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IMPROVING MINE SAFETY MONITORING & ALERTING SYSTEM BASED ON ZIGBEE

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ABSTRACT
Today, safety of miners is a major challenge. Miner's health and life is vulnerable to several critical issues, which includes not only the working environment, but also the after effect of it. To increase the productivity and reduce the cost of mining along with consideration of the safety of workers, an innovative approach is required. Coal mine safety monitoring system based on wireless sensor network can timely and accurately reflect dynamic situation of staff in the underground regions to ground computer system and mobile unit. The air pollution from coal mines is mainly due to emissions of particulate matter and gases include sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) etc. To monitor the concentration level of harmful gases, semiconductor gas sensors are used. Due to any reason miner's falls down and lose consciousness also proper treatment is not provided them at that time, so number of miners are died. 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 wearing helmet. A Limit switch was then used to successfully determine whether a miner has removed his helmet or not. This system also provides an early warning, which will be helpful to all miners present inside the mine to save their life before any casualty occurs. The system uses Zigbee technology and GSM for transmission of data. There is alert switch at receiver and transmitter side for emergency purpose.

Key Words: Zigbee, GSM, WSN, Miner Safety, Alert Switch, Coal Mine Safety, Monitoring System

1. INTRODUCTION

An accident that occurs while mining minerals or metals is known as a mining accident. Each year, tens of thousands of miners die in mining accidents, most of which occur in underground coal mining, while accidents also happen in mining. Due to rock strata that are plain, typically incompetent rock, presence of CH_4 gas, and coal powder, Coal mining is considered significantly more dangerous than hard rock mining. Most deaths nowadays occur in underdeveloped nations and rural areas of wealthy countries when safety precautions are not properly implemented [2]. As a result, it is critical to maintaining track of circumstances that might contribute to an accident to protect human safety. This project introduces a device used to keep track of the conditions within a coal mine, which might pose a threat to human life. The sensors and Zigbee are employed for monitoring in this system. This system also incorporates a smart helmet with a panic button that each worker may activate individually. All sensors are linked to specific applications and send an alert signal when it exceeds a particular value. The alarm message is sent to the control room to take the necessary action quickly. If coal mine accidents are not adequately controlled, it may result in massive human fatalities. A monitoring system has been built to record the readings of dangerous gases and risky working conditions. The information gathered is subsequently forwarded to professionals for analysis and action. Over the years, it has been observed that coal mine contributes significantly to the country's rapid economic and social development. Scholars from around the world have undertaken substantial research to improve the degree of safety. Coal mines are an essential source of energy for human growth. Mining failures may be exploited to increase security in the industry. Industrial series of failures or flaws are typically the cause of an accident. There are a number of practical measures available. Initiatives involving mines, such as the construction of safety lamps, can significantly impact.

Law and creating a self-contained coal mine safety monitoring system are both in the works. The trajectory of China coal mine accidents over the last ten years were investigated, and the human

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elements involved in these accidents were investigated using multi-dimensional statistical analysis. The number of significant coal mine accidents and the number of people killed were constantly reducing, but occasional death accidents still accounted for most deaths. Human factors accounted for 94.09 percent of the causes of these incidents, with the willful violation, mismanagement, and flawed design accounting for 35.43 percent, 55.12 percent, and 3.54 percent, respectively. A round penetrating synthetic pulse radar device to probe through a coal pillar in search of hidden structures or abnormalities was employed. To produce a velocity picture of the inside of the pillar, direct matrix inversion was performed. The reconstructed picture revealed the presence and position of a substance with a low velocity. A clay vein in the cores corresponded to the low-velocity material shown in the tomogram [4]. Technology alone will not be adequate to address the difficulties for a substantial number of individuals. The research was conducted for safety monitoring of mine roof integrity and dangerous gases in coal mines, fiber optic sensors have been developed and implemented. The inherent safety, multi-location, and multi-parameter monitoring features of the FOS-based mine danger detection system are unmatched. They might be utilized to create expert systems for the early identification and prevention of mining hazards [6]. Underground mines are prone to serious safety incidents. The development of safe mining technologies is critical. This problem can be solved with smart mining. One of the most important components in smart mining is the unmanned electric locomotive [7]. The rest of the paper is organized as follows: In section2 methodology of the proposed system has been explained. In section 3, a brief description of the system is given. Section 4 comprises of working of the monitoring system and smart helmet. Output result analysis and discussion have been specified in section 5, and the end section tells us about conclusions and the future scope of the project.

2. CASE STUDY IMPORTANCE OF PPE IN INDIAN MINING

On mine safety in India with emphasis on PPE (Personal Protective Equipment) - highlighting its role, challenges, incidents, and recommendations.

