Contents

List of Figures

Chapter 1

Introduction

1.1 General Introduction

Coal mining is a vital industry that contributes significantly to energy production worldwide. However, it is inherently hazardous due to risks such as gas explosions, roof collapses, flooding, and equipment-related accidents. Ensuring the safety of miners has always been a primary concern, necessitating the implementation of robust monitoring and communication systems

Wireless communication networks have emerged as a transformative solution for enhancing coal mine safety. Traditional wired systems face challenges like susceptibility to damage, high maintenance costs, and limited flexibility in dynamic mining environments. In contrast, wireless technologies provide real-time monitoring, seamless data transmission, and improved adaptability, making them ideal for underground operations.

This system integrates sensors, wireless communication devices, and centralized monitoring stations to detect and respond to critical parameters such as gas concentrations, temperature, humidity, and miner location. Advanced technologies like Wi-Fi, and LoRa enable the transmission of data from underground to surface-level control rooms with minimal latency. Moreover, the integration of IoT (Internet of Things) devices and machine learning algorithms further enhances predictive maintenance and accident prevention.

By leveraging wireless communication networks, coal mines can achieve a safer working environment, reduce the likelihood of accidents, and enhance rescue operations in case of emergencies. This approach not only improves the operational efficiency of mines but also prioritizes the well-being of workers, aligning with modern safety standards and regulations.

1.2 Scope of the Project

The scope of a coal mine safety monitoring system encompasses a comprehensive range of technologies and functionalities designed to ensure the safety and efficiency of mining operations. These systems monitor environmental parameters such as gas concentrations, temperature, humidity, and seismic activity to detect and mitigate hazards like explosions, cave-ins, and flooding.

They track the real-time location of workers using advanced technologies like RFID and GPS, enabling swift rescue operations during emergencies. Additionally, wearable devices and automated machinery enhance worker safety by reducing exposure to high-risk conditions. The systems also include wireless communication networks for seamless real-time data transmission and emergency alerts, ensuring effective coordination between underground and surface teams.

Integrating cutting-edge technologies like IoT, artificial intelligence, and edge computing further improves hazard prediction, decision-making, and regulatory compliance. Ultimately, coal mine safety monitoring systems play a critical role in protecting workers, optimizing operations, and fostering a safer mining environment.

1.3 Problem Statement

Coal mining operations, especially underground, pose significant safety risks due to hazardous conditions like gas leaks, equipment failures, and poor visibility. Traditional safety measures are often reactive and fail to provide real-time monitoring and alerts. Communication challenges in underground mines further hinder timely response to emergencies. There is a need for a reliable, wireless safety system that can continuously monitor miners' health, environmental conditions, and equipment status. This project aims to develop a real-time, wireless communication-based safety system to enhance miner safety and improve emergency response.

1.4 Objectives:

1. To Design and implementing security and detection of hazards inside a coal mine.

2. To Monitor critical environmental parameters such as methane gas levels, temperature, humidity, and air quality in real time. Detect early signs of fire, gas leakage,

and equipment malfunctions.

3. Collect and store real-time and historical data for analysis, enabling proactive identification of risks and improved safety protocols.

4. Enable miners and the control center to exchange critical messages through the LoRa network during emergencies.

5. Automatically trigger alarms or notifications to miners and the control center in case of hazardous conditions, such as toxic gas leaks, high temperatures, or structural instability.

1.5 Methodology:

- System Design: The system is divided into two main units— a transmitter unit worn by miners and a receiver unit located in the control room. The transmitter unit includes sensors, a NodeMCU (ESP8266) for data collection, and an ESP32 camera for image capture. The receiver unit, connected to the control room, receives and displays data in real-time, allowing mine operators to monitor conditions continuously and remotely.

- Data Collection: The transmitter unit gathers key environmental data using sensors: temperature (to detect overheating), humidity (to assess air moisture), and gas levels (such as benzene or ammonia). This data is essential for identifying dangerous conditions like excessive heat or toxic gas presence in the mining environment. The ESP8266 controller processes the data before it is transmitted to the control room

- Data Transmission: Using LoRa (Long Range) technology, the system enables efficient, low-power, and long-distance data transmission from the miner's location to the control room. LoRa is especially suitable for underground environments, as it works well in areas where internet connectivity is limited, ensuring reliable data flow in remote and hard-to-reach areas of the mine.

- Alert Mechanism: When sensor readings exceed safe thresholds (e.g., high gas levels or dangerous temperature spikes), an alert is triggered automatically. The ESP32 camera captures an image of the environment, which is then sent via email to authorized personnel. This early alert system allows quick response actions, potentially saving lives and preventing accidents.

- Data Display and Analysis: In the control room, sensor data is displayed in real-time on an OLED screen for continuous monitoring. Additionally, the data is sent to ThingSpeak, an IoT analytics platform, which aggregates, stores, and visualizes the information. This setup enables operators to observe trends and historical data, which can help in identifying potential risks and improving preventive measures.
- Software Implementation: The system is programmed using Arduino IDE, which allows for easy integration and configuration of microcontrollers and sensors. ThingSpeak serves as the data storage and visualization platform, enabling cloud-based data analysis and providing real-time insights into mine conditions. This combined software approach supports remote monitoring and enhances decision-making based on live data.

1.6 Limitations

1. Limited Range of LoRa Modules: LoRa modules, while offering long-range communication, still have certain limitations in underground environments, such as signal attenuation due to thick rock and soil. The range may be further reduced depending on the depth and layout of the mine, affecting the reliability of the wireless communication network.
2. Power Consumption: NodeMCU and Arduino Uno, combined with LoRa modules, require power sources for operation. In remote and underground environments, providing consistent and reliable power to these devices can be challenging, especially for extended periods. Battery life may be limited, requiring periodic maintenance or replacement, which could disrupt mining operations.
3. Environmental Interference: Underground mines are prone to various environmental conditions, such as high humidity, dust, and electromagnetic interference, which may degrade the performance of the wireless communication system. These factors could impact signal strength, reliability, and the accuracy of transmitted data.
4. Limited Data Throughput: LoRa communication is optimized for low-power, low-bandwidth applications. The system may struggle to handle high volumes of data,

especially if real-time video surveillance or complex sensor data needs to be transmitted alongside basic safety information. This could lead to delays in data transmission or loss of critical information.

5. Latency Issues: Although LoRa is known for its long-range capabilities, it may experience latency when multiple devices are transmitting data simultaneously, especially in a dense network. This could delay the processing of emergency signals or safety alerts, potentially compromising the timeliness of interventions.

6. Interoperability Challenges: The integration of various technologies (NodeMCU, Arduino Uno, LoRa modules, and ThingSpeak) may encounter compatibility or synchronization issues. Ensuring smooth communication and data transfer between all components in an underground mine environment can be technically complex and may require continuous maintenance and troubleshooting.

7. Limited Real-Time Monitoring and Processing: While ThingSpeak offers cloud-based data storage and analysis, its real-time monitoring capabilities are limited by internet connectivity. In underground mines, consistent internet access may be unreliable or non-existent, affecting the ability to send data to ThingSpeak for immediate analysis and monitoring.

8. Safety in Critical Failure Scenarios: In case of critical system failures, such as sensor malfunctions or communication breakdowns, the system may not provide the necessary alerts or safety notifications.

9. Data Security and Privacy: With the system transmitting safety-critical information over wireless networks, there are potential risks regarding the security and privacy of the data.

1.7 Organisation of the Report

The report is organized into five chapters.

The **Chapter 1** includes the introduction about the project with objectives, scope of the project, methodology and limitations.

The **Chapter 2** contains the theoretical information about the components and their assembly with IEEE Papers.

The **Chapter 3** includes implementation and design of the project and a brief explanation about circuit diagram and the components used in the project.
The **Chapter 4** contains about the Results of the project and Outcome of the project that obtained after implementing this project.
Finally, **Chapter 5** presents the project's conclusion based on the data gathered from the project model. Depending on the outcome, additional work has been proposed regarding the implementation of this model in the future and its improvement.

Chapter 2

Theoretical Background

This chapter provides a comprehensive literature survey and explores the theoretical concepts essential for understanding the project.

2.1 Literature Survey

[1]Thangam, S., Aryan Kothari, V. R. N. S. Nikhil, Namana Rohit, and J. Jesy Janet Kumari. "Intelligent Safety Helmet For Miners Using Arduino Leveraging Support Vector Machines." In 2024 Second International Conference on Networks, Multimedia and Information Technology (NMITCON), pp. 1-9. IEEE, 2024.

The paper focuses on creating a smart helmet designed to improve safety awareness among miners by addressing challenges such as noisy environments and discomfort associated with traditional safety gear. Each miner will carry a unique tag for identification, and the helmet will use IR sensors to detect its presence, ensuring that workers are wearing their helmets properly. The helmet is equipped with a gas sensor to detect hazardous gases in the mining environment. If dangerous gases are detected, a voice notification will alert the miner via a speaker. A MEMS sensor is used to detect head injuries, and all sensor data, including gas detection and injury alerts, is transmitted to a PC using ZIGBEE transceivers for real-time monitoring and response.

