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Enhancing Safety of Underground Coal Mine using IoT-Enabled Approach for Environmental and Strata Monitoring

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Abstract

Safety is a vital element of a healthy work environment. To improve safety of underground miner a smart monitoring system to prevent the miners and the mine from any hazardous events using Internet of Things and Wireless sensor network. Various hardware and software components are used to track the condition of underground mine in real-time comprising of environment monitoring and strata monitoring. Environment monitoring modules includes prediction of seven gases like Methane, Carbon dioxide, Carbon Monoxide, Sulphur dioxide, Hydrogen sulphide, Oxygen and Nitrogen oxide. Similarly strata monitoring, prediction and warning module includes real time monitoring through the proposed research could assist in detecting risks occurring in the mine environments by generating an alarm automatically when thresholds goes below or above specific limit. The paper describes hardware and software modules of the developed IoT-enabled smart monitoring system underground mines.

Keywords: *Mine Accidents, Sensors, Threshold Values, Wireless Network*

1.0 Introduction

The Internet of Things (IoT) is a cutting-edge standard that integrates various technologies and methodologies. It combines pervasive computing, sensing technologies, embedded devices, ubiquitous computing, internet protocols, and communication technologies to create systems where the digital and physical worlds intersect. By integrating IoT into everyday objects, these items become smart objects capable of gathering information from their surroundings, controlling, and interacting with the physical world. The vast number of interconnected devices and the immense amount of accessible data present numerous opportunities for developing services that benefit the environment, individuals, the economy, and society.

Working in underground coal mines is particularly challenging and hazardous due to the long, narrow tunnels, complex structures, and the high probability of various gas concentrations. These conditions significantly increase the risk of explosions, posing serious dangers to the lives of workers.

To mitigate the severity of these issues, numerous initiatives leveraging IoT have been implemented in the mining industry to enhance communication, particularly during unusual activities occurs[1]. However, the mining industry tends to be traditional and slow to adapt to changes due to infrastructural limitations in communication, information exchange, data management, and storage. Many research efforts on employing Industrial IoT (IIoT) in the mining industry

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have concentrated on specific issues such as monitoring ventilation, personal and fleet management, pre-alarm systems, accident analysis, and tailing dam monitoring. However, a comprehensive IIoT architecture for the general conditions of the mining industry is still missing[2]. An analysis of current Information Technology (IT) in the mining sector has revealed significant issues of vertical fragmentation caused by technological variations among devices. This fragmentation obstructs data distribution, secure information exchange between systems and devices, and interoperability.

Data processing, interoperability methods, and remote control advance all mining stages, from exploration to reclamation. Additionally, adopting IIoT architecture in this sector provides a safer mining environment for workers, improves mining operations, creates an interoperable environment for both modern and traditional devices and systems, and enables automation to minimize human intervention. It also allows for underground surveillance through the convergence of IT and Operational Technology. An automated monitoring system is essential for ensuring the safety of underground engineering constructions. A review of current international studies and the status of underground monitoring systems highlights three key aspects: data acquisition, transmission, and processing[3].

In the data acquisition process, optical fiber sensors are widely used, and Zigbee-based wireless transmission has become a prevailing trend. For data analysis and processing, numerous models have been developed over time, each with its own strengths and weaknesses. Recently, a Neural Network (NN) model has been developed for this purpose. Integrating the NN model with additional models has enhanced prediction accuracy[4].

Similarly, a Wireless Sensor Network (WSN) consisting of a range of micro sensors interconnected through a wireless communication network provides extensive monitoring and sensing services. Initially, a distributed monitoring system using WSN is recommended for underground coal mines, based on an assessment of communication conditions specific to these environments[5]. Utilizing a range of technologies such as sensors, communication systems, microcomputers, and automated detection, this system effectively manages smart mining operations and provides real-time data alerts. It employs industry cameras for remote control and image capture, and facilitates real-time monitoring of security information[6].

Similarly, a secure coal mine system has been implemented using a webpage for data transmission. This system includes devices for monitoring various parameters within coal mines, such as light detection, humidity and temperature conditions, fire detection, and gas leakage. This sensor system, also known as a large-scale device, has been installed in coal mines. Each sensor's data is automatically processed by computational units, which generate various insights for further analysis[7]. Additionally, laser detection sensors have been employed in this model to monitor light presence. Notifications are also sent to designated personnel via email to ensure prompt response in the event of a fire disaster. Vibration sensors are used to detect movements within the mines, helping to mitigate unusual events in underground coal mining. A smart monitoring system for coal mines was explored by Hu *et al.* (2013)[8]. It includes a smart server system for managers and a sensor network designed for efficiency and stability. Additionally, the operational duration of nodes in the Wireless Sensor Network (WSN) has been analysed to evaluate the effectiveness of specific functionalities.

Robustness has been a major challenge in mine monitoring. For example, sudden node failures can lead to the collapse of sub-networks. Consequently, future efforts focus on improving the robustness of the proposed sensor network. Enhancements include the integration of gas sensors, humidity and temperature sensors, and Arduino systems to ensure the safety of coal mining operations by continuously monitoring conditions and updating information for IoT platforms. These measures have confirmed worker safety[9].

Additionally, a blockchain-based system could be a promising technology for the mining industry, as it may help prevent unauthorized access and mitigate cyber-attacks through its distributed network and integration of diverse devices. Several open challenges in underground mine communications have been identified. Risk and threat analyses of data loggers in Safe Advance Goaf Edge Support Systems (SAGES), which are part of IoT information generation, have revealed vulnerabilities such as denial of service attacks and information disclosure. Therefore, it is recommended to incorporate security measures from the initial design phases to ensure the protection of storage and data transmission[10].

RFID technology has been selected for communication within mines[11]. Although this research is still in its early stages, efforts have already begun to identify gaps in current work related to cybersecurity in IoT. This includes addressing vulnerabilities, deficiencies in standards, and structural limitations with a focus on the resource and mining industries[12]. Evidence from traditional work highlights significant security issues and a lack of IoT standards. If not addressed, these deficiencies pose a threat to mining operations.

2.0 Digital-Mine System

A Digital Mine represents a virtual model of a physical mine, simulating equipment, machinery, and production processes. It functions as a comprehensive network of methods, models, and tools designed to support and optimize production operations. The digital system focuses on monitoring key aspects such as miners' movements, equipment status, geological conditions, and environmental factors in active goaf regions, potential hazards, health conditions, flood risks, dispatch status, and mineral production[13].

2.1 Mine Environment Monitoring

This system is used to monitor humidity, air velocity, and temperature in underground mines through sensors. Given the harsh conditions in mining tunnels and the high risk of accidents, there is a strong emphasis on reducing human presence in these environments. In response, a prototype for an inspection robot has been introduced, designed to assist with maintenance tasks and reduce the need for staff presence during inspections. Recently, the robot has been operated via radio control by an operator. Hotspots can also be pinpointed and their locations recorded along with corresponding images. The radio-control system ensures the operator's safety. This type of robot can be classified as a mobility monitoring system for assessing the spatial distribution of underground infrastructure[14].

3.0 Strata Monitoring

This system consists of a linear potentiometer paired with a piston and is designed to measure changes in convergence. It includes four main components: the convergence sensor, microcontroller, ESP-01, and load-cell sensor. The harsh environment of underground mines presents significant challenges in designing reliable and robust networks. Developing a consistent communication system requires understanding the unique characteristics of underground mines and addressing the various issues associated with both wired and wireless communication. Several key properties of underground passages impact the performance of communication systems in mines, including refraction, reflection, propagation velocity, noise, path loss, and multipath fading. Signal rate offset increases with higher moisture content. High-frequency communication systems require more attention than low-frequency systems. Additionally, path loss increases with the distance between the transmitter and receiver. Signals reflected off mine walls cause signal loss, while various mining equipment and reflectors lead to signal fluctuations, fading, and multipath propagation. Changes in temperature within the mine alter the dielectric properties of the medium, causing signal variation and weakening. Noise from various types of equipment degrades signal quality. Devices operating in this harsh environment must resist high moisture content, dust particles, and extreme temperatures. Commonly used Wi-Fi technology for information exchange suffers from delays, high data loss, and low transmission speeds. Therefore, suitable wireless communication is essential to address the issues of wired communication in underground mines. Considering these challenges, an IoT-based wireless and real-time monitoring system is introduced to track and monitor mines, ensuring miners' safety.

This study focuses on designing and developing an IoT-enabled web-based system for monitoring strata conditions and subsurface mine environments. The system aims to aid decision-making and predict sub-surface conditions.

3.2 System operation

The present study focuses on various parameters, including environmental and strata monitoring. The approaches and systems used are discussed in this section. Software has been introduced to unify observation and hazard prediction, enhancing safety and productivity in underground mines. The integrated software design includes several modules, as shown in Figure 1, which cover gas and environment monitoring as well as strata monitoring.

The modules are designed to encompass various aspects of mining on a single platform. Python is used for programming, while MySQL provides backend support. The software runs on a server, generating a web-based interface and real-time information that can be accessed through a browser. This web-based interface allows mine management to monitor real-time mine operations. Additionally, mine information can be accessed from any location within the coal mine with network access.

