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Advanced Coal Mine Safety Monitoring and Auto Alert system using LoRa Technology

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Abstract: **Coal mining poses several environmental challenges. There are many problems associated with coal mine accidents, land subsidence, and mining waste disposal. Environmental pollution is one of them. Our proposal addresses these issues. Our device is designed to monitor and analyze temperature, humidity, pressure, and other related parameters in an underground coal mine using the Lora protocol and a Nodemcu esp8266 controller. ESP32 camera takes a picture that is sent to authorized recipients.**

By using SMTP (simple mail transfer protocol), an individual can send emails to the server. The Nodemcu esp8266 is used in conjunction with a temperature and smoke detector as well as a gas detector to sense the mine's climate parameters and Wi-Fi to send the parameters to Thing Speak, then the OLED display (organic light-emitting diode) will show all sensor values. We must design a cost-effective and reliable device for the solution. To create a device that will ensure the lives of coal miners.

Index Terms: **Arduino Nano, ESP32camera, LoRa Technology, Node MCU esp8266 Controller, SMTP Protocol, Thing Speak Server**

I. Introduction

The country relies heavily on coal mining to meet its energy needs. Coal mines are dangerous places where carelessness/unavoidable conditions can cause accidents. As compared to underground coal mines, open cast mines can be considered safer. The workers in open cast mines do not have to worry about humidity, heat, or suffocation. It appears that some miners come out of the underground mine before their shift ends. The mine management does not keep track of early adjournments by such miners, and the number of trapped persons is always unknown. Identifying the victims of accidents may be difficult for mine managers. As mining emits toxic gases such as carbon monoxide and methane, the mining environment is complex [1]. When the concentrations of these gases exceed a certain level, miners' lives could be at risk. The corrosion in enclosed spaces causes different types of damps. In addition to removing oxygen from the atmosphere, they can also lead to explosive environments.

The primary problems in coal mining are accidents caused by a variety of reasons and by improper maintenance or monitoring. Because of the death and resource losses caused by mining, the miners' lives are at risk. The risk of prolonged illnesses may be another cause of death. The semiconductor gas sensor is used for monitoring the concentration level of harmful gases present in coal mines, such as SO_2, NO_2, CO, etc. A wireless sensor network can address the key issues of communication bandwidth, mobile data transmission, staff orientation, real-time monitoring of the work surface, and synchronization monitoring, among others.

II. Related Work

Hazardous atmospheres increase the risks associated with mining and industrial accidents. The result can be greater environmental damage, as well as property damage and human casualties[2].There are a variety of moral, legal, and commercial reasons why hazardous sites require greater care and security[3].As part of various measuring aspects of coal mining, wireless sensor networks are used in the mining environment for process control of the virtual environment. Listed below are a few examples of coal mining monitoring applications.

A. Arduino based smart helmet for coal mine safety

SurajC. Godse, *etal*had proposed an Arduino-based smart helmet for coal mine safety**.** The system measures temperature, humidity, and oxygen levels. Flammable gases are detected by sensors in the mine[4].The sensors are activated whenever the sensed parameter exceeds the limit. A comparison is made with the limit of the sensing device to verify the sensed data [5]. Workers in mines will be able to move safely with this alarm system that alerts them when an alarm goes off. With the vibration motor, mineworkers are alerted by vibrating their necks. A report concludes that coal miners are protected and their work methods are altered by the system.

B. Coal mine monitoring and alert system with data acquisition

Kugan raj S, *et al* had proposed a coal mine monitoring and Alert system with Data Acquisition [6]. An ATmega250 board is used to implement a wireless sensor network. The main controller is accompanied by pressure sensors, temperature sensors, heartbeat sensors, oxygen sensors, and an antenna for the wireless transceiver. A design system is composed of data gathering, data processing, and data monitoring components.

The goal of real-time messaging is to communicate different ideas that will enable real-time message delivery within the network. It collects mining-related data in real-time using CAN-based sensors. A transmitter between the mine station and the base station allows data collected within the mine station to be wirelessly communicated to a

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transceiver at the base station [7,8].It monitors underground conditions. Signals transmitted from underground stations are converted into lab view variables by a controller. With this design, an area can be managed using a sensor, automatic detection, and microcomputer technology. Observations and warnings of data in real-time are part of the report. Additionally, IoT systems with advanced functionality can be used.

C. *Coal mine safety monitoring and alert system*

S.R Deokar, J. S Wakode had proposed a coal mine safety monitoring and alert system [9]**.** Wireless transmitters and receivers are incorporated into wearable devices. The smart helmet contains several components, including a microcontroller, a sensor, an accelerometer, a flashlight, an alert switch, a headphone, and a memory card. A low amount of power is used in this design. In this experiment, the helmet's sensors detect when the wearer is taking it off. Whenever the system detects a gas level greater than the set level, the helmet flashes [5,10]. All sensor data are amplified by the controller when it transmits it. Through this design, an emergency message is sent to the base station via ZigBee. Information is displayed on the PC.

