

# Design and Implementation of a Zigbee-based Coal Mine Safety Monitoring and Evacuation System

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**Abstract-** Coal mine environments cause safety issues due to the presence of harmful gases, alteration of environmental conditions, and some possible structural disturbances. To address such issues, continuous monitoring and swift-response systems with emergency alerting are necessary to protect workers. In this paper, a Zigbee module-based system is used because it provides reliable communication in an underground atmosphere, and it supports monitoring, alerting, and evacuation by detecting unsafe conditions in real-time. The required data is transmitted wirelessly between the Zigbee transmitter and receiver. The system uses various sensors to monitor important parameters within the mine's network. A GSM module is integrated to alert the higher authorities by forwarding alert messages. Additionally, an emergency evacuation process is incorporated under dangerous conditions. At the surface unit, the data received is transferred to the main controlling network through a Zigbee receiver for observing and managing the network. The proposed system combines sensing, communication, and automated response, detects dangerous conditions, and produces a timely response to reduce risks in coal mines. It does this by bringing sensing technology, wireless communication, and automatic response in one system. The intention of this arrangement is to make coal mines safer by detecting hazards and responding quickly.

**Keywords**—*Arduino Uno; ZigBee modules; GSM extension; coal mine safety; Management of Coal Mine Safety; Sensor points-WSN; Emergency Evacuation System; Alerting System.*

## I. INTRODUCTION

The employment opportunities in industries are concerning due to their working environments, along with staff safety management issues. Among other industrial sectors, coal mining is regarded as the most dangerous industry, since casualties like explosions, smog leaks, and structural failures occur frequently, preceding loss of life and property. Reports over previous years resulted in mining-related incidents that affected numerous workers' lives [4][13]. Miners often have to work in such confined and in difficult spaces where even a small change in atmosphere can become a serious threat.

As nature is unpredictable, the presence of harmful gases in mines is one of the major reasons for accidents that occur inside the mine tunnels. Since most of these gases spread in closed areas with no place to escape from, they lead to suffocation, breathing problems, fire hazards, or blasts. Apart from the mentioned limitations, there are some other problems that indicate unsafe conditions inside the mines due

to changes in climate, tunnel overheating, moisture, and vibrations on the surface. The parameters discussed above are not easily predicted, as they can occur during regular mining activities such as drilling or blasting for new tunnels that cause disturbances in the mine structures. To completely prevent such hazards is not practical, and to solve the situation, we need a reliable continuous monitoring arrangement.

Previously, inspection techniques were manually conducted, which mainly depends on the CMS - cable monitoring systems and could take many days to replace the damaged wires [5][11-12]. Even though the survey is based on wired communication, cables are damaged due to underground circumstances, in particular, overheating, moisture, dust, and vibrations, making the management of the network difficult and unreliable. This may delay the process of detecting the hazardous situations and the evacuation procedure, as repairing such wired structures is time-consuming. Due to time barriers, even though we detect hazardous conditions, the communication between the control unit and the ground unit is weak. A setup is required to make the structure well-grounded, strong, and cordless to monitor the mines and transfer the data to the specified units without interruption.

A Zigbee-based coal mine monitoring, alerting, and evacuation system is established to address these issues. The arrangement is to observe key environmental parameters within the mine, which uses multiple sensors, and the collected data is transmitted wirelessly using Zigbee transmitter to the main control or monitoring unit. Alerts are generated and sent to concerned authorities through SMS using a GSM module when the structure detects hazards. Furthermore, an assist process that rescues miners is also included in the structure to ameliorate the safety of miners during emergencies. By combining sensing or identifying regulatory situations, portable communication, and signaling mechanisms, this approach provides a simple and cost-effective result for improving safety in coal mine environments.

## II. LITERATURE REVIEW

[1] A.H. Ansari et al. have exhibited a presentation highlighting the safety of workers, which in particular is work below the surface. It uses Zigbee segment because of its reliability even when located underground, it works adequately and initiates communication between the surface and ground units. The collected data on the parameters of the environmental conditions which are present in the mines are

continuously monitored by the surface station or processing unit. Common features of these types of systems are the ability to transmit the data from the mine to the monitoring station above, as well as incorporating methods of alerting the miners of dangerous conditions within the mine (such as panic buttons). Each of these systems differs from one another, however, in their communication reliability with the miners and in the automation of those alerting methods. In monitoring the miners and alerting those on the surface unit, their proposed system is helpful in addressing the potential issues faced by the miners but still has room for improvements in their reliability and automation methods to increase their safety for the miners within the mines.