[2]Banu, Sufia, Rashmi Rani Samantaray, Hajira Zaiba, Abdul Rehaan, Mansha Yasin, and Arun Kumar. "Power Efficient Intelligent Helmet for Coal Mining Security and Alerting." In 2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS), pp. 1563-1570. IEEE, 2023.

Coal mines are critical industries, as they provide fuel for steel and cement production, essential for extracting iron and creating cement. It is crucial to monitor various parameters like methane gas, high temperature, and fire incidents regularly in the underground mining environment to ensure safety. The mining environment is complex, and the variety of activities performed in coal mines requires constant monitoring of safety conditions to prevent accidents. system has been developed that monitors basic safety measures, including gas leaks, temperature, humidity, and fire sensors, with all sensors assembled into a single unit and placed in the coal mine for real-time monitoring.

[3]Rudrawar, Mangesh, Shivam Sharma, Madhuri Thakur, and Vivek Kadam. "Coal mine safety monitoring and alerting system with smart helmet." In ITM Web of Conferences, vol. 44, p. 01005. EDP Sciences, 2022.
Traditional monitoring systems in coal mines are difficult to install, hazardous, and challenging to power, making them unreliable for ensuring the safety of mineworkers. Due to the complexity of the mining environment and the range of operations, it is essential to continuously monitor critical parameters in the background to improve efficiency and safety. This research presents a ZigBee-based wireless monitoring system using a smart helmet, capable of detecting and transmitting critical parameters such as methane gas, temperature, humidity, and fire, with distress signals transmitted in case of emergency. In emergency situations, a buzzer sounds, and the monitored parameters are displayed on a user interface machine. The system wirelessly transmits data to the control room for real-time safety monitoring, and experiments have proven the system's reliability and stability.

[4]Deokar, S. R., V. M. Kulkarni, and J. S. Wakode. "Smart helmet for coal mines safety monitoring and alerting." International Journal of Advanced Research in Computer and Communication Engineering (IJARCCE) 6, no. 7 (2017).
Real-Time Hazard Monitoring: Detects harmful gases (CO, CH4, LPG) and monitors temperature to ensure air quality and safety. Emergency Alert System: Detects miner falls or unconsciousness and sends alerts to supervisors for quick response. Helmet Compliance Check: Uses a limit switch to detect if a miner removes their helmet, ensuring safety compliance. Wireless Communication: Utilizes Zigbee technology for data transmission and provides emergency switches for alerts.

[5]Paulchamy, B., C. Natarajan, A. Abdul Wahith, P. M. Sharan, and R.

Hari Vignesh. "An intelligent helmet for miners with air quality and destructive event detection using zigbee." Glob. Res. Dev. J. Eng 3, no. 5 (2018): 41-46.

An intelligent helmet is designed to enhance miner safety in the mining industry, where harmful events can cause severe injuries or fatalities. LED miner's helmets, though lightweight and energy-efficient, only provide illumination without improving safety. ZigBee wireless sensor networks are used to collect and transmit sensor data, ensuring real-time monitoring of hazardous conditions. The ZigBee-based system is cost-effective and shares data with a central control unit, enabling quick responses to emergencies.

Chapter 3

Design and Implementation

3.1 System Design

The system design for ”Coal Mine Safety Based on Wireless Communication Network” aims to enhance safety within coal mines by utilizing sensor technology and wireless communication. It is composed of two key components: the transmitter side and the receiver side, both working together to provide real-time monitoring and alerts. On the transmitter side, a NodeMCU microcontroller serves as the central hub for data collection and processing. It integrates essential sensors and components to monitor environmental conditions within the coal mine. A DHT sensor measures temperature and humidity, ensuring that critical climatic data is captured to prevent heat-related issues and ensure adequate ventilation. An MQ sensor is used to detect the presence of harmful gases, such as methane or carbon monoxide, or smoke, which could signal hazardous air quality or the risk of fire. For immediate on-site alerts, a buzzer is included in the system to warn workers of dangerous conditions. All collected data is transmitted to the receiver using a LoRa module, which provides reliable long-range wireless communication, especially important in the challenging underground environment. The system is powered by a battery, ensuring portability and suitability for remote locations where direct power may not be available. The receiver side is responsible for receiving, processing, and displaying the data transmitted from the mine. An Arduino microcontroller serves as the main controller, processing the incoming data from the LoRa module. This data includes vital information such as temperature, humidity, gas levels, and alerts. An OLED display provides a clear, real-time visualization of the data for monitoring by mine operators. A stable power supply ensures continuous operation of the receiver system. The LoRa module on this side maintains a robust communication link with the transmitter, ensuring seamless data transmission. This system significantly improves coal mine safety by enabling wireless, real-time monitoring of environmental conditions. The integration of sensors, an alert mechanism, and a reliable communication network ensures early detection of potential hazards, allowing workers sufficient time to evacuate or take corrective measures. By employing LoRa technology, the system ensures long-range, uninterrupted communication in underground environments, overcoming the limitations of traditional wired systems. The use of battery power and compact, lightweight components ensures that the system is easy to deploy and adaptable to various mine conditions. This comprehensive approach reduces the risk of accidents, enhances worker safety, and improves the overall efficiency of coal mine operations.

3.2 Block Diagram

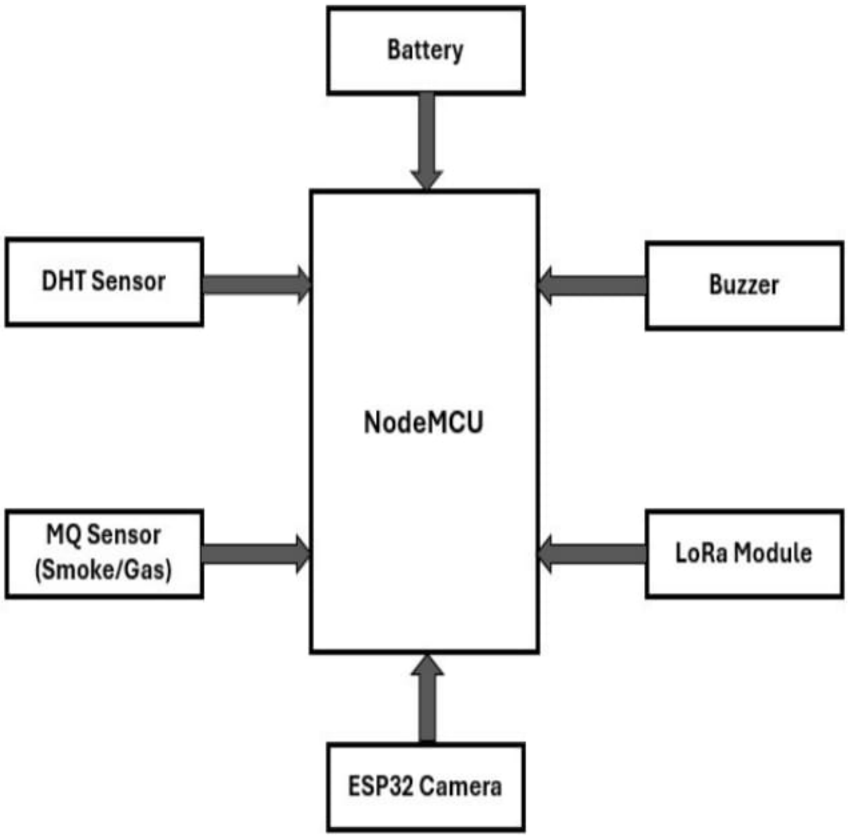


Figure 3.1: Transmitter Block Diagram

The figure 3.1 represents the transmitter module using a NodeMCU, interfacing with sensors, a camera, a buzzer, a LoRa module, and a battery for real-time monitoring and communication.The transmitter side of the coal mine safety system is designed to monitor critical environmental parameters within the mine and communicate them wirelessly. At its core is the NodeMCU microcontroller, which serves as the central processing unit. Various sensors are interfaced with NodeMCU to collect real-time data related to safety and environmental conditions. The DHT Sensor measures the temperature and humidity in the mine, ensuring the environment remains safe for workers and machinery. The MQ Gas Sensor detects the presence of harmful gases such as methane, carbon monoxide, or other flammable or toxic substances. This is crucial for identifying potential gas leaks that could lead to explosions or health hazards. A Flame Sensor replaces the ESP32 Camera and is used to detect the presence of fire or any unusual heat patterns, which could indicate an early warning of flames or ignition. In the event of hazardous conditions, such as high gas levels, abnormal temperatures, or flame detection, the Buzzer is triggered to provide an audible alarm to alert workers immediately. The data collected from the sensors is transmitted using a LoRa Module, which supports long-range wireless communication, allowing reliable data transfer even in the challenging underground environments of coal mines. The entire setup is powered by a Battery, making it portable and suitable for remote locations without direct access to power supplies. Additionally, the NodeMCU is connected to the ThingSpeak IoT platform, which allows real-time data visualization and monitoring over the internet. This ensures that mine operators or safety teams can access the environmental data remotely from any location. The data is stored on the cloud, enabling detailed analysis and historical tracking to improve safety protocols. This combination of local monitoring and IoT integration makes the transmitter system a vital part of the safety infrastructure.

