 and MQ7 sensor sense the CH4, LPG and CO respectively, if gases exceed its threshold limit the system alert to the miner by using headphone then this same data transmitted through zigbee to the base station. When concentration level of particular gases exceeds its threshold, the controller retrieves the data from memory card and send to the headphone.

If CO gas level increases miner hear the voice message in headphone "High Carbon Monoxide is detected".
If LPG gas level increases miner hear the voice message in headphone "High LPG is detected"
If Methane gas level increases miner hear the voice message in headphone "High Methane is detected"

2. Person Fall Detection Test:

For finding person fall down situation, we need angle in X, Y and Z with respect to ground. These angle are given by

$$\theta_x = \frac{A_x}{\sqrt{A_y^2 + A_z^2}}$$

$$\theta_y = \frac{A_y}{\sqrt{A_x^2 + A_z^2}}$$

$$\theta_z = \frac{A_z}{\sqrt{A_x^2 + A_y^2}}$$

Where Ax, Ay and Az are acceleration in X, Y and Z direction resp. Here we use only X and Y axis.
The accelerometer is placed on the center of the helmet. If angle of helmet to ground exceed 70^0 right, left, front and back, the flashing light is ON at helmet side. The flashing light is placed on helmet; the flashing light is indicating to other miner some miner is fall down. The real time data of X and Y axis are send to the base station using Zigbee.

3. Helmet Removal Test:

Limit switch is placed inside the helmet. If switch press, helmet is wear, buzzer is OFF and same data transmitted to the base station. The message "Helmet is not removed" display on PC at base station. If switch is not press, helmet is removed, buzzer is ON and same data transmitted to the base station. The message "Helmet is removed" display on PC at base station.

4. Wireless Data Transmission Test:

The Zigbee trance receiver placed at miner helmet and base station. The real time data are sending through Zigbee. We use one master and one slave, so the data transmission distance is 9 to 10m. If we use number of slave and form a mesh networking distance of data transmission is increases.

Fig. 4 Real time output on computer monitor at receiver side

V. CONCLUSION AND FUTURE WORK

A real time monitoring system is developed to provide clearer and more point to point perspective of the underground mine. This system is displaying the parameters on the base station PC and alerting miner if harmful gases like LPG, CO, CH4 exceed its limit, person fall detection and removal of helmet. It will be helpful to all miners present inside the mine to save their life before any casualty occurs. In future using additional sensors all possible safety issues could be monitored such as dust, vibration, water leakage etc. Also we can use number of salve and improve the data transmission distance.

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