The software operates exclusively in online mode

- In real-time (online mode), live data from various sensors are continuously displayed on the software interface. Nodes transfer data from various areas to the Base Station (BS), which then relays the data to the gateway. The gateway subsequently transfers this data to the system via a serial port, where it is automatically saved in the database. In this operational mode, application software is used for monitoring, analyzing, storing, and viewing information obtained from sensor-connected nodes. It also provides email alerts and SMS notifications to mine administrators. Data is analyzed and stored in the database. The software continuously receives all data, predicts imminent explosive conditions, and displays live data. When a sensor value exceeds the threshold limit, an alarm is generated to indicate the affected environment zone using various color codes such

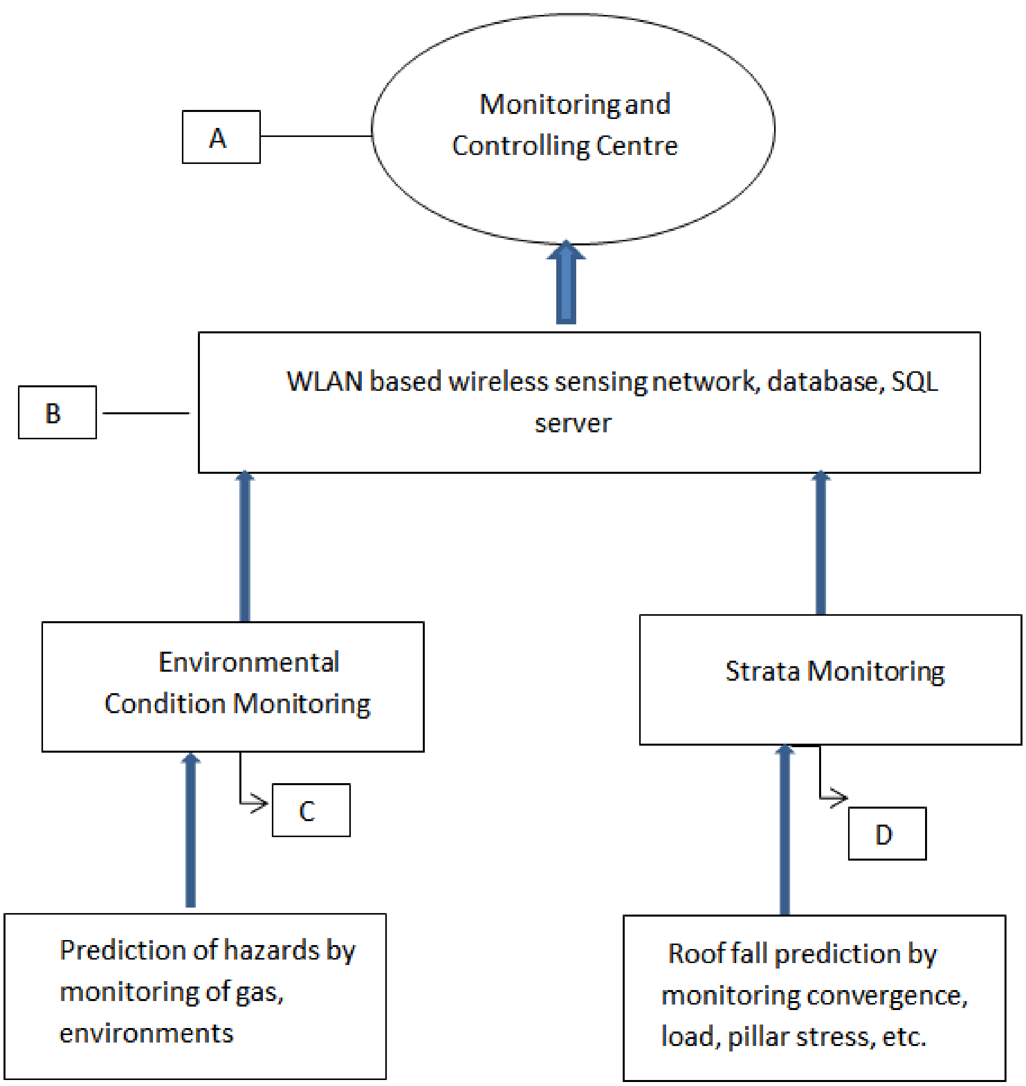

Figure 1. Block various digital mine modules.

as yellow, green, red, and orange. If a node is in a critical situation, SMS and email notifications are immediately sent to the respective individuals to ensure miner safety.

- In offline mode, users can view stored data by selecting the desired data file.
- In both operational modes, the software facilitates printing hard copies in either graphical or numerical formats, depending on user preference.

An administrator can adjust software settings, such as the mine plan's working area, scale units, router status and locations, and other essential parameters. Access and modifications are secured with password protection.

3.2.1 Environment Monitoring

This module monitors environmental conditions in sealed-off regions of an underground mine by tracking specific gas concentrations in the air, including SO_2, H_2S, O_2, and CO, to prevent potential disasters. Methane gas concentration is also monitored, as it is a primary cause of underground mine explosions. The system, model DM-O_2/SO_2/H_2S/CO-1, utilizes sensors, an ESP-01 Wi-Fi module, and an ESP8266 to upload wireless network data. This wireless LAN system is designed for low power consumption and digital signal transmission.

The sensor module includes individual gas sensors for SO_2, H_2S, O_2, CO, CO_2, NO_2, and CH_4, with each module featuring three main components: a sensor, an ESP-01, and a microcontroller. It operates within the ISM (Industrial Scientific Medical) frequency band and continuously monitors gas concentrations, sending data to the server for real-time monitoring of underground mine gases. The system comprises two main parts: the gas monitoring unit and the power supply unit.

The circuit power supply is provided by an external 12-volt intrinsically safe power source. Additional circuitry includes a high-quality voltage regulator for stable power supply and a fuse to protect against excess current. A current-limiting resistor is also used to regulate current flow within the circuit. The block diagram and circuit diagram of the gas monitoring system are illustrated in Figures 2 and 3.

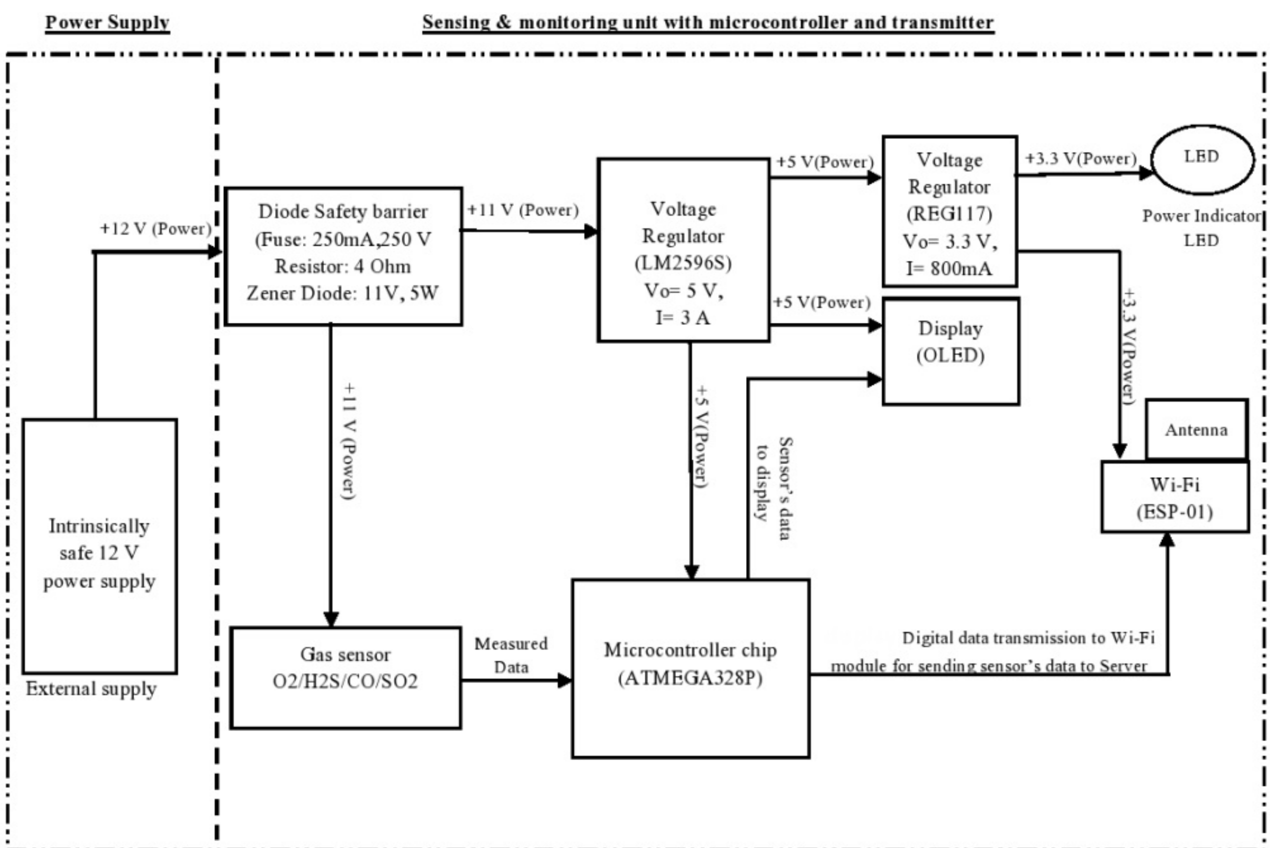

Figure 2. Block diagram: Gas monitoring system.