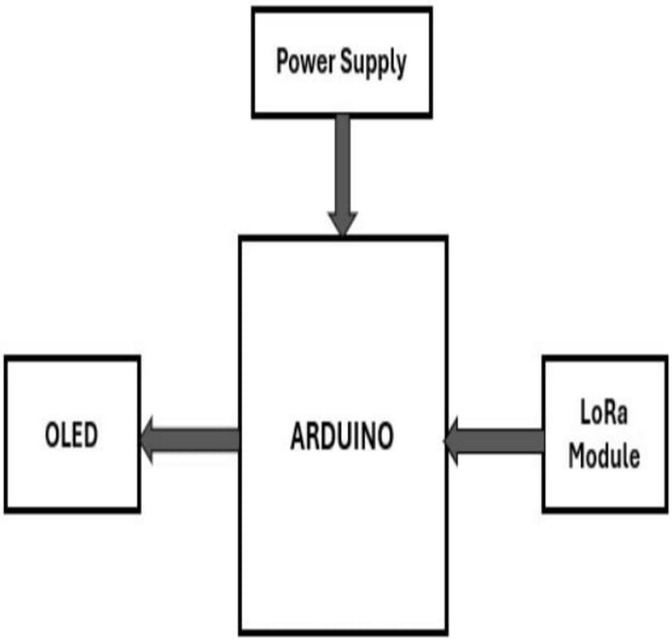


Figure 3.2: Block Diagram of the Receiver Module

The Arduino-based receiver as shown in figure 3.2 connects to a power supply, an OLED display for output, and a LoRa module for wireless communication.The receiver side is designed to process and display the data transmitted from the coal mine, enabling remote monitoring and decision-making. At its core is an Arduino board, which acts as the central controller for this system. It receives data wirelessly from the transmitter via a LoRa Module, which ensures stable communication over long distances, even in the presence of physical barriers like the underground walls of a mine. The received data is processed by the Arduino and displayed on an OLED Screen in a user-friendly manner. The OLED display provides clear and concise information about the temperature, humidity, gas concentrations, and fire alerts. This ensures that operators can monitor the safety conditions of the coal mine in real time. The small and efficient display is particularly useful in control rooms or portable monitoring setups. A Power Supply is used to ensure continuous operation of the receiver system. This can be a direct power connection or a portable battery, depending on the deployment scenario. The simplicity of the receiver design makes it easy to set up and operate while providing critical information to prevent accidents or emergencies. The receiver system works in tandem with the ThingSpeak platform. While the transmitter uploads data to the cloud for global monitoring, the receiver focuses on localized, on-the-ground data presentation. This dual functionality ensures that both the safety teams in the field and remote supervisors can access the information they need to make informed decisions. The system is efficient, reliable, and vital for maintaining a safe working environment in coal mines.

3.3 Hardware Requirements

The Hardware Components used in Coal Mine Safety Based On Wireless Communication Network are:

1. Arduino Uno
2. NodeMCU ESP12E Microcontroller
3. Temperature Sensor
4. MQ135 Gas Sensor
5. Flame Sensors

6. OLED Display
7. LoRa Module
8. Buzzer

3.3.1 Arduino UNO

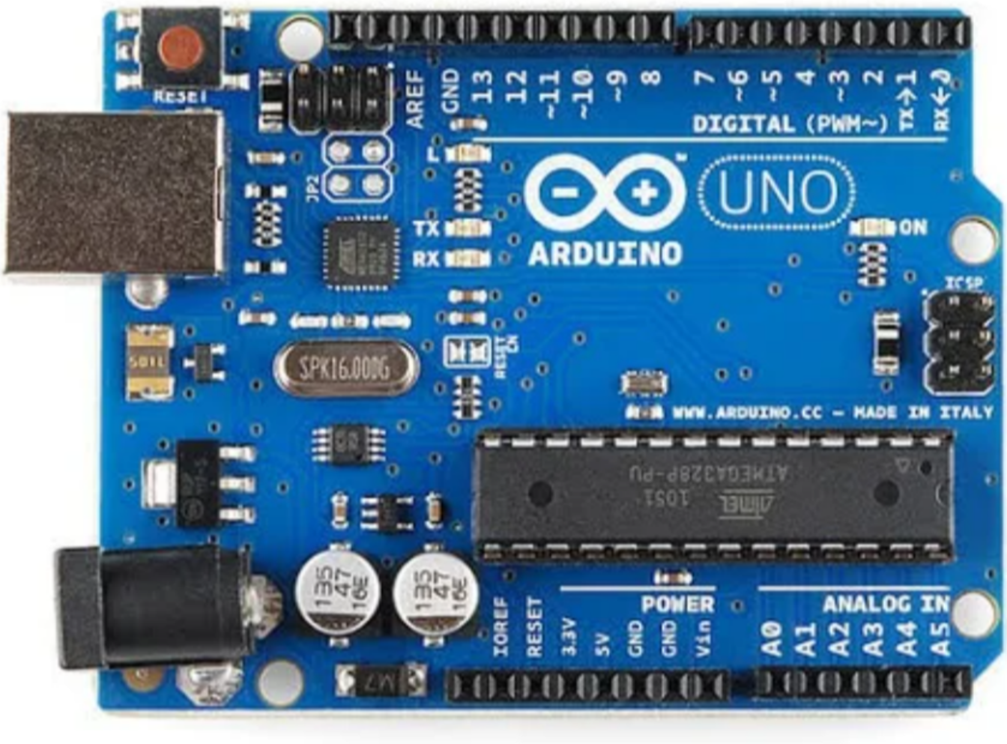


Figure 3.3: Arduino Uno

The Arduino Uno which is shown in figure 3.3 is a microcontroller board based on the ATmega328P microcontroller, widely used for electronics projects due to its simplicity and versatility. It features 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, and a reset button. The board operates at a voltage of 5V with a recommended input voltage range of 7-12V. It is equipped with a 32 KB flash memory, 2 KB SRAM, and 1 KB EEPROM, making it suitable for small to medium-scale projects.

The Uno communicates with a computer via the USB interface and can be programmed using the Arduino IDE (Integrated Development Environment). The IDE uses a simple programming language based on C/C++, allowing developers to upload sketches (programs) directly to the board. The ATmega328P microcontroller features a hardware UART, SPI, and I2C interfaces, enabling seamless communication with other devices such as sensors, displays, and wireless modules. The Uno also includes onboard voltage regulation to ensure stable operation, and its pin layout allows compatibility with a wide range of Arduino shields for expanded functionality.

One of the key features of the Arduino Uno is its bootloader, which enables programming without the need for an external programmer. This makes it highly user-friendly, even for beginners. The Uno is ideal for applications ranging from simple LED blinking to complex systems involving multiple sensors, actuators, and communication modules. With its robust hardware, extensive community support, and compatibility with numerous libraries, the Arduino Uno serves as a reliable platform for prototyping and deploying embedded systems in educational, industrial, and personal projects.