D. *Coal mine safety system using a wireless network*(*GSM*)

VSwarna,*et al*had proposed the development of a coal mine safety system using a wireless network (GSM). The main objective of this system is to receive signals by receiving information from sensors [11]. The system also addresses bandwidth issues. According to the system, conventional approaches are more cost-effective when it comes to data transmission methods used by Arduino microcontrollers, thermometers, gas sensors, IR sensors, and GPS mobile phones. The cost of these systems will be reduced by wireless sensor networks and GPRS. In addition to monitoring any parameters within a coal mine and alerting when they exceed the tolerance limits, it can also assist in implementing coal mining technologies [12].

E. *Automatic safety and alarming system for coal mines*

NazminA, *et al* had proposed an automatic safety and alarming system for coal mines [13]. This design is aimed at providing underground conditions in mines to reach the stations. In a mining environment, properties such as temperature, humidity, gas sensors, and the water level would be monitored in real-time. When the threshold limits are exceeded, miners would be notified.

There are two parts to the system. The hardware consists of RF transmitters and receivers[14,15]. Sensors in the ground control room continuously monitor underground parameters. Mineworkers wear wristbands attached to sensors in the ground control room.

A variety of sensors are connected to the system, including temperature sensors, humidity sensors, gas sensors, water level indicators, and wireless sensor networks. Based on research, it is necessary to install a real-time safety monitoring system to track underground parameters. The system will alert authorities to take appropriate action.

III. Methodology

A. *Method*

This methodology proved to be effective in completing the project and making it usable. In coal mine safety systems, several sensor modules are used, including smoke detectors, temperature, and humidity sensor buzzers, OLED, Arduino Nano, ESP32 cameras, and Lora modules. Monitor and control the system by connecting all of the sensors to the ESP8266NodeMCU.Ultimately, the system is designed for monitoring and controlling[3,16].When the gas levels exceed the normal range the gas sensor sounds and the esp32 camera takes a picture that is sent to an authorized person via email. The data from the sensors is sent to the cloud regularly for analysis. In coal mines, we carefully monitor the quality of the air, temperature, and humidity levels [17]. The control of the entire system is handled via the IoT thing speak platform. Using the internet of things platform, we have developed widgets that can control the buzzer manually, if there is no internet connection, the Nodemcu, and Arduino Nano exchange data through Lora RF modules.

B. *Hardware Description Materials*

NODEMCU (ESP8266)

The Nodemcu CP2102 board is a highly integrated Wi-Fi device that can be used for a wide range of applications. Because it is self-contained, it can address a wide range of networking requirements to host or offload various Wi-Fi functions. In addition, ESP8266 has built-in peripherals that make it easy to integrate with a variety of application-specific devices. As a result of the onboard peripherals, the development environment is low-complexity, and external peripherals are minimized. Figure 1 shows the ESP8266 Development board. It is used for a wide range of applications.

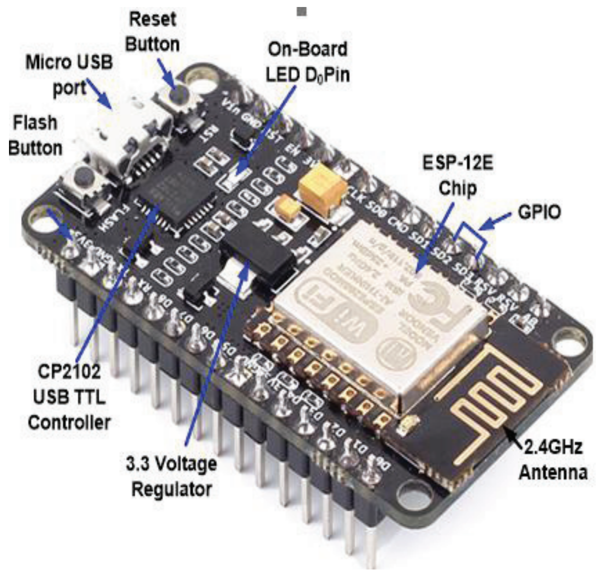

Figure 1. Node MCU ESP8266 Wi-Fi Development Board

ARDUINO NANO

An ATmega328P chip developed in Italy in 2008 is used on the board. It has 30 male DIP30 I/O headers. There are 14 digital pins, 8 analog pins, 2 reset pins, and 6 power pins. The Arduino IDE can be downloaded from the Arduino website. The Arduino Nano has almost all of the same features as the Arduino UNO. The Arduino Nano operates at 5 volts, and input voltage can range from 7 to 12 volts. The maximum current rating of the Arduino Nano is 40mA, so any load connected to its pins shouldn't exceed that. Each digital and analog pin has two main functions: input and output. The Arduino pins connected to sensors must be used as output pins to drive some load. Figure 2 illustrates the Arduino Development board. It is used for an extensive range of applications.