Personal Protective Equipment (PPE) is the last line of defense for mine workers in India, where harsh working conditions in underground and surface mines pose continuous risks. Ensuring the correct use of PPE is critical to reducing injuries and fatalities.

3. IMPORTANCE OF PPE IN INDIAN MINING

Key PPE in Mines:

- Helmets: Protection from falling objects and roof falls
- Respirators/Masks: Protection from coal dust, silica, and toxic gases
- Ear Protection: Noise-induced hearing loss prevention
- Reflective Jackets: Visibility in low-light or night operations
- Safety Footwear: Protection from sharp objects, electrical hazards
- Safety Goggles: Eye protection from flying particles and chemical splashes
- Gloves: Hand protection from abrasions, chemicals, and machinery

3.1 Case Study: PPE Violation at Eastern Coalfields Limited (ECL), West Bengal (2019)

In 2019, an underground worker at an Eastern Coalfields Limited (ECL) mine in West Bengal sustained facial burns and partial blindness while inspecting a faulty fuse box. The incident occurred due to the absence of appropriate personal protective equipment (PPE), specifically a face shield and safety goggles.

Investigation Findings: The investigation revealed that the worker was not wearing the standard-issue eye protection at the time of the incident. It was further found that PPE was either not available at the site or its use was not enforced by supervisory personnel. Additionally, no safety training had been conducted for workers in the preceding six months.

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Aftermath and Response: Following the incident, the Directorate General of Mines Safety (DGMS) issued a show-cause notice to ECL. The company was directed to conduct regular mine safety drills and implement strict PPE audits. Compensation was provided to the injured worker, and ECL renewed its focus on the proper distribution of PPE and enforcement of safety protocols across its sites.

Challenges in PPE Use in Indian Mines:

Poor Quality PPE → Substandard equipment sourced to cut costs

Lack of Awareness → Workers unaware of the importance or correct use of PPE

Non-compliance by Workers → Discomfort or carelessness leads to non-usage

Irregular Supply → Logistic delays or corruption in procurement

Weak Enforcement → Supervisors not strictly monitoring PPE compliance

DGMS Regulations on PPE

- Mines Act, 1952 mandates employer responsibility for safety.
- DGMS Circulars regularly issue technical guidance on mandatory PPE usage.
- PPE Inventory Management and audits are required by law.
- National Safety Week Campaigns promote PPE awareness.

3.2 Best Practice Case: PPE Safety Initiatives at Tata Steel's Noamundi Iron Ore Mines, Jharkhand

Tata Steel's Noamundi Iron Ore Mines in Jharkhand have implemented a range of innovative personal protective equipment (PPE) strategies to enhance worker safety and accountability. These initiatives represent a forward-thinking approach to occupational health and safety in the mining sector.

Key Highlights of the PPE Initiative:

- **RFID Tagging of PPE Kits:** Each PPE kit is equipped with RFID (Radio Frequency Identification) tags to ensure individual accountability and track usage in real time.

- **Smart Helmets:** Workers are provided with smart helmets integrated with gas sensors and GPS tracking, enabling real-time monitoring of hazardous gases and worker location for improved emergency response.

- **Virtual Reality (VR) Safety Training:** PPE usage and safety protocols are taught through immersive VR simulations, providing workers with hands-on training in a controlled, risk-free environment.

- **PPE Vending Machines:** Automated PPE dispensing machines are installed at mine entrances, ensuring easy and timely access to essential safety gear for all personnel.

These measures have significantly strengthened the safety culture at Noamundi, setting a benchmark

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for digital integration and innovation in industrial PPE management.

4. METHODOLOGY

The Arduino microcontroller is used to detect and monitor variables in a coal mine. Live readings are provided by the temperature sensor, humidity sensor, IR flame sensor, and gas sensor. A microcontroller and a transreceiver are connected to all of these sensors. The data is sent to the microcontroller, and communication between the gateway and the specific node is done via Xbee WPAN IEEE 802.15.4. As mentioned previously, the data is sent to the control room via the XBee protocol. In an abnormal situation, an alert message is sent to the system, which is also displayed on an LCD screen connected to Arduino at the coalfield's entrance. A buzzer is also programmed and controlled with the help of Arduino, which activates at any abnormal reading detected by the above sensors. A smart helmet is also computed with a microcontroller which simply has a push button connected to it. The microcontroller is also comprised of a ZigBee transceiver. This measure has been taken to maximize the safety of workers in coalfield. Whenever a worker needs medical attention or has any discomfort, a panic button can be used, which transmits a message in the control room about an emergency so that medical attention can be given to that worker.