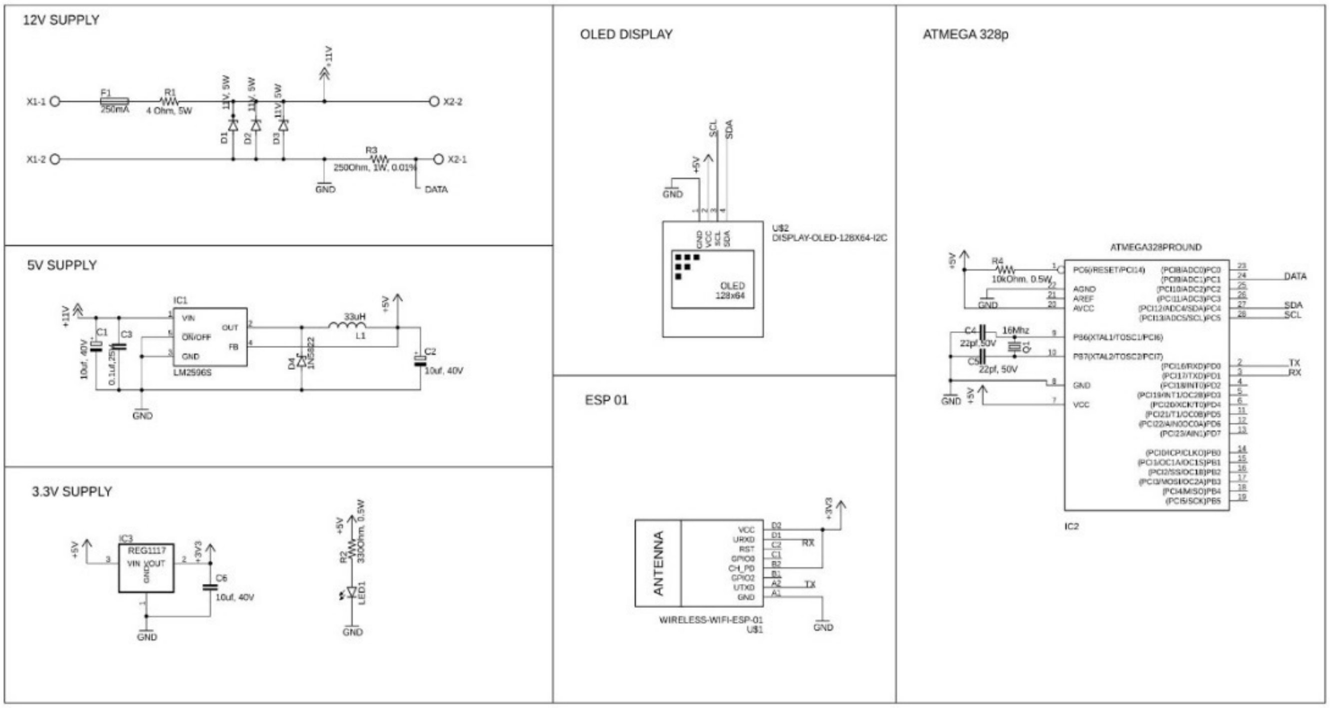

Figure 3. Circuit diagram: Gas monitoring system.

3.2.2 Technical Requirements

Technical requirements of the device and gas sensors are tabulated in Table 1 and Table 2. In addition, the threshold and radiated power is presented in Table 3.

The flow charts of Gas monitoring system along with hardware sensor modules are depicted below in Figure 4 - 5. Table 4 – 12 represent the calibration and performance of different sensors (O_2, CH_4, CO, SO_2, NO_2, CO_2, H_2S) in the laboratory.

4.0 Strata Monitoring

Strata monitoring employs a Wi-Fi network for the wireless transmission of sensor data. This data is continuously collected from various areas within underground operations and sent to the control room. The system tracks load and roof convergence and is managed by a microcontroller that provides audio and visual alarms in hazardous situations.

The software component of the system monitors, analyzes, and stores information received from sensor nodes, which is then saved in a database. The software continuously updates and displays real-time data for each parameter through a graphical interface. It also generates SMS and email alerts, including alarm notifications for supervisors. When sensor values exceed the threshold, the system automatically highlights the affected zone with different colors, triggering a pop-up window on the control room screen.

Table 1. Technical requirements of the device

S.no	Parameter	Values
1.	Temperature range of the operating ambient	-20°C to 50°C
2.	Microcontroller	Type: 8-bit AVR Programmable flash: 32KB RAM: 2KB
3.	Modulation	PWM (Pulse Width Modulation)
4.	Wireless-Standard Compliance	TELEC (Japan) ETSI EN 300 (Europe) FCC-Part 15.247 (USA)
5.	Voltage range of operating supply	10V to 35V, usually 12V
6.	Radio part	Receiver sensitivity: -91dBm Range of RF frequency: 2.4-2.41 GHz

Table 2. Technical requirements of O_2, SO_2, CO and H_2S

S.no	Parameter and its value	Sensitivity
	O_2 Sensor:	
	Operating voltage: 10V-35V	
1.	Measuring range: 0 to 25 %	
	Sensor-type: electro-chemical	
	Operating current: 90mA-200mA	
	H_2S Sensor	
	Operating voltage: 10V-35V	
2.	Measuring range: 0 to 200 ppm	
	Sensor-type: electro-chemical	
	Operating current: 90mA-200mA	
3.	*CO Sensor*	
	Operating voltage: 10V-35V	
	Measuring range: 0 to 2000 ppm	
	Sensor-type: electro-chemical	
	Operating current: 90mA-200mA	
	SO_2 Sensor	
	Operating voltage: 10V-35V	
4.	Measuring range: 0 to 20 ppm	0.5±0.1 uA/ ppm
	Sensor-type: electro-chemical	
	Operating current: 90mA-200mA	

Table 3. Radiated power and threshold power

Type	Threshold power
Gas monitoring system (O_2/SO_2/CO and H_2S) with model number DM-O_2/ CO/H_2S/SO_2-1	EIRP*antenna (3.28mW) Circuit device (3W)
Gas Group-I standard (IEC 60079-0, 2007)	6 W

The module integrates AI and mathematical models to graphically analyze and interpret sensor data. The hardware includes a microcontroller, convergence meter, ESP-01, and load cell sensor, along with other necessary electronic components for wireless data transfer. These components are installed at various locations in underground mines: the load cell is placed at the base support, and the convergence meter is mounted on the roof.

When activated, the module begins monitoring, reads the meter and load cell sensor values, and sends computed data to a designated IP address via the ESP-01. The software retrieves these values from the IP address and compares them to a set of threshold values. Based on this comparison, the software determines if strata movement is within safe limits, selecting and displaying the appropriate alarm or warning level from three options.

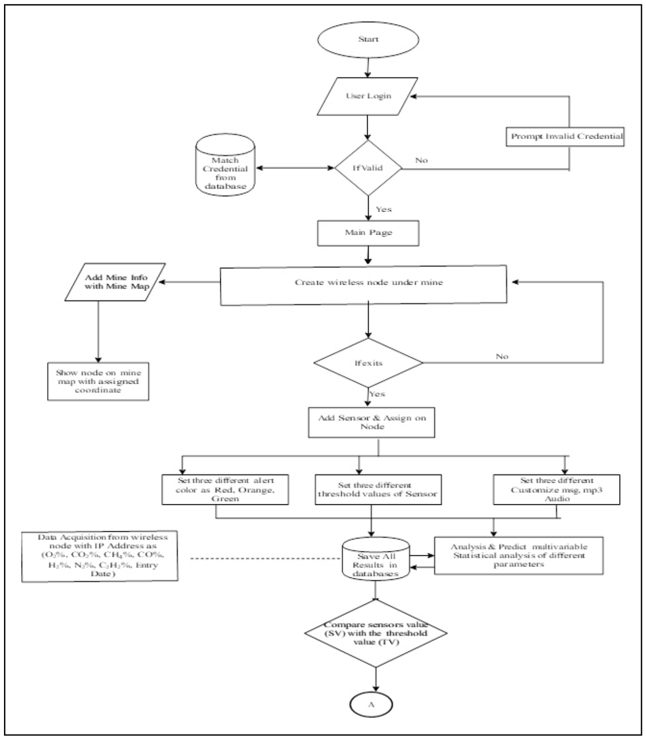

Figure 4. Flow chart of Gas monitoring system.

The device's threshold power is lower than the value recommended in IEC 60079-0. It operates within a temperature range of -40°C to 70°C, requires a 12V supply voltage, has a circuit current consumption of 250mA, and complies with the IEEE 802.11 wireless standard.

The IP-based strata monitoring device features a linear potentiometer with a piston length of 225 mm. It measures convergence changes up to 225 mm with an accuracy of 1 mm. The device is divided into four main components, as described below.

a. Convergence
b. Microcontroller – Atmeaga328
c. Load cell sensor
d. ESP-01

Initially, the analog output from the potentiometer is sent to a digital converter, then transmitted to the ESP-01 wireless module. This data is subsequently relayed to the server via a shared WLAN network. The convergence

(a)

(b)

(c)

(d)

(e)

Figure 5. **(a)-(d).** Different gas sensors in FLP enclosure. (e) Installation of sensors of gas monitoring system (O_2, H_2S, CO, SO_2, CO_2, CH_4, NO_2).