3.3.2 NodeMCU ESP12E Microcontroller

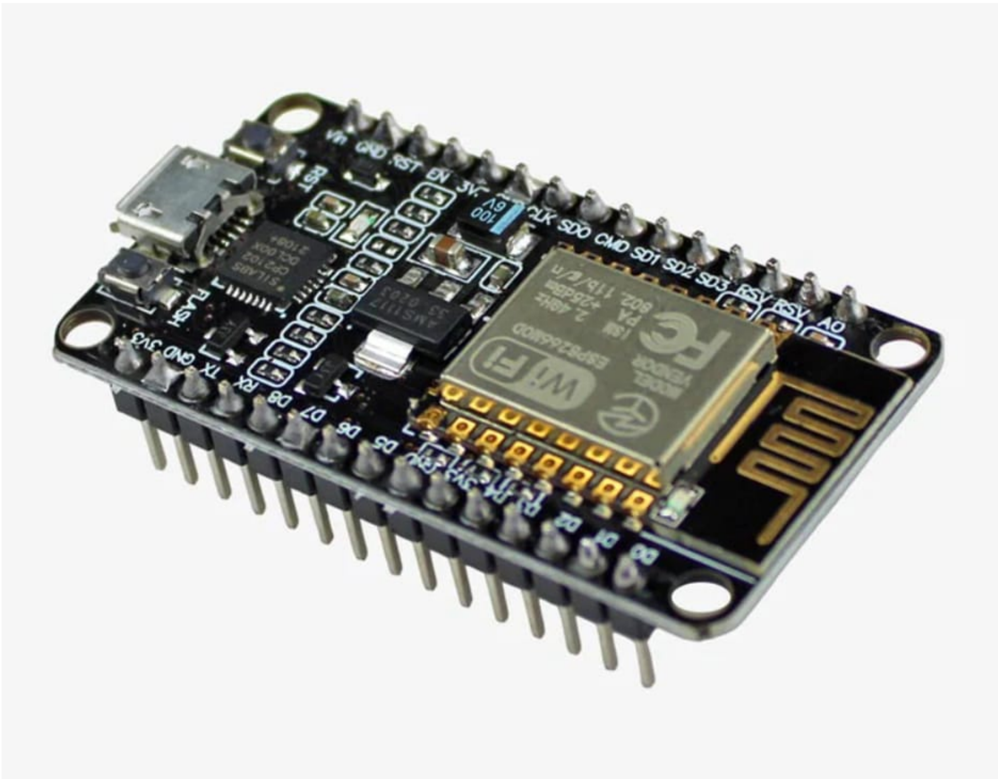


Figure 3.4: NodeMCU ESP12E Microcontroller

The figure 3.4 shows a NodeMCU which is a highly versatile and cost-effective IoT platform based on the ESP8266 Wi-Fi module, widely used for IoT applications. It combines a microcontroller and built-in Wi-Fi functionality in a compact package, making it ideal for wireless communication and real-time data transmission. NodeMCU features a 32-bit Tensilica L106 microcontroller with a clock speed of 80 to 160 MHz, 128 KB of RAM, and 4 MB of flash memory, providing sufficient processing power and storage for most IoT tasks. It includes multiple GPIO pins for interfacing with sensors, actuators, and other components, and supports digital I/O, PWM, ADC, and UART functionalities. Programmable using the Arduino IDE or Lua scripting, NodeMCU is beginner-friendly and widely supported by the developer community.

Its power flexibility allows it to operate on a 3.3V supply or be powered via a 5V micro-USB port. Additionally, it supports MQTT, HTTP, and WebSocket protocols, enabling seamless integration with IoT cloud platforms like ThingSpeak, Blynk, or Firebase for remote data monitoring and control. The NodeMCU's compact size and integrated voltage regulator make it suitable for space-constrained and portable applications. With applications ranging from smart home automation to environmental monitoring, NodeMCU is a popular choice for IoT projects. Its affordability, ease of programming, and robust features make it an ideal component for real-time monitoring and safety systems like coal mine safety networks.

3.3.3 Temperature Sensor

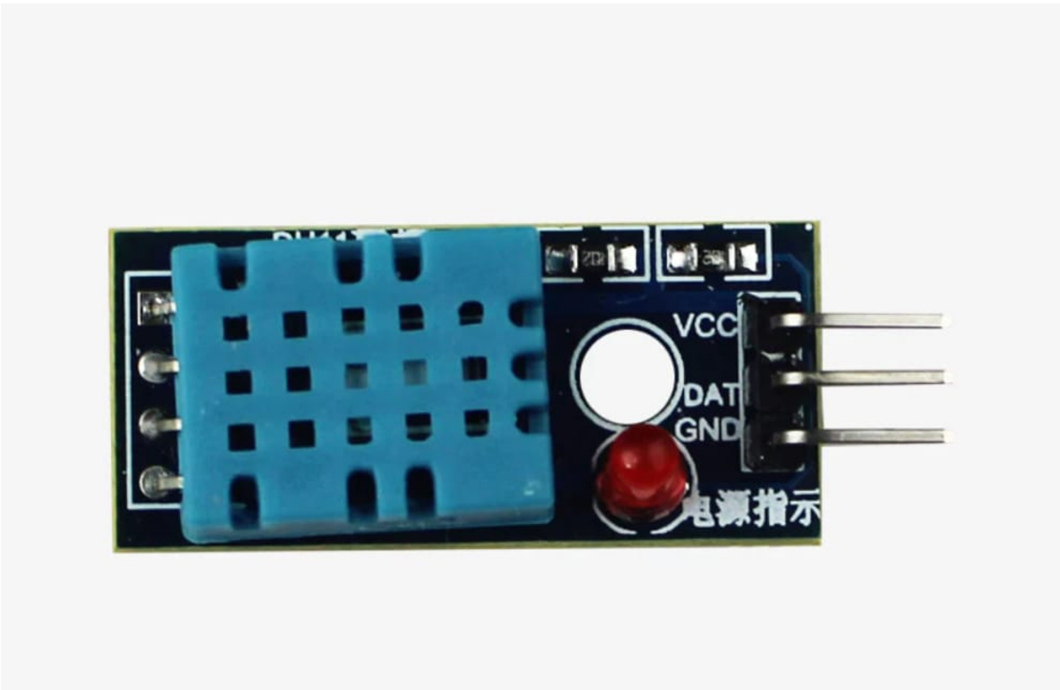


Figure 3.5: Temperature Sensor

The DHT11 shown in figure 3.5 is a widely used temperature and humidity sensor that provides a reliable and cost-effective solution for monitoring environmental conditions. It can measure temperatures in the range of 0°C to 50°C with an accuracy of ±2°C and humidity levels between 20% and 90% relative humidity (RH) with an accuracy of

±5% RH. The sensor outputs calibrated digital signals, eliminating the need for external analog-to-digital conversion, and operates on a voltage range of 3.3V to 5V, making it compatible with microcontrollers such as Arduino, Raspberry Pi, and NodeMCU. Its compact design and simple 3-pin interface (VCC, GND, and data) make it easy to integrate into various projects. The DHT11 uses a thermistor to measure temperature and a capacitive humidity sensor to detect moisture levels, transmitting data through a single-wire communication protocol. This sensor is commonly used in applications such as environmental monitoring in weather stations, greenhouses, and agricultural systems, as well as in IoT projects for real-time data collection and cloud integration. It is also employed in industrial and home automation systems to maintain optimal environmental conditions and in health-related devices like air purifiers and HVAC systems. While the DHT11 is affordable and easy to use, it has limitations, including a narrower measurement range and lower accuracy compared to advanced sensors like the DHT22. Despite these limitations, its low power consumption, dual functionality, and reliability make it an ideal choice for basic temperature and humidity monitoring, especially in safety-critical applications such as coal mine safety systems.

3.3.4 MQ135 Gas Sensor

Figure 3.6: MQ135 Gas Sensor

The figure 3.6 shows a MQ135 Gas Sensor.The MQ135 is a versatile gas sensor designed for detecting a wide range of gases, including ammonia (NH3), benzene, alcohol, smoke, carbon dioxide (CO2), and other harmful substances. It is widely used in environmental monitoring systems, industrial safety applications, and IoT projects. The sensor operates on a voltage range of 3.3V to 5V, making it compatible with microcontrollers like Arduino, Raspberry Pi, and NodeMCU. The MQ135 uses a metal-oxide semiconductor (MOS) to detect gases, where the gas concentration causes a change in the sensor's resistance, which is then converted into an analog output. It is sensitive to air quality and can detect gases in the range of 10 ppm to 1000 ppm, providing real-time data about air pollution and gas concentration. The sensor is compact, affordable, and has a fast response time, making it ideal for projects requiring continuous gas monitoring. However, it requires calibration to improve accuracy and reduce false positives, as it is sensitive to humidity and temperature changes. The MQ135 is commonly used in air quality monitors, industrial equipment, and safety systems to detect potentially hazardous gas leaks, ensuring the safety of workers and equipment. Its low cost, simplicity, and versatility make it a popular choice for integrating gas detection capabilities into IoT-based safety systems, such as those used in coal mines for detecting dangerous gas levels.