[2] Chowdhury and Pramanik's work in this area has mainly focused on utilizing the Internet of Things in conjunction with modern elements that enable long-range interaction or transmission to increase the safety of miners within underground coal mines. One study that deploys IoT and LoRa technology to allow for transferring information between sensor devices within the coal mine and the surface station above the mine. Including the use of these cordless interactions for transferring data is a common shift in these modern days, which includes data transfer from the sensor devices to controlling stations, as well as the use of algorithms to analyze the data to provide alerts of potential safety issues for the miners within the mine. Various approaches to these establishments, however, incorporated different methods of processing the data from the mines and communicating with the miners. Various types of networks are good enough at managing the mines for various factors and providing alerts to the miners of those factors, but generally lack methods of ensuring the safety of the miners within those mines during those dangerous conditions.

[3] Deokar and Wakode's existing work in the area of coal mine safety generally relates to the use of wireless sensor-based systems to monitor the location of workers and the environmental conditions within the mine. The collected information from the mines that use mechanisms like Zigbee and GSM devices to send data from the underground mines to managing units to indicate the presence of harmful gases and overall environmental conditions within the mine. Most of these present arrangements include features like early warning alerts and safety mechanisms to address the environmental dangers within the mines, but do not include elements like fall detection or helmet monitoring systems that could prevent injuries to the miners. Furthermore, most of their still depends upon sending the alerts to the miners rather than taking any actions to ensure the safety of those workers within the mines.

[4] H. Subhadra and V. Sreelatha. designed and implemented a life-saving worker's setup that senses and alerts based on IoT(Internet of Things). They have explained remote continuous monitoring of various parameters using WSN and

IoT platforms. So that real-time monitoring could be done along with alert mechanism such as alarms, safety visuals that provide instant notification, an approach of microcontrollers integrated with cloud to cloud communication is setup. The system works pretty well as it senses hazardous conditions and alerts the workers. But this system just uses alerting and taking care of emergencies. Automated response can also be integrated for more efficiency in vital cases.

[5] Yu Zhang et al. worked in the field that manages underground coal mines for safety, which generally involves the use of WSN in conjunction with the present structures for monitoring the mines. One such example of such work has combined a wireless sensor network with the traditional system of monitoring the mines with cables. Such systems typically include all of the elements necessary to provide for reliable monitoring of the mines with both wired and wireless networks. However, they also differ in how they handle issues like energy usage, network stability, and communication efficiency. Introduction to these structures has resulted in the mines becoming more efficient, but there is still a need for even more streamlined systems that can respond quickly to the issues that may occur within those mines.

[6] Mo Li and Yunhao Liu presented an underground coal mine management system that is related to the concept of WSN in order to enhance the various environmental situations and safety within the mining areas. The Structure-Aware Self-Adaptive Wireless Sensor Network system (SASA) was established to manage the changes that occur within the underground mines. The system creates a system to regulate the mesh sensor networks to detect any changes in the structure of the mine due to potential collapses within the mine. Furthermore, a reliable query-handling mechanism is introduced to the network to enhance communication efficiency within the network. A prototype of the network comprised of 27 Mica2 motes has been created, and the simulations of the network using the real-time data collected from the network show that the system can provide reliable and scalable monitoring within coal mines.

[7] Mangesh Rudrawar et al. also created an alternative system for the monitoring of coal mines - a reformulation of the smart helmet to incorporate preventive measures within the mines. The Zigbee wireless communication system is used to transmit data between the worker in the mine and the main control room of the mining operation. These helmets are equipped with sensors that monitor parameters like the Methane gas within the mine, humidity, temperature, and the presence of fire within the mine. If any of these parameters reach the danger levels for that specific parameter, a distress signal is sent from the helmet to the worker, and the helmet emits warning buzzes. Furthermore, the parameters are

displayed on a monitor that accompanies the helmet and the data is sent wirelessly to the control room. The helmet structure is established to be reliable and adaptable to future improvements. The results are shown for the established network, and it is reliable and efficient in monitoring the parameters within the mines.