Table 4. Performance of O_2 sensor

Applied O_2 concentration (%)	Measured O_2 concentration by Digital Mine System Monitoring Device (%)					Average reading (%)	Measurement accuracy (± % of full scale division)
18.00	18.01	18.00	18.02	17.99	18.00	18.00	0.02
21.00 20.98		20.99	21.00	20.97	20.98	20.98	0.08
25.00	24.99	25.00	25.01	25.00	25.02	25.00	0.01
						Average accuracy	0.037

Table 5. Performance monitoring of CH_4 sensor

Applied CH_4 concentration (%)	Measured CH_4 concentration by Digital Mine System Monitoring Device (%)					Average reading (%)	Measurement accuracy (± % of full scale division)
0.75	0.74	0.74	0.76	0.74	0.78	0.75	0.27
1.50	1.47	1.52	1.47	1.55	1.59	1.52	1.33
2.50	2.48	2.49	2.53	2.49	2.39	2.47	0.96
						Average accuracy	0.85

Table 6. Performance monitoring of CO sensor

Applied CO concentration (ppm)	Measured CO concentration by Digital Mine System Monitoring Device (ppm)					Average reading (ppm)	Measurement accuracy (± % of full scale division)
75.00	74.15	74.05	73.98	73.90	74.98	74.21	1.05
100.00	99.99	99.98	98.59	98.99	99.50	99.41	0.59
200.00	200.01	200.04	200.02	200.01	200.06	200.02	0.01
						Average accuracy	0.55

Table 7. Performance monitoring of SO_2 sensor

Applied SO_2 concentration (ppm)	Measured SO_2 concentration by Digital Mine System Monitoring Device (ppm)					Average reading (ppm)	Measurement accuracy (± % of full scale division)
10.00	9.00	9.00	9.00	11.00	11.00	9.80	2.00
50.00	48.00	49.00	50.00	49.00	51.00	49.40	1.20
100.00	98.00	97.00	96.00	98.00	102.00	98.20	1.80
						Average accuracy	1.67

Table 8. Performance monitoring of NO_2 sensor

Applied NO_2 concentration (ppm)	Measured NO_2 concentration by Digital Mine System Monitoring Device (ppm)					Average reading (ppm)	Measurement accuracy (± % of full scale division)
5.00	4.85	5.00	4.60	5.30	5.10	4.97	0.60
10.00	9.94	10.06	9.80	9.60	10.50	9.98	0.20
20.00	19.50	19.60	18.90	20.20	20.40	19.72	1.40
						Average accuracy	0.73

Table 9. Performance monitoring of CO_2 sensor

Applied CO_2 concentration (%)	Measured CO_2 concentration by Digital Mine System Monitoring Device (%)					Average reading (%)	Measurement accuracy (± % of full scale division)
1.50	1.45	1.47	1.49	1.51	1.54	1.49	0.53
2.50	2.44	2.46	2.49	2.49	2.53	2.48	0.72
3.50	3.42	3.42	3.44	3.46	3.44	3.43	1.83
						Average accuracy	1.03

Table 10. Performance monitoring of H_2S sensor

Applied H_2S concentration (ppm)	Measured H_2S concentration by Digital Mine System Monitoring Device (ppm)					Average reading (ppm)	Measurement accuracy (± % of full scale division)
15.00	14.95	14.90	14.45	14.78	14.52	14.72	1.87
25.00	26.16	26.02	25.05	25.08	25.10	25.48	1.93
200.00	199.19	199.20	199.60	199.80	199.66	199.49	0.25
						Average accuracy	1.35

meter, which includes an on-board display, allows miners to view the convergence status directly. Sensors collect data from the underground mine, which is then sent to the Microcontroller Unit (MCU) and forwarded to the software via the server. The software compares these values to predefined threshold values and generates three types of audio and visual warnings if needed. It also produces reports and alerts mine management via email or SMS based on the severity of the detected danger. The system provides real-time monitoring of load and roof convergence, with data recorded by location in the database. The device operates with a maximum input voltage of 12V from the internal battery, which is regulated down to 3.3V and 5V using the REG1117 regulator and LM2596S. This ensures that component analysis for strata monitoring is performed at the required voltage levels. The circuit diagram for the strata monitoring system is shown in Figure (3, 6, 7-9).

Table 11-13 lists technical specifications of strata monitoring system, sensors, threshold power, input and output details, etc[15].

5.0 Software Description

This section outlines the varying outputs of each module, focusing on the monitoring phase and ensuring the safety of miners during the mining process. The results are generated by executing the application software module by module, according to the specified objectives. The application software modules handle tasks for both Strata Monitoring and Mining Environmental Monitoring phases. The Digital Mine Software is designed to enhance productivity and maximize mine safety by integrating sensor technology, computing power, and Wi-Fi-based network technology. The software comprises various components and modules, each contributing to determining environmental conditions and strata monitoring. The software produces effective results that assist mining managers and individual users in tracking environmental status and strata conditions within the mining environment. Outcomes are generated through the execution of Python for the front end and MySQL for back-end support. Typically, the results are obtained during the software's execution on the server side. Web-based screenshots and real-time data are accessible via a browser, and the software can be accessed from any location

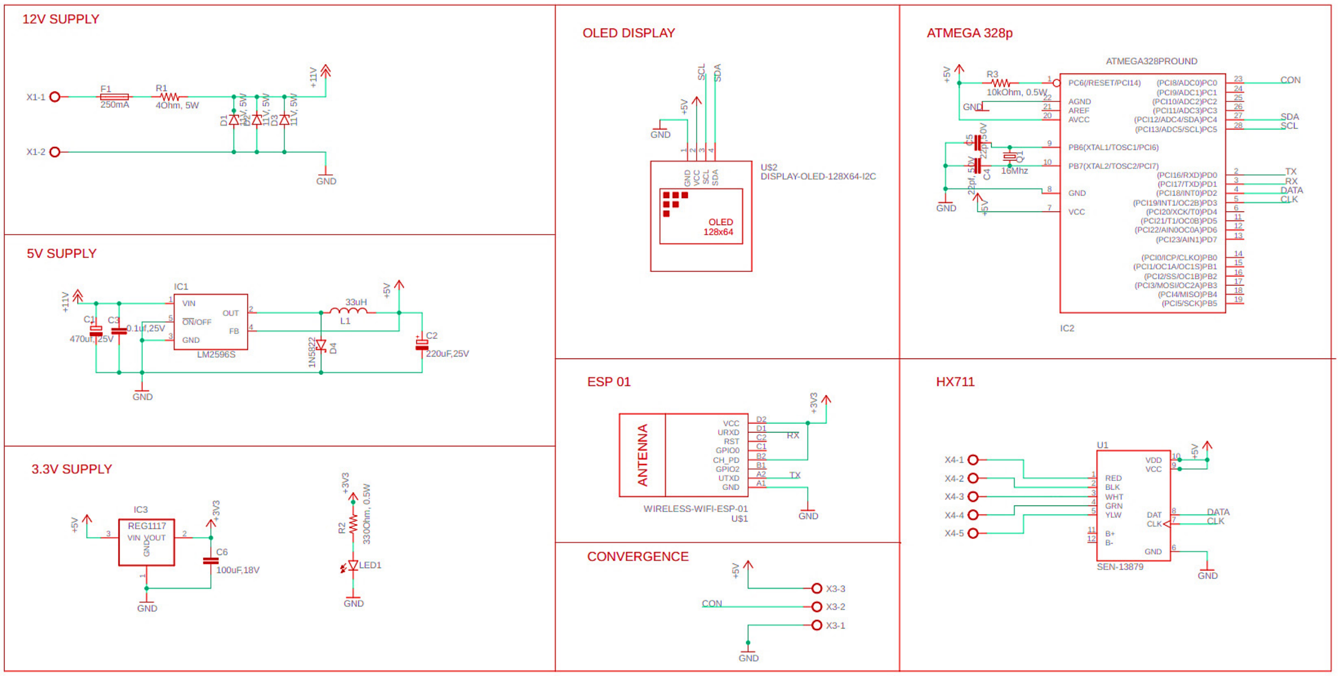

Figure 6. Circuit diagram: Strata monitoring device.[15]

Table 11. Technical specification of the strata monitoring device

Parameter	Values
1. Operating ambient temperature range:	– 40 ° to 70 °C
2. Operating supply voltage range:	12V
3. Current consumption of the circuit:	250 mA
4. Microcontroller	
• Type	ATmega328P
• EEPROM	1K Bytes
• Programmable flash	32K Bytes
• RAM	2K Bytes
5. Wireless standard compliance:	IEEE 802.11

Table 12. Technical specification of the sensors

Sl. No.	Sensor	Measurement Range	Output
1	Convergence meter	Max 225 mm	mV
2	WBK-EXP Load cell	Max 50 Tonne	mV

Table 13. Threshold power and radiated power of the sensors

Type	Threshold Power
Standard for Gas Group I (IEC 60079-0, 2007)	6.0 W
Strata Monitoring Device (DM-SM-1)	3 W (Device of the circuit) 3.28 mW (EIRP * of the antenna)

(a) (b) (c)

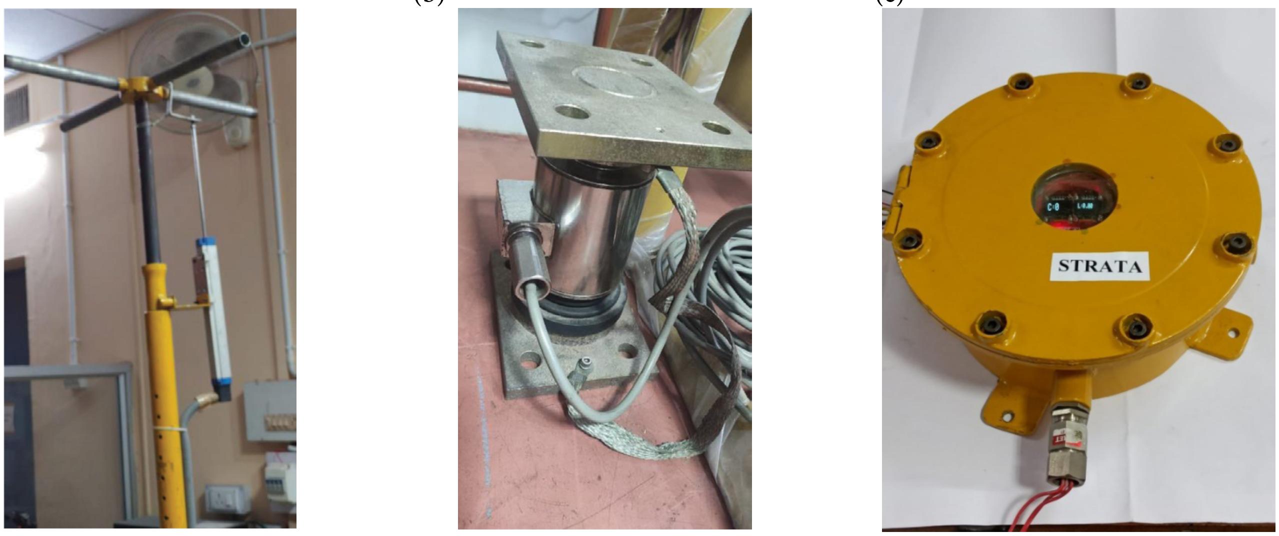

Figure 7. Strata monitoring system having the (a) convergence sensor (b) Load cell (c) flame proof data reading circuit with displayed[15].

a.

b. c.