3.3.5 Flame Sensors

Figure 3.7: Flame Sensors

A flame sensor which is shown in figure 3.7 is an electronic device designed to detect the presence of fire or a flame. It is a crucial component in fire detection and safety systems, widely used in industrial, commercial, and domestic applications. The flame sensor operates by detecting infrared (IR) or ultraviolet (UV) radiation emitted by a flame. Most flame sensors are sensitive to radiation in the 760 nm to 1100 nm wavelength range, allowing them to identify flames from a distance effectively. These sensors typically consist of a photodiode or phototransistor, which converts the detected radiation into an electrical signal that can be processed by microcontrollers like Arduino, Raspberry Pi, or NodeMCU. Flame sensors are highly responsive and can detect flames within a range of 1 to 5 meters, depending on the sensor's sensitivity and the size of the flame. They operate at a voltage range of 3.3V to 5V and provide both digital and analog outputs, making them versatile and easy to integrate into various systems. The digital output is a binary signal indicating the presence or absence of a flame, while the analog output provides information on the flame's intensity. Flame sensors are often equipped with adjustable sensitivity, allowing users to fine-tune their performance for specific applications. These sensors are used in fire detection systems, industrial safety mechanisms, gas furnaces, and even robotics. For instance, in coal mine safety systems, flame sensors play a critical role in detecting fires at an early stage, allowing for immediate action to prevent accidents or damage. They can also trigger alarms, activate extinguishing systems, or shut down equipment automatically when a flame is detected. Additionally, flame sensors are employed in applications like combustion monitoring, welding processes, and gas-powered appliances to ensure operational safety. One of the key advantages of flame sensors is their ability to detect flames in challenging environments, including those with high temperatures or low visibility. However, they have limitations, such as susceptibility to interference from sunlight, ambient heat, or reflective surfaces, which can cause false readings. To mitigate these issues, flame sensors are often combined with other safety sensors, such as smoke or gas detectors, to provide a comprehensive safety solution. Overall, flame sensors are essential for enhancing safety and reliability in environments where fire poses a significant risk. Their low power consumption, quick response time, and compatibility with microcontroller platforms make them an integral part of modern fire detection and prevention systems, including IoT-based monitoring solutions.

3.3.6 OLED Display

Figure 3.8 shows an OLED (Organic Light Emitting Diode) display, it is a modern visual output device that uses organic compounds to emit light when an electric current is applied. Unlike traditional LCDs, OLED displays do not require a backlight, as each pixel generates its own light. This results in sharper images, higher contrast ratios, deeper blacks, and vibrant colors, making OLEDs a superior choice for compact, energy-efficient

Figure 3.8: OLED Display

displays in various applications, including IoT devices, wearables, and industrial systems. OLED displays are available in various sizes, with the most common being 0.96-inch and 1.3-inch screens. These displays often have resolutions of 128x64 or 128x32 pixels, offering sufficient clarity for text, symbols, and simple graphics. OLEDs are compatible with popular microcontrollers like Arduino, Raspberry Pi, and NodeMCU, and they communicate using protocols such as I2C or SPI. The I2C interface, in particular, reduces the number of required connection pins, making OLEDs ideal for compact and low-power systems. Operating on a voltage range of 3.3V to 5V, OLED displays consume minimal power, further extending battery life in portable devices. Additionally, their fast response times make them suitable for dynamic updates, such as real-time sensor readings or system notifications. One of the key advantages of OLED displays is their wide viewing angles and excellent readability, even in low-light conditions. This makes them ideal for IoT and monitoring systems where quick and clear visualization of data is essential. For instance, in a coal mine safety system, an OLED display can show critical data such as temperature, gas levels, or flame detection status, enabling users to quickly assess environmental conditions. The compact size of OLED displays also allows them to be integrated into handheld devices or embedded systems without adding significant bulk. Applications of OLEDs extend beyond safety systems to include smart home devices, medical equipment, industrial automation, and consumer electronics. They are frequently used in smartwatches, fitness trackers, and compact user interfaces. Despite their numerous advantages, OLED displays have some limitations, such as susceptibility to burn-in and a higher cost compared to traditional LCDs. However, their superior performance, low power consumption, and sleek design often outweigh these drawbacks in most applications. Overall, OLED displays are a popular choice for modern electronic systems due to their versatility, efficiency, and high-quality visuals. Their ability to provide clear, real-time data in compact and low-power devices makes them especially valuable in IoT-based monitoring solutions, such as coal mine safety systems, where timely and accurate information is critical for maintaining safety and operational efficiency.

3.3.7 LoRa Module

Figure 3.9: LoRa Module

The LoRa (Long Range) module is a wireless communication device shown in figure 3.9 is designed for long-distance, low-power, and low-data-rate applications, making it a key technology for IoT and remote monitoring systems. LoRa operates on sub-GHz frequencies such as 433 MHz, 868 MHz, and 915 MHz, depending on regional regulations. It uses a unique spread-spectrum modulation technique called Chirp Spread Spectrum (CSS), which allows it to achieve exceptional communication ranges of up to 10–15 kilometers in open areas, with low power consumption. This makes it ideal for environments like coal mines, agriculture, industrial automation, and smart cities where reliable and energy-efficient communication over long distances is essential. LoRa modules are often integrated with microcontrollers like Arduino, Raspberry Pi, or NodeMCU to transmit and receive data wirelessly. They typically consist of a transceiver chip, such as the SX1276 or SX1278, that supports bidirectional communication. The module operates on a supply voltage of 3.3V to 5V and features adjustable transmission power and data rates, allowing for optimal performance in different scenarios. It supports point-to-point, star, and mesh network topologies, providing flexibility in network design. LoRa is also highly resistant to interference, making it reliable in environments with high noise or obstructions, such as underground coal mines. One of the standout features of LoRa is its low power consumption, enabling battery-powered devices to operate for years without replacement. This is particularly useful for IoT deployments where devices are often placed in remote or inaccessible locations. LoRa modules also support encryption protocols like AES-128, ensuring secure data transmission. In addition to standalone modules, LoRa is commonly integrated into LoRaWAN (Long Range Wide Area Network) systems, which add networking capabilities such as device provisioning, data routing, and cloud integration. Applications of LoRa modules are vast and include environmental monitoring, smart metering, asset tracking, industrial automation, and disaster management. In coal mine safety systems, LoRa modules enable real-time data transmission from sensors, such as gas, temperature, or flame detectors, to a remote monitoring station or cloud platform. This ensures timely alerts in case of hazardous conditions, allowing for prompt action to ensure worker safety. Despite its many advantages, LoRa has some limitations, such as a relatively low data rate (ranging from 0.3 kbps to 50 kbps) and potential interference in densely populated networks. However, these are offset by its exceptional range, energy efficiency, and scalability, making it one of the most popular choices for IoT and wireless communication systems. The LoRa module's ability to combine long-range communication with low power usage has made it an integral part of modern remote monitoring and IoT applications, including safety-critical systems in challenging environments like coal mines.

3.3.8 Buzzer

Figure 3.10: Buzzer

A buzzer which is shown in figure 3.10 is an electronic device that generates sound through vibration, commonly used for alarms, notifications, and alerts.It operates by converting electrical energy into mechanical movement, producing audible tones. Buzzers come in different types, including piezoelectric buzzers, which use a vibrating piezoelectric element, and electromagnetic buzzers, which rely on an electromagnet to move a diaphragm. These devices are widely used in applications such as household appliances, security systems, automotive alerts, and industrial warning signals. Their reliability, compact size, and ease of integration make them essential in various electronic circuits and systems.

3.4 Software Requirements

3.4.1 Arduino IDE

The Arduino Integrated Development Environment (IDE) is an open-source software platform used for writing, compiling, and uploading code to Arduino microcontrollers and compatible boards. The IDE provides a simple, user-friendly interface that supports programming in C and C++ using Arduino's built-in libraries and functions. It is cross-platform and available for Windows, macOS, and Linux. The core of the IDE includes a text editor for writing code, a message area for displaying errors and status updates, and a serial monitor for real-time communication with the board.

The Arduino IDE uses a simplified version of the GCC (GNU Compiler Collection) toolchain to compile sketches (Arduino programs) into machine code that can be executed by the microcontroller. Sketches are typically saved with a .ino extension. The IDE also includes a bootloader for uploading code to the board via a USB cable, eliminating the need for external programmers. Additionally, it provides built-in functions like pinMode(), digitalWrite(), and analogRead() to simplify interfacing with hardware components such as sensors, actuators, and communication modules.

Another key feature of the Arduino IDE is its extensibility. Users can add third-party libraries to integrate additional functionalities, such as controlling displays, wireless communication modules, or motor drivers. The IDE also supports board package management, allowing users to program a wide variety of microcontroller boards, including Arduino Nano, Mega, ESP32, and others. Its simplicity and robust community support make the Arduino IDE an essential tool for hobbyists, students, and professionals in the fields of embedded systems and IoT development.

3.4.2 Thing Speak

ThingSpeak is an open-source Internet of Things (IoT) analytics platform that enables users to collect, store, visualize, and analyze real-time data from sensors and devices. Developed by MathWorks, it serves as a cloud-based service that facilitates the management of IoT projects, making it easier for developers and engineers to deploy and monitor their applications. ThingSpeak supports a variety of data types, allowing users to send data using HTTP or MQTT protocols, which can be received from a wide range of IoT devices, including Arduino, Raspberry Pi, and ESP8266. Once data is collected, users can leverage ThingSpeak's built-in analytics tools to visualize the data through customizable graphs and dashboards, facilitating better understanding and decision-making based on the insights gained. The platform also integrates seamlessly with MATLAB, enabling users to perform complex data analysis and create algorithms for predictive analytics or machine learning applications. ThingSpeak includes features such as alerts and notifications, which can trigger actions based on specific conditions, enhancing automation capabilities in IoT systems. Moreover, ThingSpeak supports a wide range of applications across various sectors, including agriculture, healthcare, environmental monitoring, and smart cities. Its flexible API and extensive documentation allow developers to create custom applications and solutions tailored to their specific needs. The platform also promotes collaboration by allowing users to share their channels and projects with the community, fostering innovation and knowledge exchange. Overall, ThingSpeak is a powerful tool that streamlines the process of building and managing IoT applications, making it accessible for both beginners and experienced developers alike.