4.1 Block diagram

As shown in Figure 1, this block diagram is of a prototype that includes some sensors that would be needed in a coalfield and are connected to a microcontroller to detect environmental conditions. The Arduino Uno microcontroller was used and connected to LM35 (Temperature sensor), DHT11 (Humidity sensor), MQ2 (Gas sensor), and an IR flame sensor. With the help of these sensors, continuous readings of temperature, humidity, and gases present in the coalfield can be taken, as well as air density, and we have programmed the Arduinoboard in such a way that any abnormality in the parameters as mentioned above will trigger an alert, and the buzzer will be activated. A 16x2 LCD display was added, which will display all of the readings. Workers will be able to monitor the live circumstances of the coalfield and take necessary action using this LCD, which will be installed at the coalfield's entrance. To create safe and dependable communication to the control room, the ZigBee Protocol has been employed. The environmental parameters of the coalfield are communicated with the aid of the XBee transmitter and receiver, which are coupled together with the help of XCTU software so that necessary measures may be done in time in critical situations. Figure 2 below is a block diagram. Another safety gadget is a smart helmet equipped with a push-button, buzzer, and a ZigBee transmitter. At any sudden point of time, if any worker feels uneasiness or needs medical attention, that worker can use the push button, which will trigger the buzzer and transmit an emergency message to the control room via ZigBee.

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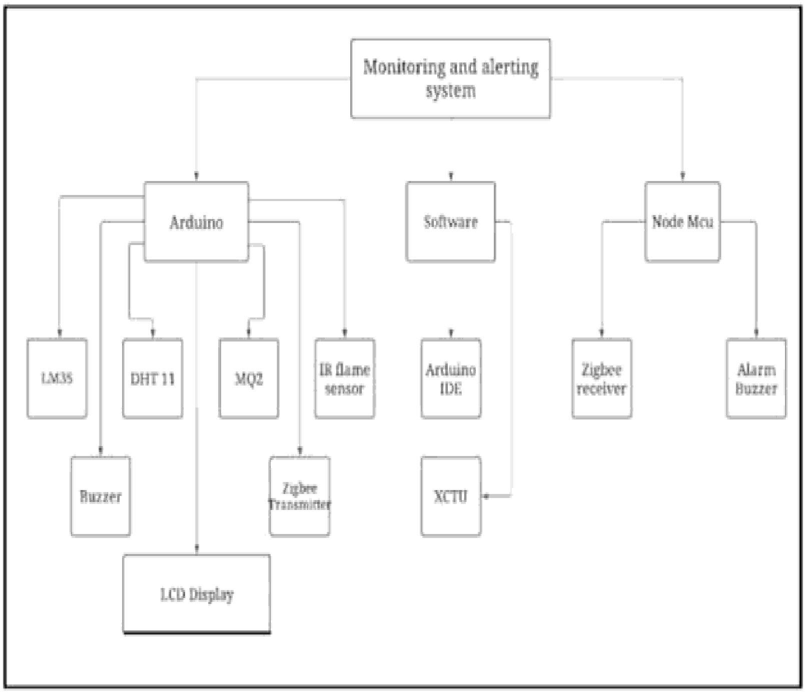