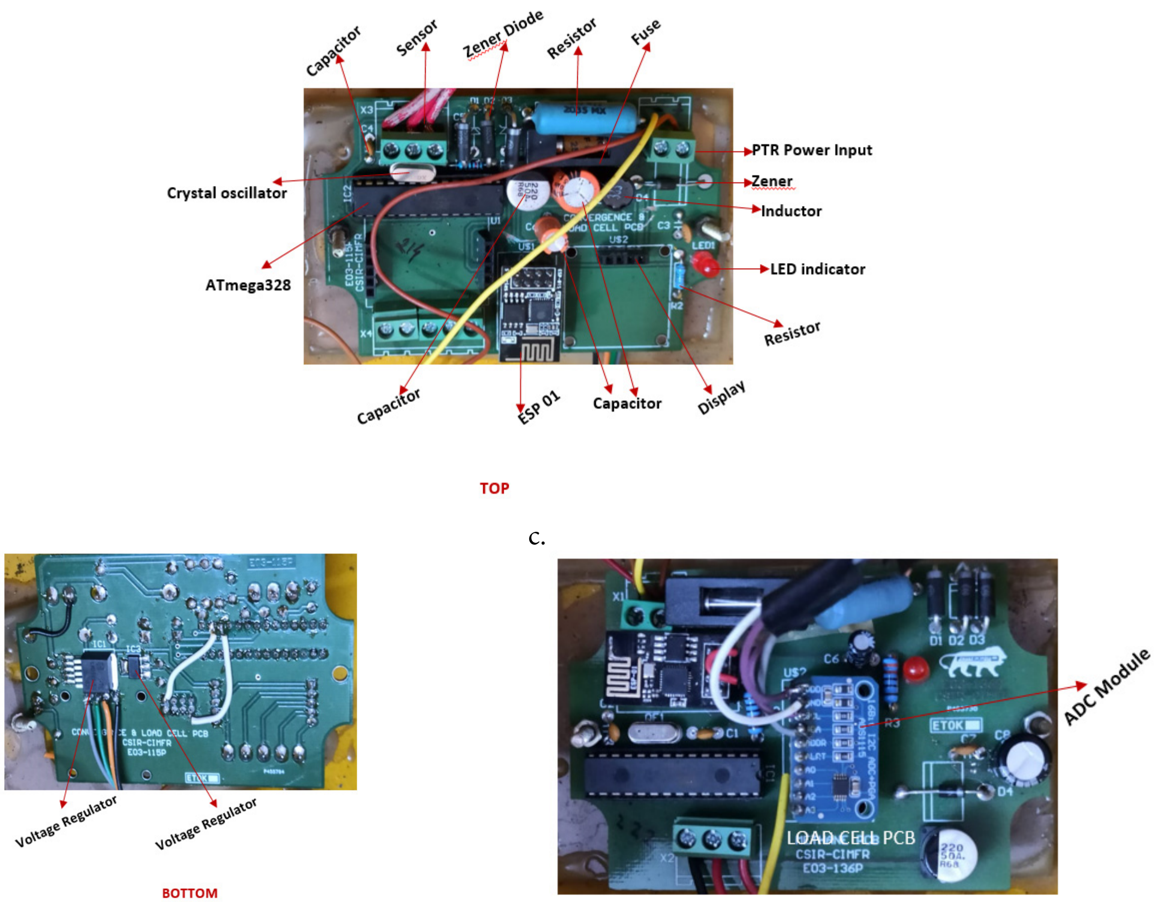

Figure 8. (a) Top view of the convergence circuit, (b) Bottom view of convergence circuit, (c) printed circuit board of the strata monitoring device.[15]

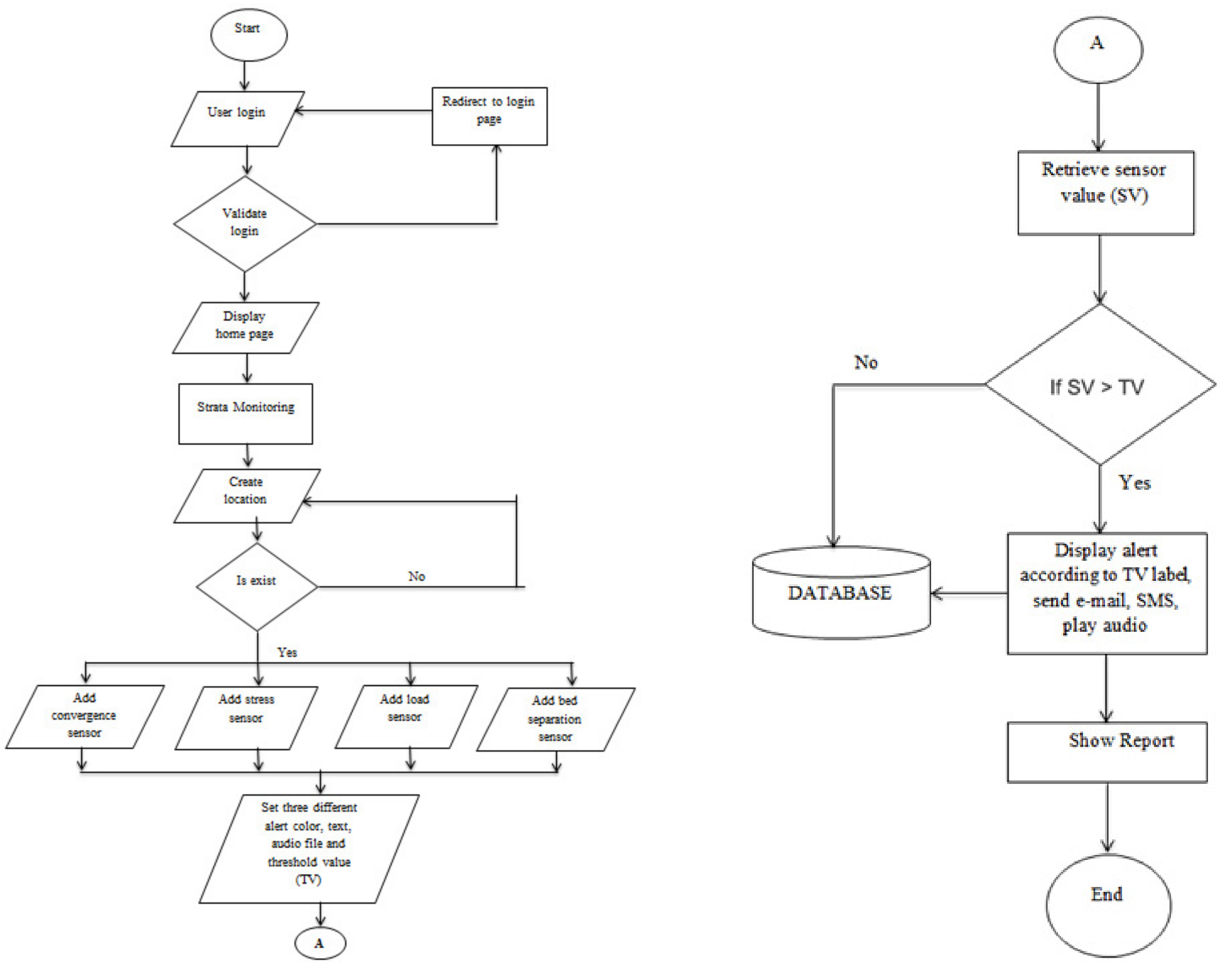

Figure 9. Flow chart for Software Development for Strata Monitoring System.[15]

within the mining site. Mining-related information is displayed through graphical representations and map-based interface reports.

In the application software, data is continuously received, environmental conditions are predicted, and monitoring processes for both environmental and strata data are managed. Users log in to the software through an authentication process using a username and password. Upon successful login, the software's home page and dashboard appear, featuring various components as illustrated in Figures (10-13).

1. System Login process, through authentication by Valid User-name and User password
2. Then the user would be directed to the default home page after the login phases.
3. Traverse to Environmental monitoring option → Select Manage Wireless node, seen as the first label → After clicking the option, select add Wireless-node button on that manage page.

Move to Monitoring option → Select Environmental Monitoring option → Select Add Wireless-node option from the respective navigation bar.

The selection will yield you an appropriate Wireless node page. All the details related to the Wireless node are filled up in the page. After this, X-axis or then Y-axis is clicked. The selection adds the exact node location in the specified place.

After the process, the map is opened, such that the wireless node is located in a specific physical address. After node location in map, the escape key is pressed, which exits map.