3.5 Design Considerations

3.5.1 Communication Protocol

1. **Communication** Utilizing LoRa (Long Range) technology is essential for a wireless communication network in a coal mine. LoRa is known for its low power consumption and long-range capabilities, making it suitable for challenging environments. It is important to select the appropriate frequency for the LoRa modules to ensure compliance with local regulations. Additionally, the required data rate must be calculated based on the frequency of sensor readings, ensuring that the modules can effectively cover the necessary distances, as coal mines often present

obstacles such as dense structures and varied terrain that can affect signal propagation.

2. **NodeMCU Configuration (Transmitter)**
   For the transmitter side, the NodeMCU must be configured to interface seamlessly with the various sensors, including the DHT11, flame sensor, and MQ135. This integration requires the use of compatible libraries and a robust connection setup. Power management is another critical aspect; implementing sleep modes or low-power states can significantly conserve battery life, particularly if the NodeMCU is reliant on battery power. Additionally, the data packaged for transmission should be efficiently structured, possibly in JSON or a binary format, to optimize the encoding of sensor readings for minimal latency and reliable delivery.

3. **Arduino Uno Configuration (Receiver):**
   On the receiver side, the Arduino Uno needs to be equipped with a compatible LoRa module, such as the SX1278, ensuring correct wiring and software configuration for effective communication. The Arduino's code must be designed to process incoming data, parsing it accurately and triggering alerts or actions based on sensor readings, such as high temperature or the detection of flames. For user interaction, it may be beneficial to incorporate an LCD display or LED indicators to provide real-time monitoring of sensor data and alerts, thus enhancing the overall usability of the system.

3.5.2 Sensor Considerations

The placement and calibration of sensors are paramount for accurate environmental monitoring in a coal mine. The DHT11 sensor should be strategically located to reflect the mine's ambient conditions, ensuring reliable readings of temperature and humidity. The flame sensor should also be positioned in critical areas where fire hazards may arise, and it may be necessary to deploy multiple sensors for comprehensive coverage. Furthermore, the MQ135 air quality sensor must be calibrated correctly and positioned to effectively detect hazardous gases, ensuring the safety of personnel working in the mine.

1. **Environmental Factors**
   Environmental factors can significantly impact the performance of the wireless communication network in a coal mine. It is crucial to account for potential interference

caused by physical barriers, such as walls and machinery, as well as electromagnetic interference from mining equipment. Additionally, all electronic components should be housed in durable enclosures that protect against dust, moisture, and physical impact, as the rugged conditions in a mine can pose risks to sensitive equipment. Addressing these environmental factors is essential for maintaining reliable operation in challenging conditions.

2. **Power Supply**

   Deciding on an appropriate power supply is critical for the functionality of the wireless communication network. The system can be powered either by batteries or a stable power source available in the mine. If batteries are chosen, using rechargeable options may provide a sustainable solution, minimizing operational costs over time. Moreover, voltage regulation is important to ensure that the NodeMCU, Arduino, and sensors receive the correct voltage levels, which prevents damage and ensures optimal performance of the system.

3. **Data Management**

   Effective data management is vital for the overall functionality of the network. Implementing a system for logging data on the Arduino can facilitate historical reference and analysis, helping to identify trends and issues over time. It is equally important to set an appropriate transmission frequency for the sensor data to balance responsiveness with power consumption, ensuring that critical data is sent without unnecessary strain on the power supply or network bandwidth.

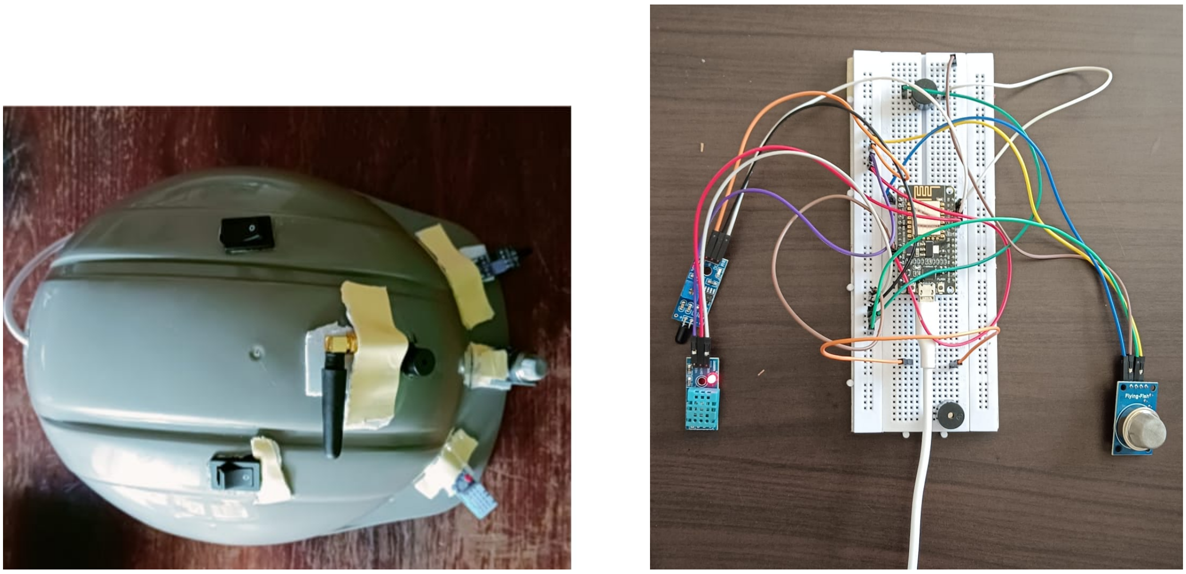
Chapter 4

Results And Discussion

The implementation of a wireless communication network in a coal mine using NodeMCU and Arduino Uno, along with various sensors such as the DHT11, flame sensor, and MQ135, promises to significantly enhance environmental monitoring and safety. Leveraging LoRa technology allows for long-range communication with low power consumption, addressing the challenges posed by the mine's terrain and structural barriers. The NodeMCU must be configured for effective data collection and transmission, while the Arduino Uno serves as the central hub for processing and displaying critical environmental data, triggering alerts when predefined thresholds are exceeded. Strategic placement and calibration of sensors are essential for accurate monitoring, and robust enclosures protect components from dust and moisture in the harsh mining environment. Power supply decisions, including the use of rechargeable batteries and proper voltage regulation, will optimize operational efficiency. Effective data management, including logging and analysis, ensures responsiveness to safety concerns, while scalability allows the network to adapt to evolving monitoring needs. Safety measures, such as real-time emergency alerts and redundancy in sensor measurements, enhance worker protection. Rigorous testing and compliance with local regulations are crucial for the system's reliability and legitimacy, marking this wireless communication network as a significant advancement in ensuring safety and efficient monitoring in coal mines.

4.1 Transmitter

The helmet unit shown in figure 4.1a worn by miners is equipped with multiple sensors to continuously monitor environmental conditions. The DHT11 sensor measures temperature and humidity, ensuring that extreme conditions are detected in real-time. The MQ135 gas sensor detects the presence of hazardous gases such as carbon monoxide and methane, which are common in coal mines and pose serious health risks. Additionally, the flame sensor identifies potential fire hazards, providing an early warning system for



(a) Prototype Circuit on Breadboard (b) Smart Helmet with Integrated Sensors

Figure 4.1: Transmitter

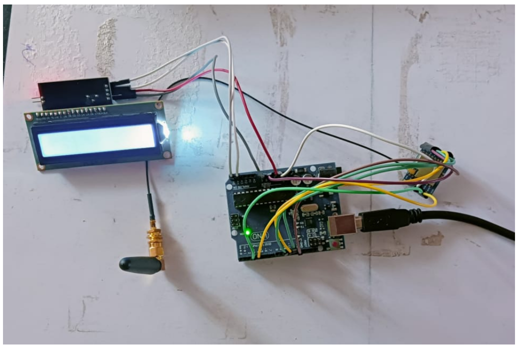
fire outbreaks.

All sensor data is processed by a microcontroller (such as an ESP32 or Arduino) and transmitted wirelessly using LoRa (Long Range) communication.LoRa is an ideal choice for underground mining environments due to its low power consumption and long-range capability, even in areas with weak or no cellular network coverage.The circuit connection is shown in figure 4.1b. The helmet continuously sends real-time data to the base station, ensuring that any dangerous conditions are promptly reported to prevent accidents and ensure worker safety.