Figure 1 Block Diagram of Coal Mine Safety and Monitoring System

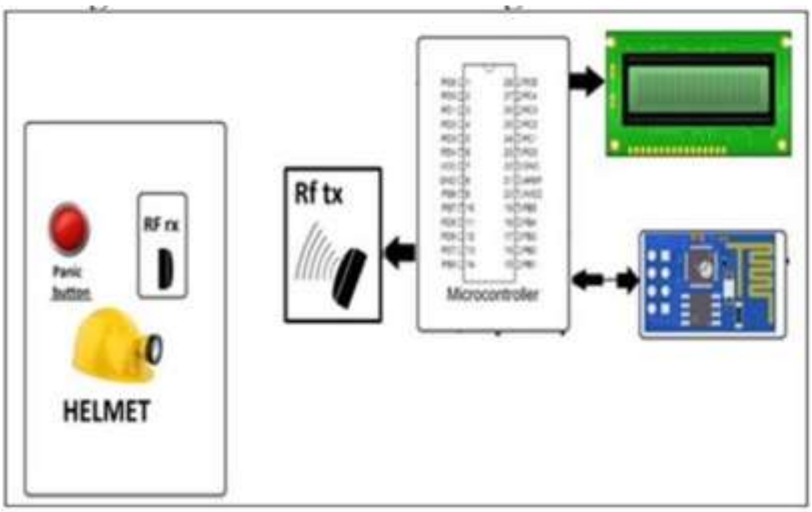

Figure 2 Block Diagram of Smart Helmet

4.2 Sensors Specifications

This prototype is intended to monitor and measure environmental factors such as temperature, gas concentrations such as CH_4, CO_2, and humidity, as well as to detect inflammation or fire. Table 1 show the sensors utilized in the prototype and their parameters. The LM35 sensor measures temperature since it is small and accurate to within 3°C [8]. An MQ2 gas sensor is used to detect gas concentration with an accuracy of 85%, while a DHT11 sensor is used to measure humidity with an accuracy of ±5% RH. Another sensor used in the prototype is an infrared flame sensor, which is used for fire detection and has a higher sensitivity and better accuracy than other types of flame sensors. These sensors are long - lasting, can withstand the harsh environmental conditions of the coalfield, and are cost - effective. For wireless M2M and IoT networks that are low cost and low-power, Zigbee is a wireless technology that is based on standards. In comparison to a WIFI network, ZigBee provides significantly lower data rates and use a mesh networking protocol to eliminate hub devices and build a self-healing architecture. This allows for the potential mixing of

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implementations from different manufacturers; however, it has been changed and improved. Zigbee is a standard protocol with a modest data rate and consumes less power [9].

Table 1 Specifications table for selected sensors

Sr no.	Parameters	DHT11 Humidity sensor	MQ2 Gas sensor	LM35 Temperature sensor	IR Flame sensor	ZigBee Module
1	Sensing variable/Uses	Humidity	Gas concentration	Temperature	Fire	Transceiver
2	Operating Voltage	3.5V to 5.5V	5V	+4V to 30V	3.3V to 5V	2.1V to 3.6V
3	Operating Current	0.3 mA	800 mW	60 micro-A	15 mA	45 mA
4	Output Voltage	5.5 V	0 to 10 V	10 mV	Digital output (0 or 1)	–
5	Operating Temperature Range	0 to 50 degrees Celsius	-20 to 70 degree Celsius	-55 to 150 degrees Celsius	-25 to 85 degrees Celsius	-40 to 85 degree Celsius
6	Output/sensing Range	20% - 90%	300 to 10000 ppm	-55 to 150 degrees Celsius	760 to 1100 nm	4000 ft

4.3 Flowchart

Begin by connecting the prototype circuit to a power source. Now we'll have to keep track of all of the sensors values attached to the Arduino UNO. Set a threshold value for each sensor after evaluating the readings and determining when environmental circumstances become aberrant. The condition will be true if the sensor output is greater than the defined threshold value, and a buzzer will sound, readings will be displayed on the LCD screen with an alert message, and data will be transferred through Zigbee protocol to the control room. The Buzzer will not turn on if the sensor value is less than the defined threshold value, but the sensor readings will be shown on the LCD and relayed to the control room. This is when the flow of the procedure comes to a stop. Flow Chart for Controller Programming is shown in Figure 3.

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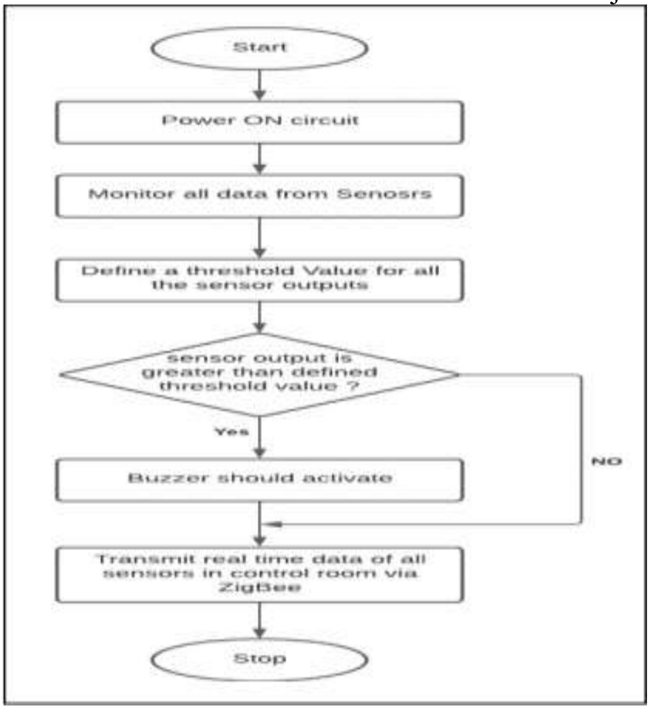

Figure 3 Flow Chart for Controller Programming

4.4 Working

Arduino UNO is the central component, and it sends the information on the internet via the Zigbee module. DC power supply is used for supplying voltage to the circuit. This is the circuit diagram for the smart helmet's monitoring and alerting system. This system will be built using Arduino, ZigBee modules, and sensors such as the DTH11 humidity sensor and the IR flame sensor, among others. The sensors we'll use will detect changes in the coal miner's environment, and variables like temperature, gas concentration, and fire detection will be continuously monitored. It will also have an extension that will connect to an LCD display, which will be placed at the entrance to the coal minefield. Also, the data which will be recorded by sensors will be transmitted via the Zigbee module to the control room so that proper actions can be taken effectively in minimum time. Figure 4 shows prototype of smart helmet. A push-button, a buzzer, and a ZigBee transmitter will be included in another safety device, the smart helmet. If any worker becomes uneasy or requires medical attention at any time, that worker can use the push button to activate the buzzer and send an emergency message to the control room via ZigBee.