4. For any node creation, create node-button is pressed for any wireless node addition to the application database. After the addition of a wireless node in the database, the next page directs

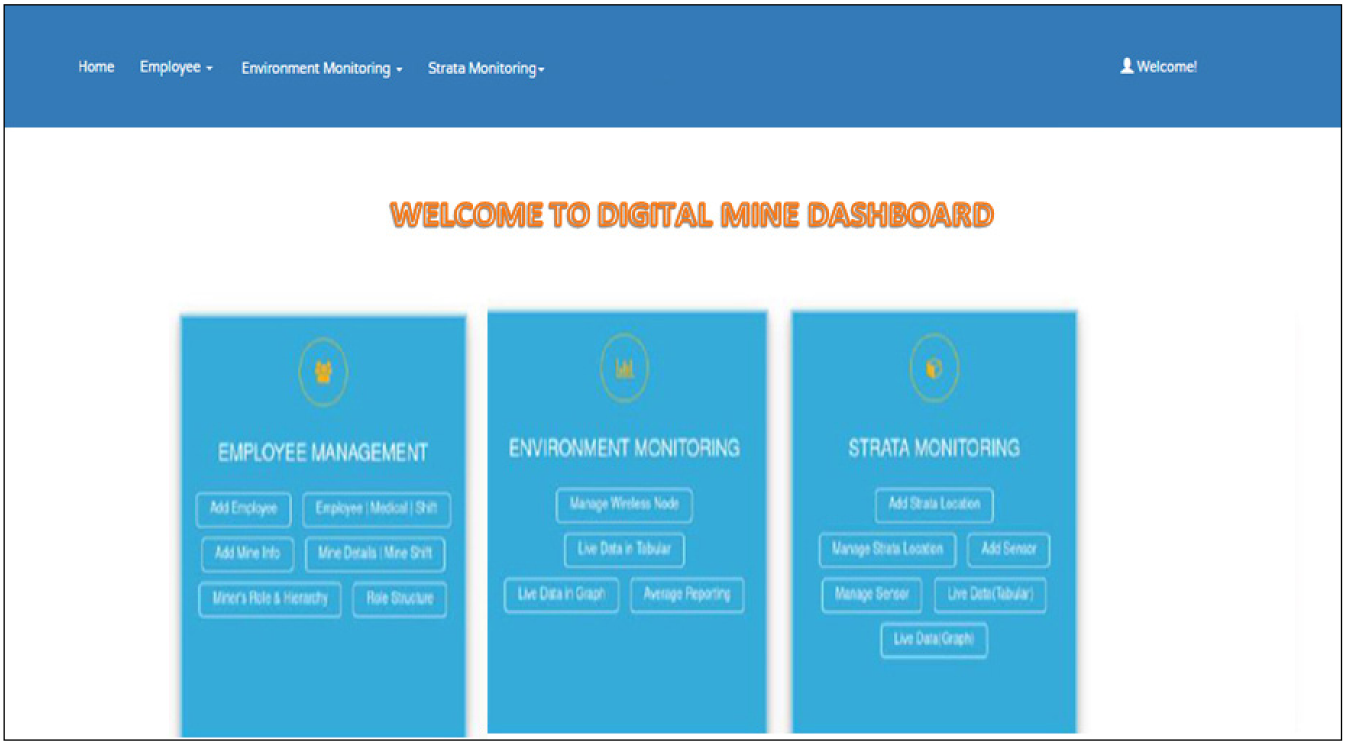

Figure 10. Properties of Dashboard.

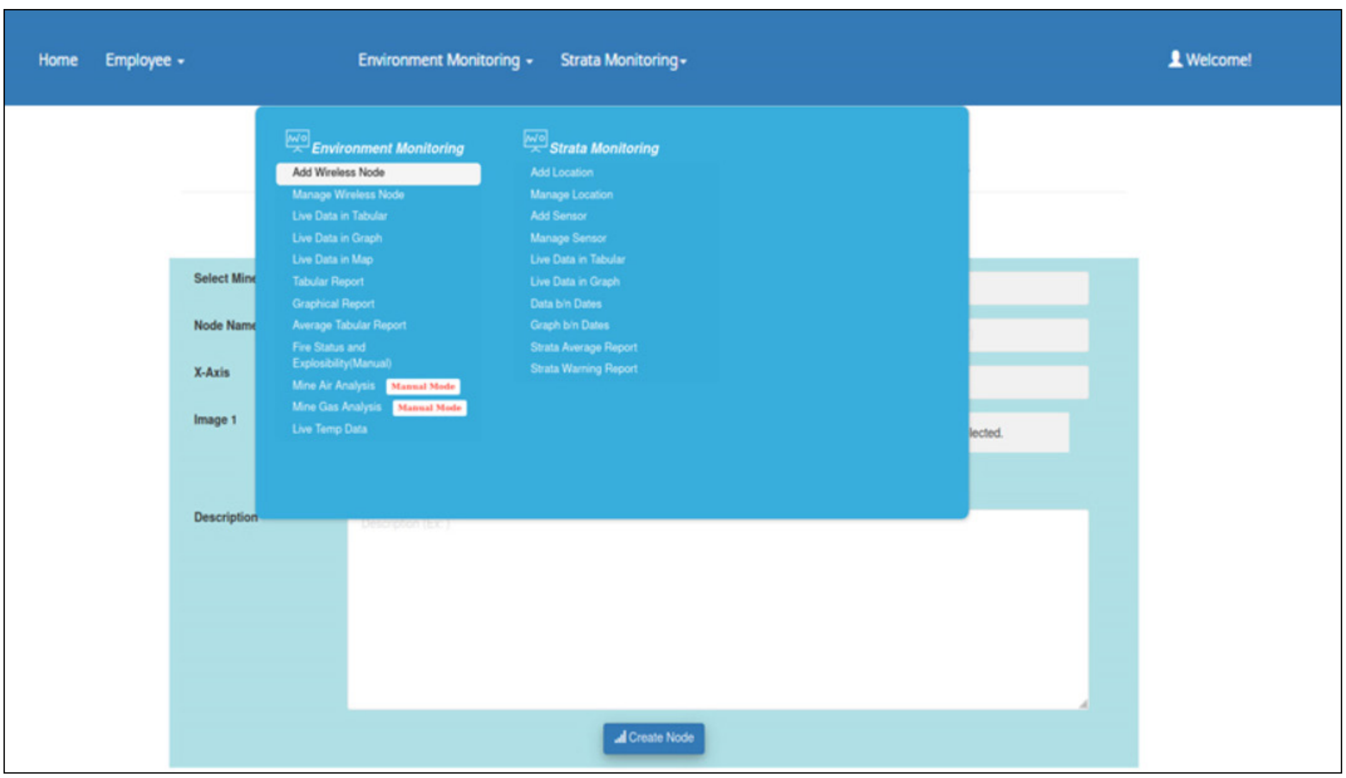

Figure 11. Add Wireless Node Option.

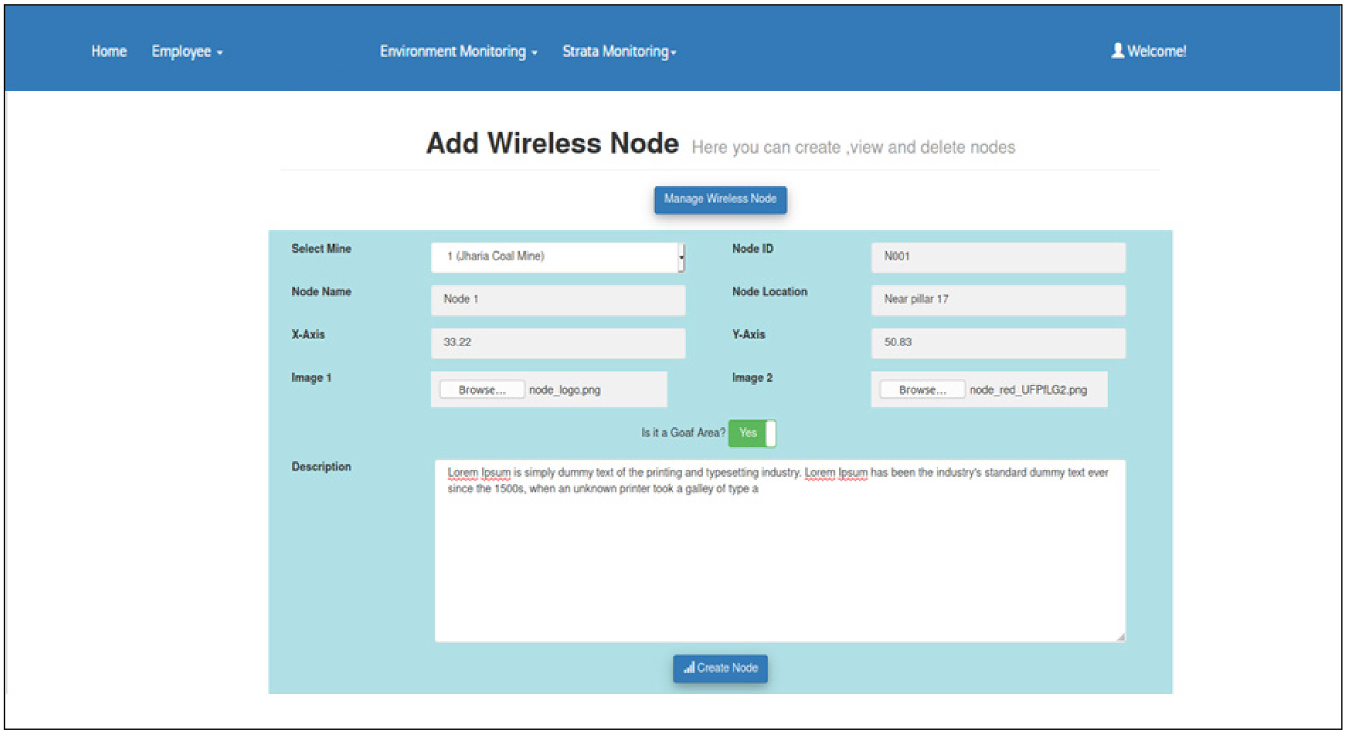

Figure 12. Wireless Node Details in Data Form.