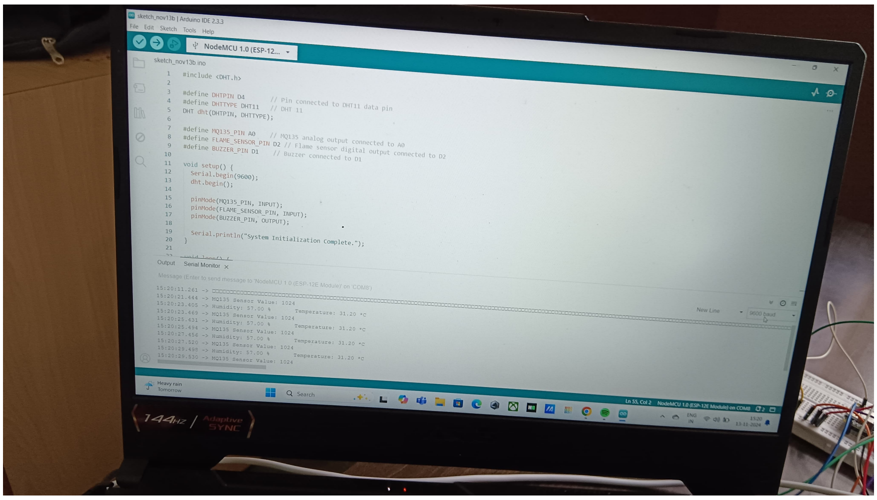
4.2 Receiver

Receiver Side (Base Station) - Coal Mine Safety System

The receiver side, or base station, plays a crucial role in monitoring environmental conditions inside the coal mine in real time. It consists of an Arduino Uno microcontroller connected to a LoRa module as shown in figure 4.2a, which receives data wirelessly from the transmitter (helmet). The received data includes temperature and humidity readings (DHT11), air quality levels (MQ135), and flame detection alerts from the transmitter unit. Upon successful reception, the Arduino Uno processes the incoming signals and triggers an appropriate response shown in figure 4.2b. If hazardous conditions such as high temperature, poor air quality, or fire are detected, the system activates an LED alert system to notify the mining authorities immediately. The base station can also



(a) Prototype of the coal mine safety system, featuring an Arduino-based transmitter with sensors and an LCD display.



(b) Receiver module displaying real-time data on a laptop via serial communication.

Figure 4.2: Receiver

be expanded to display data on an LCD screen or transmit alerts to a cloud-based IoT platform for remote monitoring. This setup ensures real-time hazard detection and enhances worker safety by allowing quick intervention in case of emergencies.

4.3 Analysis

The IoT-based coal mine safety system continuously monitors temperature, gas concentration, and humidity levels to ensure worker safety. Consider temperature readings shown in the figure 4.3 remain stable between 30-33°C, which is within a safe range. However, a sudden drop to 0.0°C on December 21 indicates a possible sensor malfunction or transmission error. Maintaining accurate temperature readings is crucial, as excessive heat can increase the risk of fires and equipment failure. Regular sensor calibration and connectivity checks can help avoid such inconsistencies.

The humidity readings shown in figure 4.4 indicate a consistently high level of 95%,

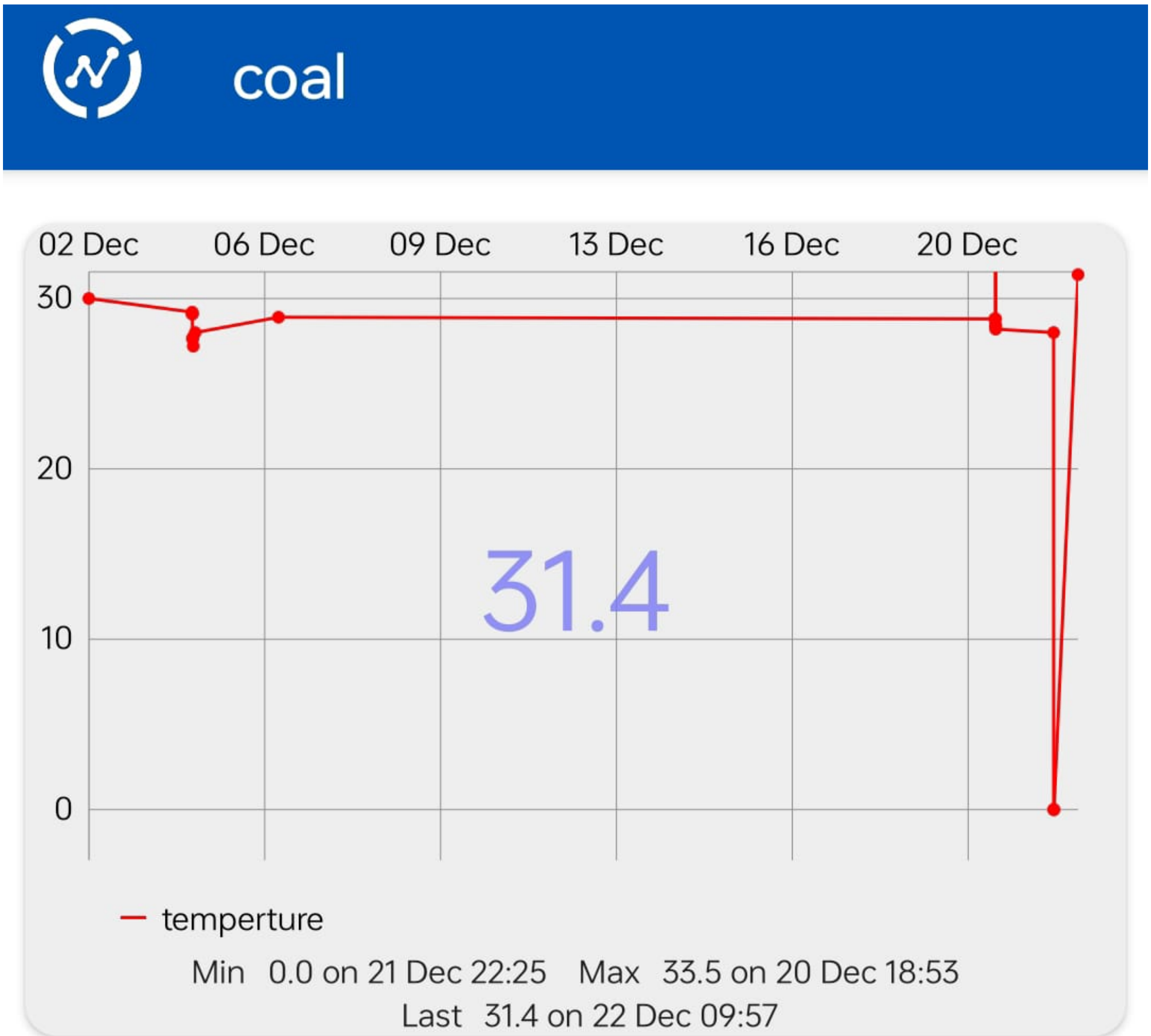


Figure 4.3: Temperature data displayed in cloud-based IoT platform

which could contribute to equipment corrosion, electrical failures, and reduced air quality in the mine. A sudden drop to 0.0% on December 21 suggests a sensor failure or data transmission issue similar to the temperature readings. High humidity levels may require better ventilation, dehumidifiers, or maintenance of drainage systems to avoid safety hazards. Overall, the system is effective but requires improvements in sensor reliability and data transmission stability for more accurate and real-time monitoring.

The gas concentration (MQ135 sensor) data as shown in figure 4.5 shows a sharp peak of 1000 PPM on December 21, signaling a potential toxic gas leak or ventilation failure. Such high levels of gas in underground mines can be hazardous to workers and may indicate the presence of CO, CO_2, or other dangerous gases. After this peak, the gas concentration returned to a normal level of 6.0 PPM, suggesting that the issue was either temporary or resolved. However, to prevent future incidents, automated alerts should be activated, and ventilation systems should be regularly inspected.