[8] Junwen Zhang built a structure for coal mines based on Geographic Information System (GIS) technology which improves welfare and decreases accidents in underground mines. A mobile console module that is intelligent and it assists in real-time management of coal mines is created additionally, aside from planning stationary point assembling and remote arrangements via PC platforms. To perform an effective data manipulation, a software platform is programmed using the Java programming language. Some functional problems have been spotted and sorted out during system testing so as to make the system run smoothly. In the second test of the system, an accident passing rate of more than 99.88 percent was obtained.

[9] T. Porselvi et al. considered workers' health conditions and monitoring underground mines collectively, these are handled by LoRaWAN technology that emphasizes the protection of miners in dangerous situations. They have prepared a system that consists of various modules for health status monitoring and supervising overall underground mine situations. For climatic or other environmental changes, they used smoke sensors and semiconductor gas sensors for detecting harmful gases like Sulphur dioxide, nitrogen dioxide, and carbon monoxide. If the sensing values exceed than the tolerance value of sensors, this it triggers the structure, then the processor processes the data through LoRaWAN communication device, and a buzzer or alarm is switched on to alert workers.

[10] SB Lenin et al. prepared a wireless coal mine monitoring system that is integrated by the ESP-NOW protocol. The arrangement helped to gather information in real-time and to analyze underground situations in coal mines. Their way replaces the traditional wired monitoring systems, which consume low power and is implemented on NdeMCU, which in turn reduces installation and maintenance complexity of the system. The arrangement gathers data from various sensors, such as gas, temperature, humidity, and particulate matter sensors from inside the mines. The data is transmitted without cables to the main controlling station for analysis. Improving safety in coal mines, and additionally the arrangement also provides early warnings and supports workers' tracking.

### III. IMPLEMENTATION

The IoT-based embedded coal mine monitoring system is accomplished, which combines sensing, processing, cordless transmission, alerting, and evacuation units into a single

integrated setup, and it has two major sectors, namely the underground unit (transmitter) and the surface control unit (receiver). The transmitter section is deployed within the mines, which continuously monitors the coal mine tunnels for any hazardous conditions, and the receiver section is used for login purposes, data observation, and decision support at the surface level.

The control unit presented is an Arduino Uno (ATmega328 Microcontroller), which processes all operations that occur in mines, and is the main part of the transmitter unit. It is linked with various sensing devices, including MQ4 and MQ7 gas sensors for detecting methane and carbon monoxide, respectively, a DHT11 sensor for overheating and moisture measurements, and a vibration sensor for identifying unusual surface or other structural disturbances. To identify the changes in the mine atmosphere effortlessly and to cover a large amount of area of the network, these sensors are placed at certain positions in the mine tunnels. The acquired sensor readings are at predefined intervals and fed into the microcontroller for processing.

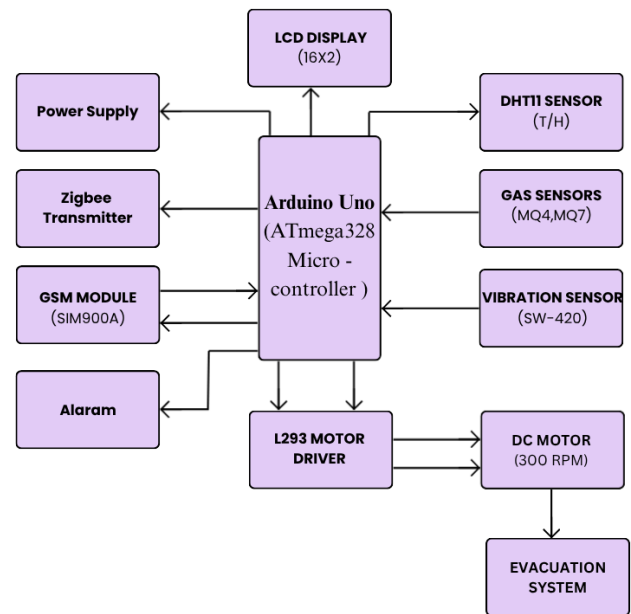


Figure 1. Block diagram of Transmitter Unit.