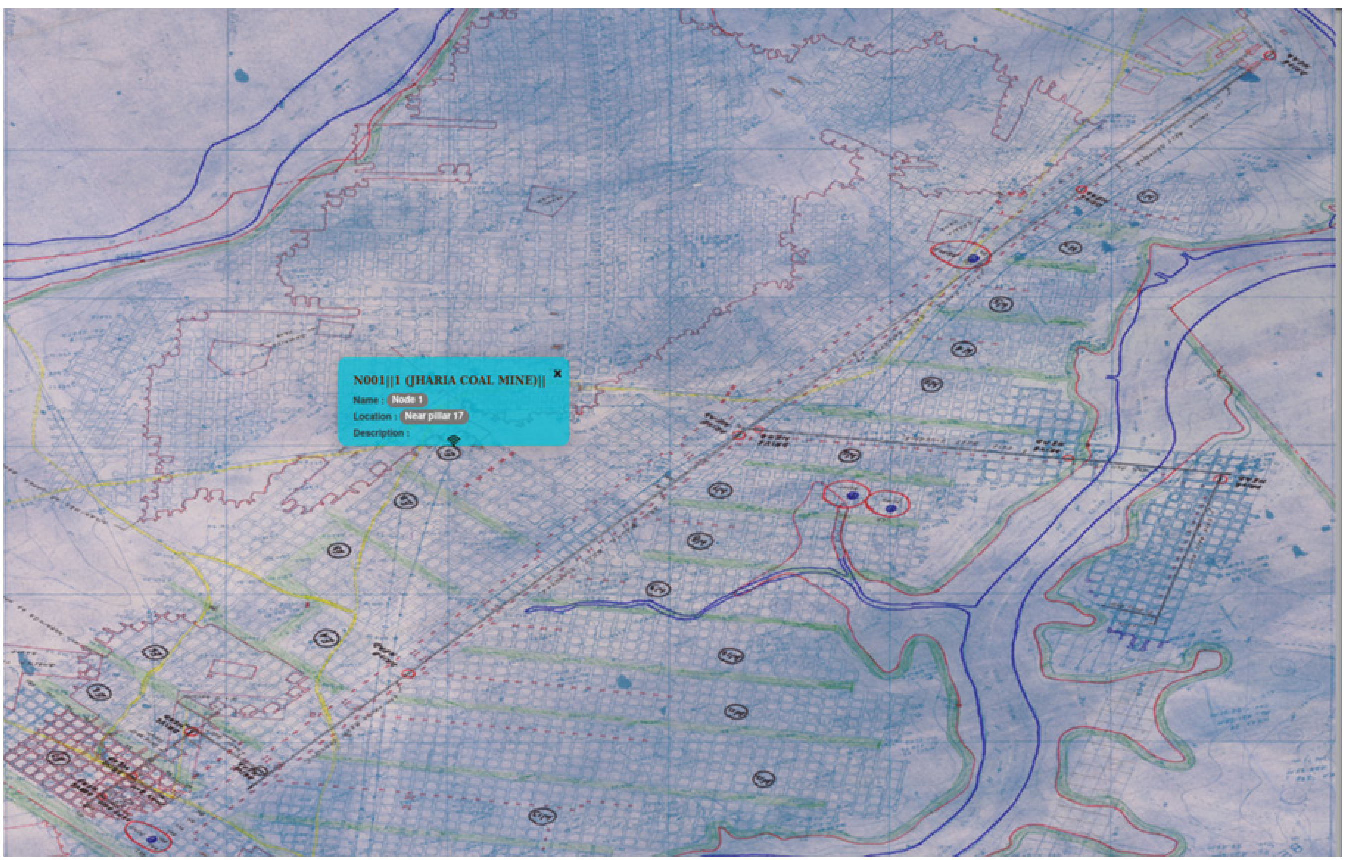

Figure 13. Incorporation of wireless nodes at designated locations on the mine map.

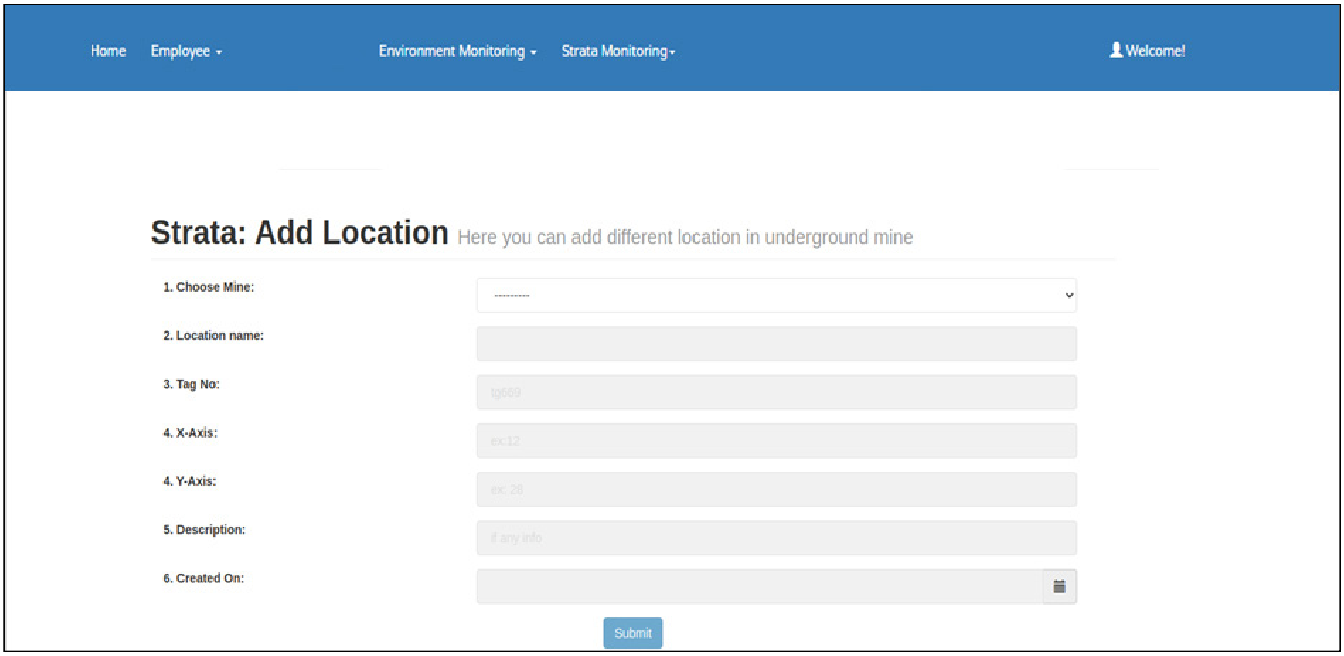

Figure 14. Adding Locations to Mining Sites.

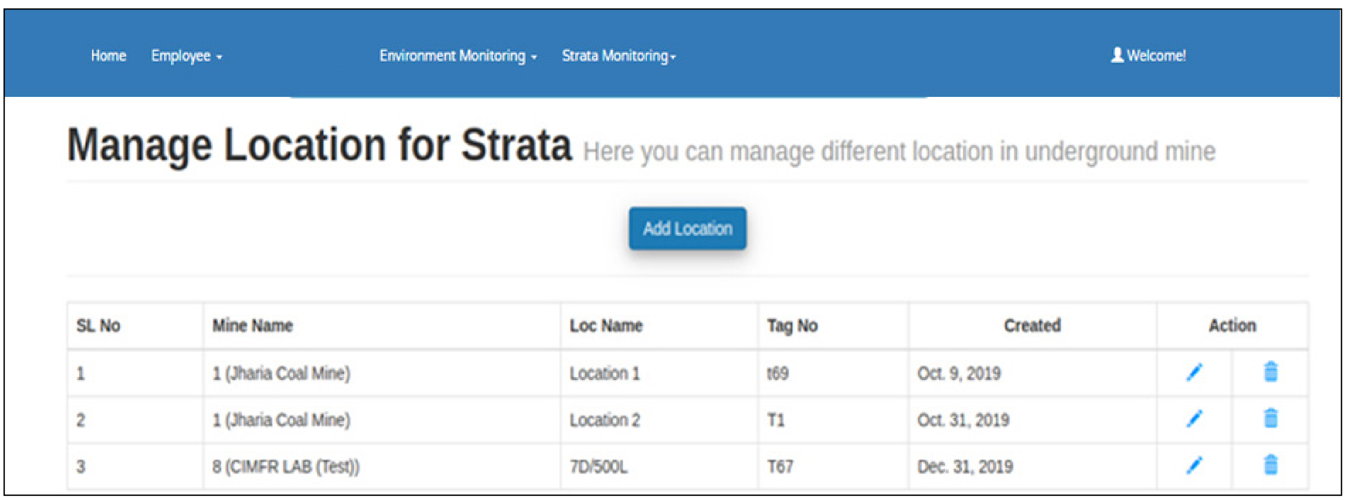

Figure 15. Strata Location Administration.

the user to manage the Wireless node. (Manage Wireless-node option).