The sensor system operates based on predefined conditions that trigger hardware responses. When the sensor reading is 0, it indicates a safe condition, and as a result, the buzzer remains OFF, signifying that there is no immediate threat or abnormality in the environment. However, when the sensor reading changes to 1, it signals an emergency situation. In this case, the system responds by turning the buzzer ON, providing an audible alert to notify workers or control personnel of the potential hazard. This simple binary logic helps ensure quick and effective response to unsafe conditions, enhancing the overall safety mechanism of the system.

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Figure 4 Prototype of Smart Helmet

4.5 Architecture of the system

The developed system can be divided into two sections. First is a hardware circuit that will be attached with the body of the mine workers. This may be preferably fitted with the safety helmet of the workers also. The circuit has a sensor module consisting of some MEMS based sensors that measures real-time underground parameters like temperature, humidity and gas concentration. Gas concentration is meant for the harmful gases like methane and carbon- monoxide. A microcontroller is used with the sensors to receive the sensor outputs and to take the necessary decision. Once temperature is more than the safety level preprogramed at microcontroller, it decodes beep alarms through the headset speaker connected with controller as shown in Figure 1. Again, once the measured humidity value is more than the safety level ZigBee based Mine Safety Monitoring System With GSM International Journal of Computer & Communication Technology ISSN (PRINT): 0975 - 7449, Volume-3, Issue-5, 2012 64 preprogramed at microcontroller, it decodes different type of beep alarms. Figure 1 General Blocks in Mine Safety System Similarly when gas concentration crosses the safety level, microcontroller decodes siren alarms. In all such cases, this will send an alarm through an urgent message and alarm sound to the ground control terminal through Zigbee. For the voice CODEC the low size, low power, CMX639 is used which is a continuously variable slope delta modulation (CVSD) digital voice communication system. With its robust and selectable coding algorithms, 8kbps to 128kbps data/sampling rates, supported internal clock signals makes it versatile [1]. It has analog input interface with encoder that connects the microphone and microcontroller and also an analog output interface with decoder that connects speaker/headset and microcontroller. Communication through these encoding and decoding of voice and alarm signals is effectively established with the help of microcontroller. Figure 2 Connections through Zigbee module, the microcontroller data is transmitted through two separate boards i.e. ZigBee transmission module to the data collector or receiver module. The microcontroller used here is PIC 16F877A with 20MHz operating frequency. It has five I/O ports, eight A/D input channels and 368 bytes data memory. As shown in Figure 2, the data receiving terminal of Zigbee XB_RX and data transmitting terminal XB_TX are cross connected to the microcontroller corresponding transmitter and receiver terminals TxD and RxD respectively. No extra component like MAX 232 and MAX233 is required between these connections. This is the advantage of PIC 16F877A .If the structure of UART (Universal Asynchronous Receiver Transmitter) system is completed, sending and receiving signal is possible using ZigBee, after installing necessary software. The RESET pin of Zigbee is used to provide an optional reset facility of user through a reset button. A transistor is used for this purpose. The Zigbee Modules used in the interfacing boards, are engineered to meet IEEE 802.15.4 standards. It is low-cost, low-power, reliable 20 pin device that operates within the ISM 2.4 GHz frequency band. It has 30 to 100 meter data transmission capability with rate of 250,000 bps. Zigbee modules operate in five modes. When not receiving or transmitting data, the RF module is in Idle Mode. The RF module shifts into the other modes of operation under various conditions. In transmit mode serial data is received in the DI (data in) buffer and the data is stored in the DI Buffer until it can be processed. When the DI buffer is 17 bytes away from being full, by default, the module de - asserts CTS (high) to signal to the host device to stop sending data (as shown in Figure 2). CTS are reasserted after the DI Buffer has 34 bytes of memory available. Smaller size

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data or low baud rate can be selected to avoid this state of overflow. In receive mode valid RF data is received through the antenna. When RF data is received, the data enters the DO (data out) buffer and is sent out the serial port to a host device. Once the DO buffer reaches capacity, any additional incoming RF data is lost. If RTS (hardware flow control) is enabled for flow control, data will not be sent out the DO buffer as long as RTS is de-asserted. Sleep Modes enable the RF module to enter states of low - power consumption when not in use i.e. not transmitting/receiving data for the amount of time predefined by the ST (Time before Sleep) parameter. To modify or read RF Module parameters, the module must first enter into Command Mode - a state in which incoming characters are interpreted as commands. The programming requires the installation of X-CTU software and a serial connection to a PC. The detail of the software is given in the next section. When communication occurs between two networked devices, each data packet contains a _Source Address ‘and a _Destination Address ‘field.