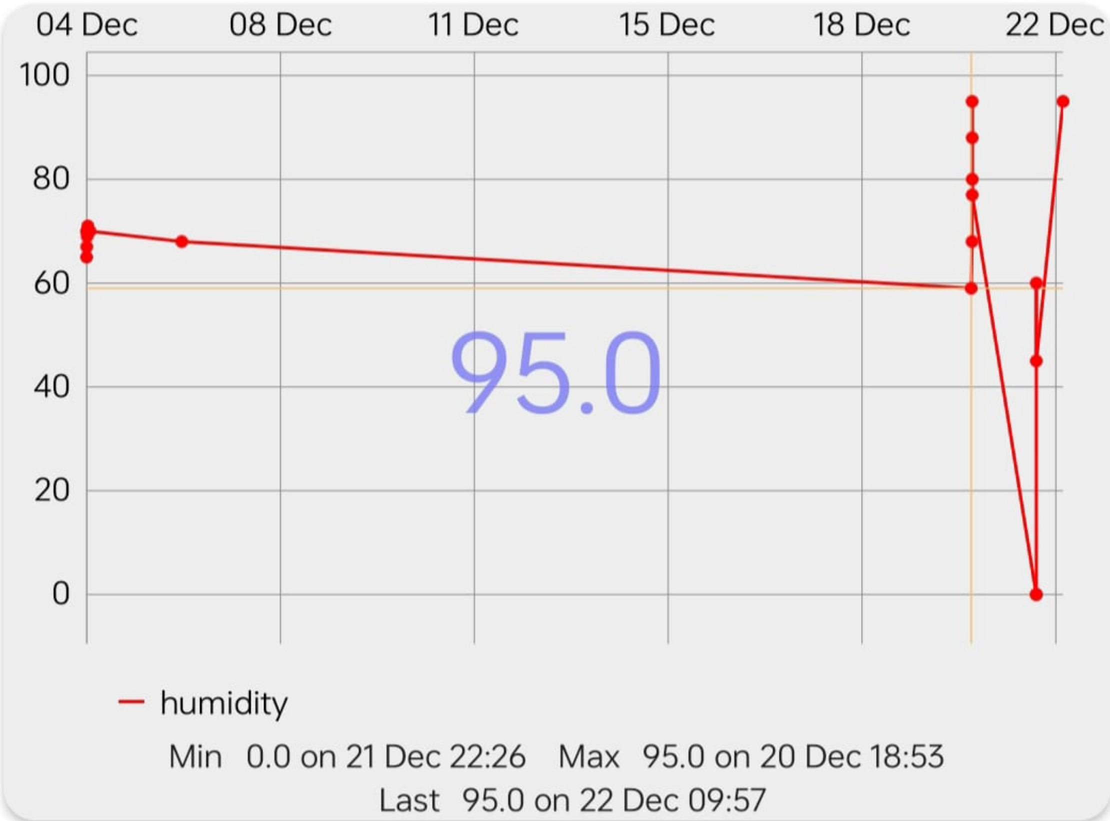


Figure 4.4: Humidity data displayed in cloud-based IoT platform

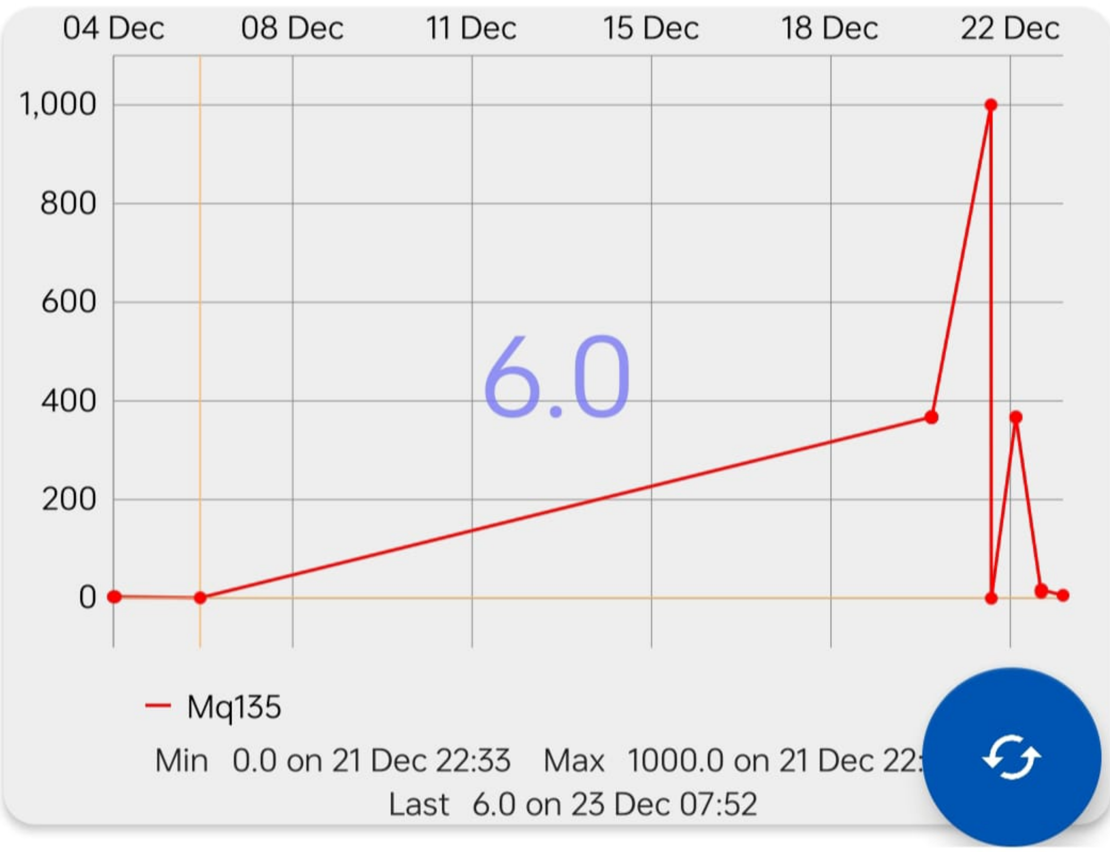


Figure 4.5: MQ135 gas sensor data displayed in cloud-based IoT platform

Chapter 5

Conclusions and Future Scope

5.1 Conclusion

Wireless communication networks have revolutionized coal mine safety by enabling real-time monitoring of environmental parameters. These systems continuously track critical factors such as gas levels, temperature, and humidity, helping to detect hazardous conditions before they escalate. By providing instant data to both miners and control centers, the system allows for proactive safety measures, reducing the risk of explosions, fires, or toxic gas exposure.

Seamless and reliable communication between miners and the control center is another significant advantage. Traditional wired communication methods often fail in the harsh underground environment, whereas wireless networks ensure uninterrupted connectivity. This real-time exchange of information allows for quick decision-making and better coordination in case of emergencies, improving overall safety and operational efficiency.

Automated alert systems and tracking technologies further enhance miner protection by identifying potential hazards and sending immediate notifications. These features help locate trapped or injured miners during emergencies, ensuring timely rescue operations. By continuously monitoring safety parameters, the system minimizes human errors and enhances situational awareness, making coal mining a safer profession.

Beyond safety, implementing wireless communication technology also boosts operational efficiency. By reducing manual inspections and providing automated data collection, mining companies can optimize their workflows and minimize downtime. This advanced system not only improves workplace safety standards but also contributes to a more productive and sustainable mining operation.

5.2 Future Scope

Future advancements in coal mine safety systems can focus on integrating artificial intelligence (AI) and machine learning for predictive analysis, enabling early detection of potential hazards before they become critical. The adoption of 5G networks and edge computing can significantly enhance real-time data processing and communication efficiency, improving response times in emergencies. Additionally, the use of autonomous drones equipped with sensors can aid in remote mine inspections, reducing human exposure to dangerous environments. Enhancements in sensor technologies, such as self-calibrating and energy-efficient sensors, can improve the accuracy and reliability of safety monitoring. Blockchain technology can also be leveraged for secure and tamper-proof data logging, ensuring transparency and compliance with safety regulations. Furthermore, optimizing energy consumption in wireless networks can extend the lifespan of monitoring systems, reducing maintenance costs. By incorporating these advancements, future coal mine safety systems can become more intelligent, efficient, and reliable, further enhancing the protection of miners and ensuring safer working conditions.

References

[1] S. Thangam, A. Kothari, V. Nikhil, N. Rohit, and J. J. J. Kumari, "Intelligent safety helmet for miners using arduino leveraging support vector machines," in *2024 Second International Conference on Networks, Multimedia and Information Technology (NMITCON).* IEEE, 2024, pp. 1–9.

[2] S. Banu, R. R. Samantaray, H. Zaiba, A. Rehaan, M. Yasin, and A. Kumar, "Power efficient intelligent helmet for coal mining security and alerting," in *2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS).* IEEE, 2023, pp. 1563–1570.

[3] M. Rudrawar, S. Sharma, M. Thakur, and V. Kadam, "Coal mine safety monitoring and alerting system with smart helmet," in *ITM Web of Conferences*, vol. 44. EDP Sciences, 2022, p. 01005.

[4] S. Deokar, V. Kulkarni, and J. Wakode, "Smart helmet for coal mines safety monitoring and alerting," *International Journal of Advanced Research in Computer and Communication Engineering (IJARCCE)*, vol. 6, no. 7, 2017.

[5] B. Paulchamy, C. Natarajan, A. A. Wahith, P. Sharan, and R. H. Vignesh, "An intelligent helmet for miners with air quality and destructive event detection using zigbee," *Glob. Res. Dev. J. Eng*, vol. 3, no. 5, pp. 41–46, 2018.