The microcontroller-based device is used as it continuously checks the incoming data against predefined limit values. These values are chosen referring to safe operating boundaries of gas concentration, temperature, humidity, and vibration levels. In normal conditions, where all parameters are within their safe limits, the system proceeds with the same activity while concurrently displaying the real-time values on an LCD for local observations. This ensures awareness of the mine environment. Under any circumstances, if any of the key parameters cross the tolerance value, then it is considered as a hazardous condition. At this stage, several actions will be initiated simultaneously. At the initial phase, an alarm is arranged that will provide an immediate warning to workers present in the mine. Secondly, a GSM module will be used to send alert messages to higher authorities or control stations so

that they can immediately arrange help if required. This provides not only local awareness but also interaction with external authorities, and during emergencies, an evacuation process has been incorporated into the setup to increase the safety of workers further. A motor driver circuit (L293D) has been used to control a DC motor as a part of the reestablishment setup. Once a condition is identified, then the motor is switched on to assist in reallocating, thus helping the workers to move towards safe areas. This feature highlights how extra safety measures go beyond just monitoring and alerting.

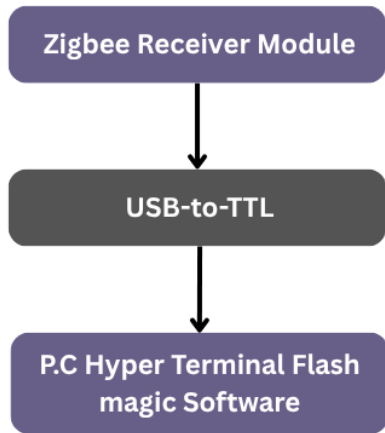


Figure 2. Block diagram of Receiver Unit.

Zigbee modules are used for communication to achieve this, as they offer low power consumption and reliable performance in short-range wireless communication. The processed data from Arduino is transmitted using the Zigbee transmitter module. The Zigbee receiver collects the processed data and transmits it to a computer system through a USB-to-TTL interface at the surface unit. The data is ultimately displayed using serial communication software, allowing for real-time monitoring and recording and the overall conditions inside the mine.

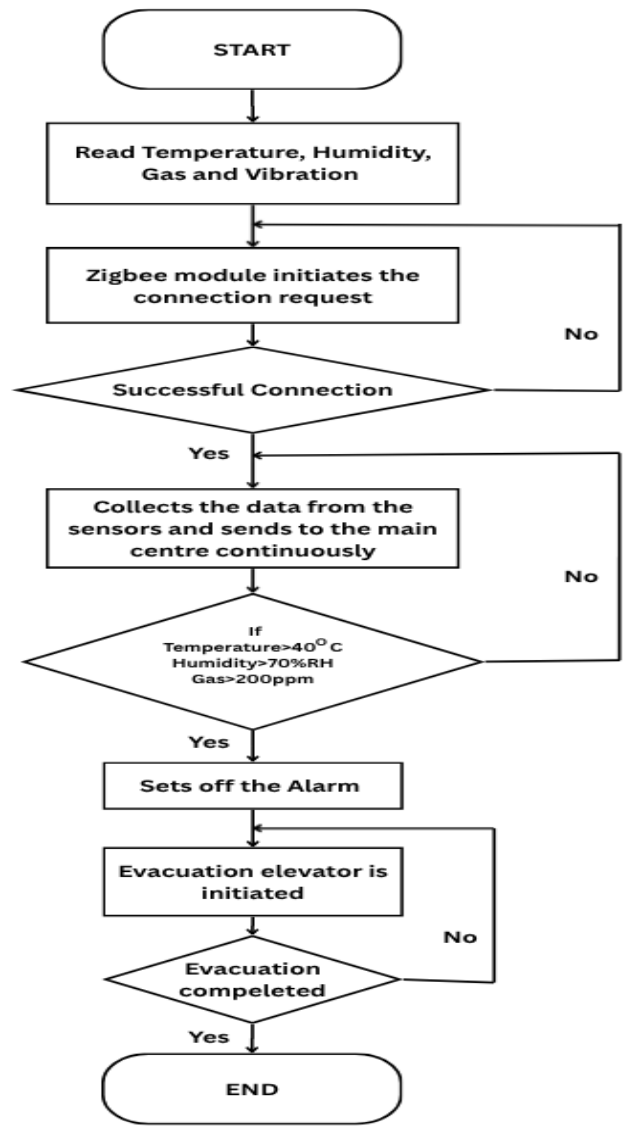
The structure is operated in a continuous loop where the detecting, data handling, transferring, and rapid response actions are performed repeatedly without interruption. These nodes can also be placed at different locations inside the mine to extend the coverage of the management of mines, forming a simple wireless sensor network that increases the overall reliability of the system and ensures better detection of hazardous conditions.