4.6 Hardware implementation

ZigBee wireless sensor nodes mainly consist the sensor unit, signal conditioning circuitry, microcontroller (MCU), RF modules MC13193, timers, memory and power management module and other components shown in Figure 3. ZigBee based Mine Safety Monitoring System With GSM International Journal of Computer & Communication Technology ISSN (PRINT): 0975 - 7449, Volume-3, Issue-5, 2012 65 Micro-controller is responsible for collecting environmental information (such as temperature, carbon monoxide, methane, wind speed, etc.) and do some data conversion, responsible for controlling and managing the entire nodes; RF module MC13193 is responsible for the communication between nodes by a certain protocol ; the power module provides the necessary power for the nodes separately to run the various parts. Sensor nodes are the basis unit of wireless sensor network; node stable running ensures the reliability of the whole network. Sensor node is comprised of data acquisition module, data processing module, wireless communication module, alarm module and the power module. Node hardware connection is shown in Figure 3. The data acquisition module is used for sensing, collecting information and converting to digital signals. According to the need for monitoring parameters of coal mine, the processor module is connected to gas sensor, pressure sensor, temperature sensor, and other kinds of sensor module, which is in charge of processing the data and coordinating the whole system.

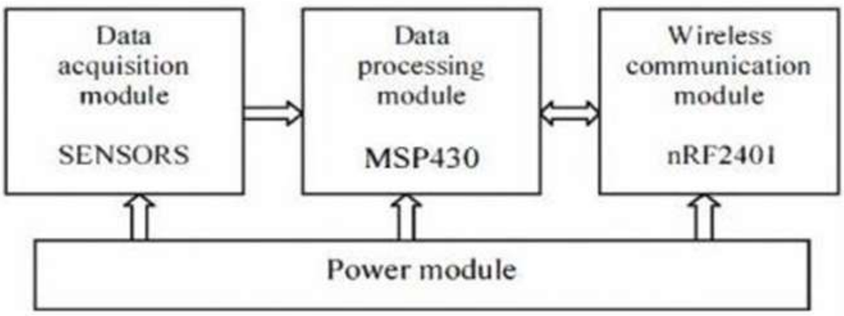

Figure 3 Wireless Sensor at Network Node

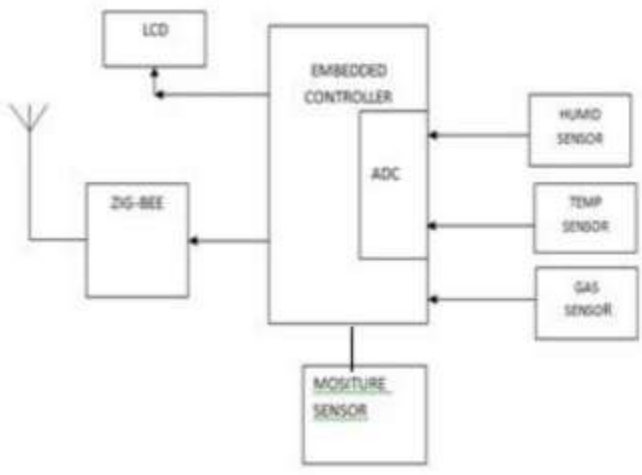

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Figure 4 Block diagram for Central Monitoring System

The wireless communication module is mainly responsible for communicating with other nodes. In addition, the energy problem is the key problem, because once nodes exhaust the energy of the battery, which will drop out of the wireless sensor network, so power consumption of the wireless sensor network should be low as far as possible. Figure 4 & Figure 5 Shows the Block diagrams of the Present work. The Circuit diagrams of the Present work are shown in Figure 6.