6.0 Strata Monitoring System

The strata monitoring analysis and control were conducted using sensors attached to miners or placed at specific locations. This analysis provides valuable data on strata conditions, enabling managers or users to develop preventive strategies and measures in advance. The strata monitoring module estimates roof fall risks by continuously monitoring strata conditions in goaf sites or working areas of underground mines using IoT-enabled sensors. These sensors collect real-time data from the mines and periodically verify the sensor values against predefined threshold values. The data is transmitted to a microcontroller unit, which then communicates with the designated software through the server. The application generates various reports and audio-visual warnings based on the data. The module's operations provide detailed information on strata monitoring, and the results are depicted accordingly. The application system employs two

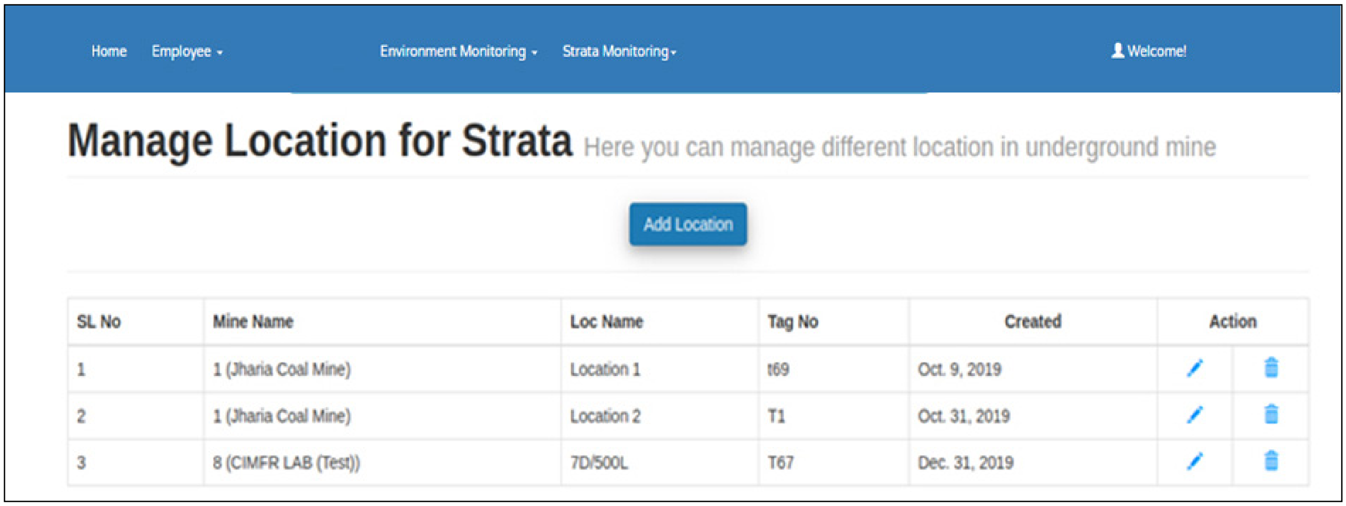

Figure 16. Removing a Location (via the trash icon).

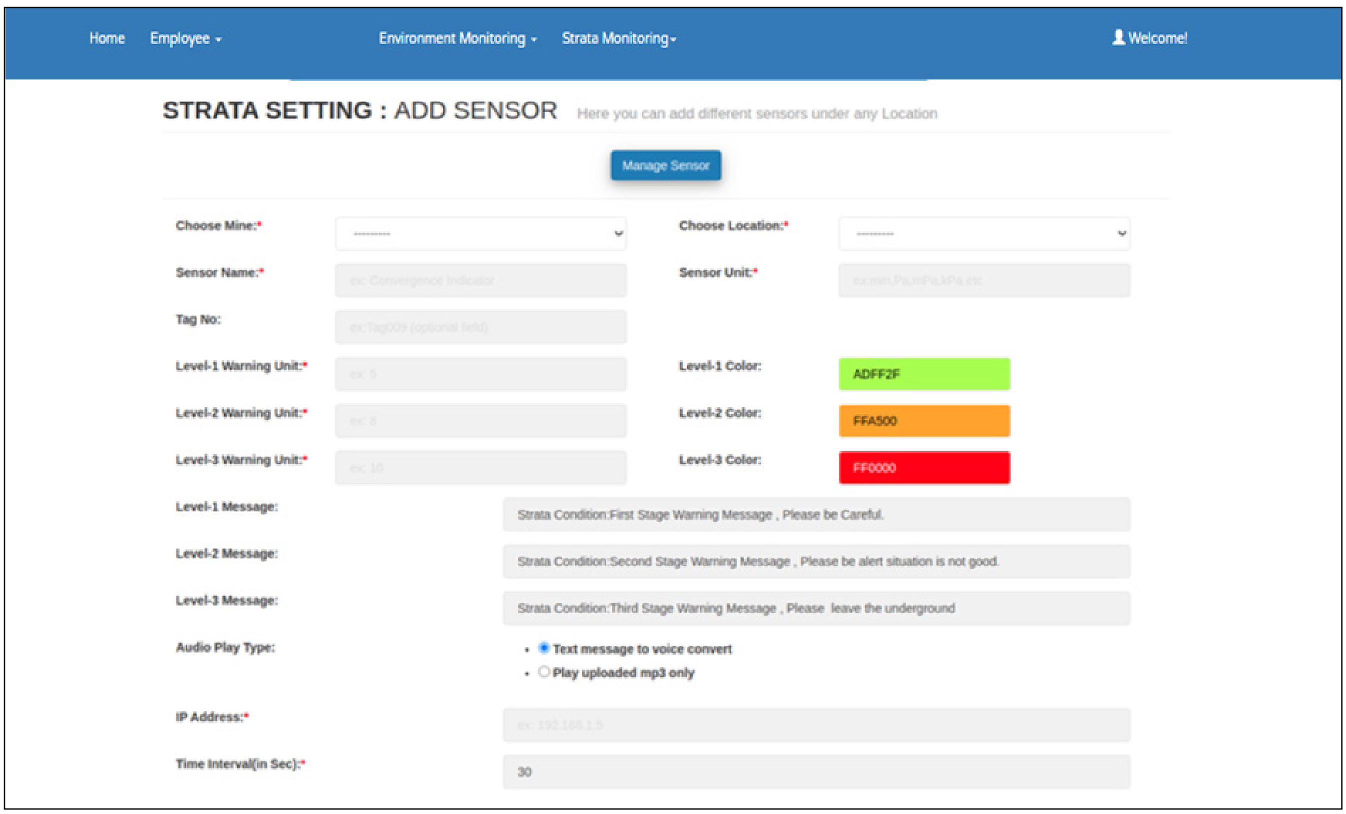

Figure 17. Configuring and Managing Sensors for Strata Monitoring.

types of sensors: load cells and roof-convergence sensors. These sensors measure various strata conditions, including bed separation of the mining roof, roof load at specific points, roof convergence, and stress on pillars. Additionally, the module assesses rock-mechanical parameters such as convergence, dilation load, and roof stress to ensure safe strata control for miners. Before assigning employees or starting operations, the site must complete the following steps to prepare for the monitoring process (Figure 14 -17).

Click on the Home icon → click on monitoring option → then select Add location option from drop-down menu options.

After selecting the “Add Location” option, a new data form appears. This form includes fields such as Choose Mine, Location Name, Tag Number, X-axis Notation, Y-axis Notation, Created Date, and Location Description. Once all the required information is entered, clicking the Submit button saves the data to the database. Similarly, the “Manage Location” option allows for the manipulation or management of existing locations. To access this feature, go to the Home menu, select the Monitoring option, and then click on “Manage Location.”

Figure 15 illustrates the screen that appears after selecting the “Manage Location” option. This window presents a table listing all previously added strata locations. The table includes columns for Mine Name, Location Name, Tag Number, Actions, and Creation Date, allowing users to view and manage location details effectively.

Through the figure 16, it is clearly revealed that the particular location entry could be added or deleted from the tabular lists. The information can be added through “Add location” in the topmost space. The Entry of location could be deleted through clicking down the Trash icon. In similar to the above feature, the sensor could be managed or added to the location site through performing steps such as Click Home menu → Select Monitoring option → from the drop-down options, select “Add Sensor” option. As soon as the option is clicked, the new data form is shown as below.

The above Figure 17, represents the data form of “Add Sensor” option. The data form consists of several fields, such as mine name, Level-1 message, level-2 message, level-3 message, Audio play-type, Name of a sensor, Tag number, IP address of sensor, Time-interval Level-1 colour, level-2 colour and level-3 colour, location of the sensor and the Sensor units. These all the fields need to be given for inputs by the user. With respect to the conditions monitoring, various messages are displayed in sensors. The Warning messages are defined in the sensor addition step. Level-1, Level-2 and level-3 messages can be defined as per the severity conditions. The respective colour for respective message levels is denoted in green, yellow and red colour. The Audio could be defined by converting the text message to audio signals. The feature may alert the miner more predominantly, and good significance is based on the severity. The prior information safeguards the miners from hazardous occurrences.

The study’s findings detail the results from various research modules, including environmental and strata monitoring phases. The software modules and parameters are designed to create a safe and efficient working environment in the mine, enhancing miner safety. The application software is used to store, analyze, view, and monitor data from sensors connected to various nodes in the workplace. It features capabilities for sending email alerts, messages, and visual notifications to mine administrators. All results are saved in a database, and the software employs integrated artificial intelligence and mathematical models to estimate changes in sensor data. If sensor data deviates from the threshold values, a pop-up alert appears on the control room’s monitoring screen. The study provides a graphical representation of the data obtained from sensors, showcasing the module options through tabular formats and graphs. The dashboard displays real-time data, consolidating all parameters into one view to facilitate oversight of mining activities and employee safety by management. The experimental results, covering both Environmental Monitoring and Strata Monitoring phases, are comprehensively presented in the study.

7.0 Conclusion

The mining sector presents a highly hazardous work environment, exposing workers to significant risks such as gas explosions, fires, and roof collapses. These dangers underscore the necessity of safeguarding miners by providing early warnings about potential hazards. Recent advancements in IoT-enabled monitoring and smart tracking systems aim to enhance safety in underground coal mines. While traditional research has explored protective measures for miners, there has been limited focus on applications specific to India. Existing studies that address coal mine safety in India often fall short in real-time monitoring and tracking capabilities. This research offers recommendations to address these gaps and improve the effectiveness of mine safety systems. Proposed enhancements include increasing packet delivery efficiency and reducing packet loss. Future work could involve experimental analysis of various network parameters such as network lifetime, communication costs, coverage area, and energy consumption. Robustness remains a critical challenge in mine monitoring systems. Future research could explore the development of more advanced frameworks and sensors to better assess underground mine hazards. Additionally, there is potential for creating more sophisticated IoT frameworks to further improve safety measures in mining environments.

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