The performance of the implemented arrangements was tested under different conditions. The communication between the transmitter and receiver remained stable, and the alert system promptly responded to the introduction of abnormal conditions. Overall, the setup demonstrates the effectiveness of combining sensing, wireless communication, and automated response mechanisms to significantly improve safety and reduce risks in underground. Coal mining environments.

IV. OPERATIONAL FLOW

The operation of the proposed system is regulated with an initialization stage, through which all hardware components, consisting of the sensing devices, microcontroller, and communication-oriented modules, are activated, and nodes are configured without any manual connections to ensure proper functionality. Once initialized, the sensor unit begins continuous monitoring of critical environmental parameters within the coal mine, such as temperature, humidity, gas concentration, and vibration levels. The key parameters mentioned are essential for assessing the safety conditions of the underground environment.

The acquired sensor data is processed by the microcontroller and prepared for transmission. Subsequently, the ZigBee communication module initiates a connection request with the central monitoring station or network coordinator. The system continuously verifies the connection status, and in the event of a communication failure, repeated attempts are made until



a stable and reliable connection is successfully established. Figure 3. Flow chart of the system.

Sensor	Parameter	Limited Value	Measured Value	Unit	Status
MQ4	Methane	170	140	Analog value	Normal
MQ7	Carbon Monoxide	170	140	Analog Value	Normal
DHT11	Temperature	40	35	°C	Normal
DHT11	Humidity	70	60	%RH	Normal
SW-420	Vibration	-	-	-	-

Upon successful connection establishment of the communication link, the system transitions into a real-time monitoring mode. In this continuously collected sensor data is transferred to the central control unit, where it is logged, analyzed, and used for decision-making purposes. The incoming data is systematically compared against predefined threshold values that represent safe operating conditions within the mine. If any of the monitored parameters exceed their respective safety tolerances, such as temperature exceeding 40°C, humidity surpassing 70% relative humidity, or gas concentration rising above 350 ppm, the system classifies the situation as potentially hazardous. An immediate alert is generated in the form of audible and/or visual alarms to warn both the mine workers and the control center operators in response.

Following the detection of hazardous conditions, the arrangement automatically initiates emergency response procedures. This includes activating evacuation support mechanisms, such as evacuation elevators or guided exit pathways, to facilitate the safe and efficient movement of workers from the affected area to secure locations.

The structure monitors the progress of the evacuation process continuously to ensure its successful completion. If the evacuation procedure is still progressing, then it maintains the alert state and continues to support emergency operations. Once all personnel have been safely evacuated and the process is confirmed complete, the system concludes its operational cycle, marking the termination of the emergency response sequence.

## V. RESULTS AND DISCUSSION

The proposed system was tested under normal and abnormal conditions to evaluate its performance. During normal operation, sensor values remained within safe limits, and the system continuously monitored and transmitted data through Zigbee transmitter without any interruption. When unsafe conditions are detected, such as high gas levels or temperature were introduced, the system quickly detects the changes and activates the alert mechanism through an alarm, provided immediate warning, GSM alerts are sent to authorities and monitoring units, and the evacuation system responds as expected. The communication was stable, and the response time was fast, showing that the system can effectively monitor mine conditions and provide timely alerts.

Table 1.

Comparison table of Threshold and Measured Sensor values

## VI. CONCLUSION

In conclusion, the embedded system and IoT-integrated Zigbee-based coal mine monitoring and evacuation system Safety provides a reliable, low-power, and cost-effective solution for enhancing safety in underground mines. It continuously monitors key parameters in the mines and ensures real-time communication between underground and surface units. The system responds quickly to hazardous conditions by generating alerts by activating alarms, displaying detected values on the LCD, sending SMS through the GSM module, and supporting evacuation. Overall, the proposed system helps in early detection of dangers and timely response, which can reduce risks and improve worker safety in coal mine environments.

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