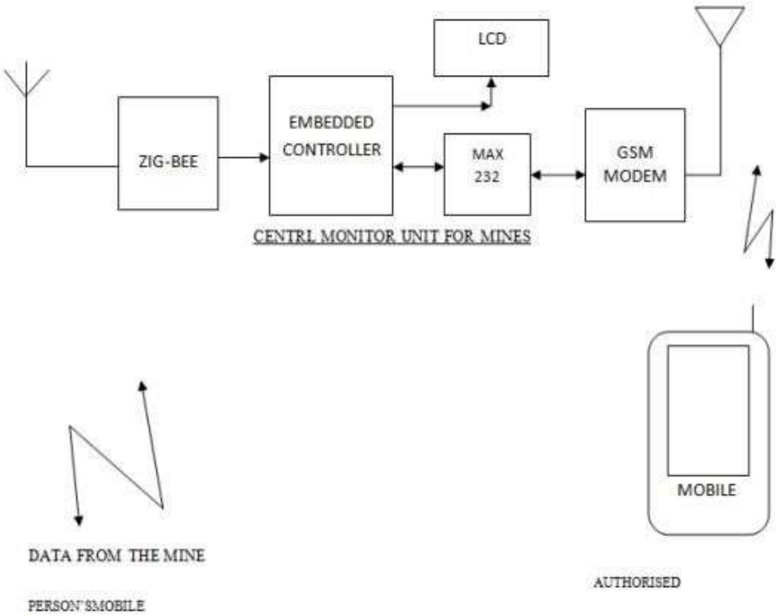

Figure 5 Block diagram for Node Equipment design

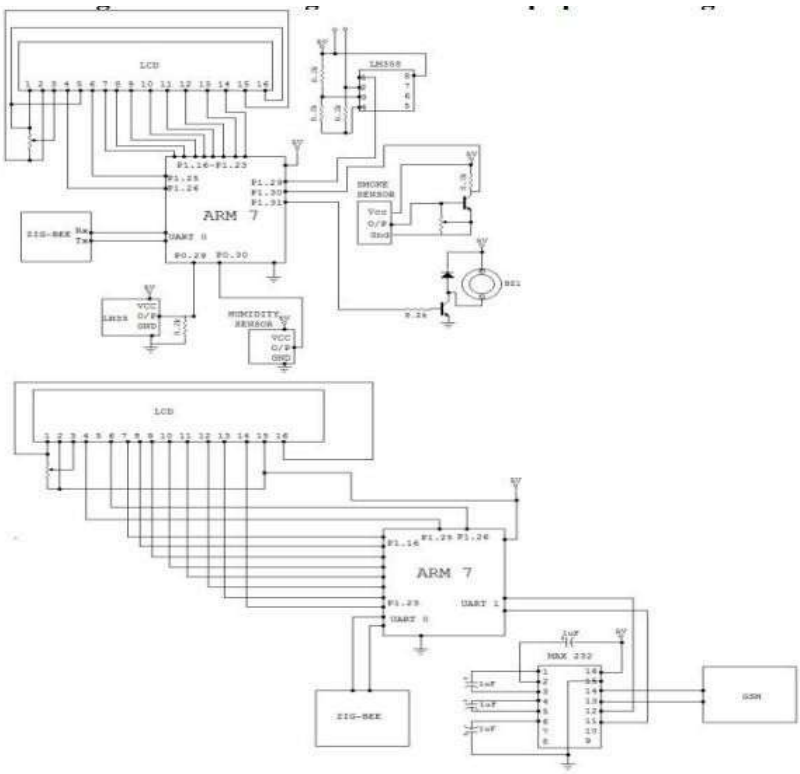

Figure 6 Circuit Implementation

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4.7 Software design flow

In software design, communication protocol layers have the energy conservation for the center. Take the communication between the sensor nodes and the network coordinator as an example to introduce the flow of communication between the ZigBee modules. Before making communication, ZigBee module need effective initialization, the initialization process between ZigBee sensor nodes and the network coordinator shown in Figure 3. During initialization, the network coordinator issues a active signaling request to connect the sensor nodes. After the sensor nodes successfully receive and verify a data frame and MAC command frames. Return Acknowledgment frame to the sink node, the sensor node's ZigBee module is in sleep mode. After initialization, ZigBee module information processing as shown in Figure 4, the network coordinator is from the working mode to waiting for connection request signaling for the response of the sensor node, and on the regular time, the sensor nodes take the initiative request to connect the network coordinator and report the detected security information inside the mine to the network coordinator.

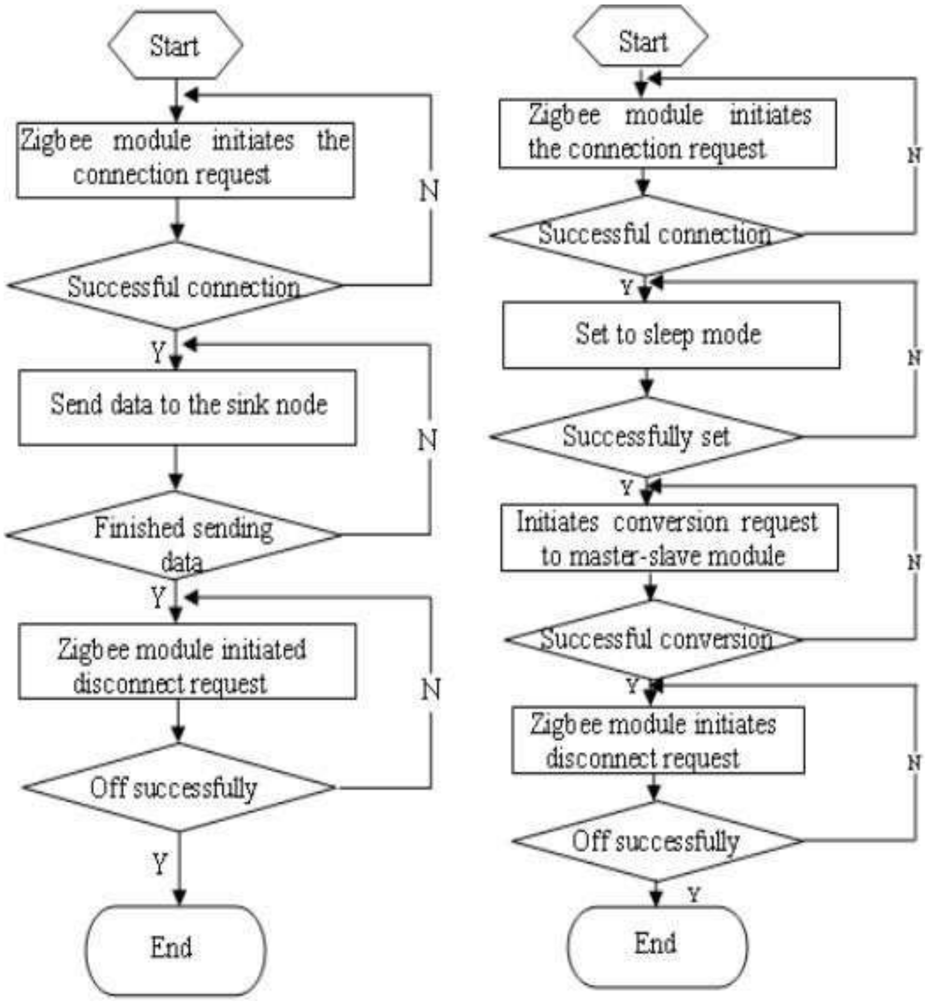

Figure 7 Design Flow for Initialization and Processing

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The communication between sensor nodes and sink nodes, and exchange between sink nodes and networks coordination are similar. Software design mainly programmed with C language combining Lab view is responsible for the collected data display, analysis and storage etc.

5. RESULT & DISCUSSION

Table 1 Result Analysis of Smart Helmet

Sr.no	Sensor reading	Hardware changes	remark
1	0	Buzzer OFF	Safe condition
2	1	Buzzer ON	emergency

Table 2 : Result analysis of monitoring system

Sr no.	Parameter	Threshold value set	Sensor reading	Hardware changes	remark
1	Temperature (degree Celsius)	25	21.09	Buzzer off	Safe condition
2	Gas (PPM)	600	518.2	Buzzer off	Safe condition
3	Humidity(%RH)	45	33	Buzzer off	Safe condition
4	IR flame sensor (digital output)	0	0	Buzzer off	Safe condition

Table 3 : Result analysis of monitoring system

Sr no.	Parameter	Threshold value set	Sensor reading	Hardware changes	remark
1	Temperature (degree Celsius)	25	31.05	Buzzer on	unsafe condition
2	Gas (PPM)	600	694.1	Buzzer on	unsafe condition
3	Humidity(%RH)	45	48.3	Buzzer on	unsafe condition
4	IR flame sensor (digital output)	1	1	Buzzer on	unsafe condition

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IMPACT

- Zero fatal accidents since 2024.
- 98% compliance in PPE audits.
- Recognized with National Safety Award by DGMS in 2021.

RECOMMENDATIONS

- Mandatory PPE Training during induction and refresher courses.
- Use of Smart PPE (e.g., helmets with sensors, connected gloves).
- PPE Compliance Audits monthly with third-party checks.
- Worker Incentive Programs for consistent PPE usage.
- Awareness Drives in regional languages using posters, videos, and peer role models.

6. CONCLUSIONS

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 monitoring unit; it will be helpful to all miners present inside the mine to save their life before any casualty occurs. Alarm triggers when sensor values cross the threshold level. This system also stores all the data in the computer for future inspection.

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