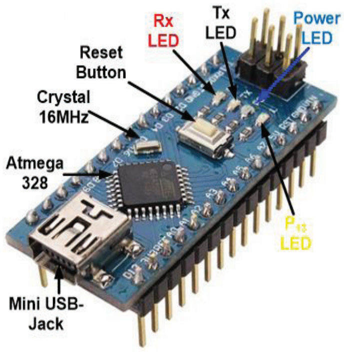

Figure 2. Arduino NANO

ESP32 Camera

The ESP32 has been used to develop a low-power camera module based on the CAM-ESP32. The board has a TF card slot and an OV2640 camera. IoT applications involving Wi-Fi image uploading, QR codes, etc. can be developed using an ESP32-CAM device. With the onboard ESP32-S module WIFI and OV2640 flash camera, data can be stored on a 4G TF card. Images can be uploaded via Wi-Fi. It has multiple sleep modes and a low sleep current of up to 6 mA. Pin headers can be integrated into many products. Wireless LAN connectivity is provided by the ESP-32S module. Devices connected to the internet can use the ESP32-D0WD Processor. Figure 3 demonstrates camera module pin components and how each of them is used for its functioning.

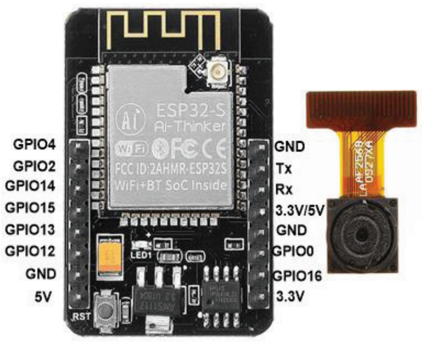

Figure 3. ESP32 Camera

DHT11

Temperature and humidity are measured by an NTC and a microcontroller run on an 8-bit processor. A voltage range of 3.5-5.5 V is used for operation, the device draws 0.3 mA and 60 µA in standby. Serial information is contained in this output. Its temperature range is 0 to 50 degrees Celsius with ± 2 degrees accuracy. The humidity range is from 20% to 80%. There is a 16-bit resolution for temperature and humidity with a precision of 1% and 1°C. Many sensors, such as the DHT11, measure temperature and moisture. An 8-bit microcontroller calculates the humidity and temperature values based on an NTC sensor. Other microcontrollers can easily be connected to it, as well as calibrated. With a sensor that measures 0°C to 50 °C and 20% to 90%, temperature and humidity can be measured within 1°C and 1 percent. When measuring in this range, this might be the best option. Figure 4 explains the DHT11 module pin components and how each of them is used for its working.

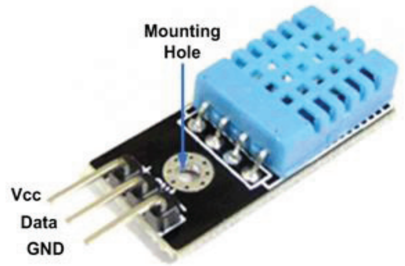

Figure 4. DHT11 Sensor

MQ135

MQ-135 sensors detect poisonous gases in mines and offices, as well as air quality. The sensors use tin dioxide (SnO_2) as their gas sensor. The conductivity of tin dioxide increases pollution. Ammonia, oxides of nitrogen, smoke, CO_2, benzene, and other dangerous gases can be detected by the air quality sensor. On the air quality sensor is a small potentiometer that allows the load strength to be adjusted. For operating 5V power supply is required and it produces digital logic output 0 or 1 or analog output 0-4V. In this project, it is used for measuring the concentration level of benzene gas in free space. Figure 5 elucidates the MQ135 module pin diagram.

Figure 5. MQ135 Sensor

LoRa Module

This LoRa Ra-02 module uses SEMTECH's wireless transceiver SX1278 to transmit data wirelessly. With advanced LoRa spectrum distribution technologies, it is possible to communicate over a distance of 10,000 meters. Air wake-up consumption is highly effective in terms of anti-jamming capability and function. For smart homes, spectrum modulation is used in LoRa technology with sensitivity of -148dBm.It is possible to program approximately 300 kbps FSK, GFSK, MSK, GMSK, LoRa, and OOK modulations are supported by this module. RSSI dynamically adjusted from 127dB to 129dB.The main highlight of LoRa has automatic radio frequency (ARF)sense and CAD with ultra-fast automatic frequency control (AFC) packet engine up to 256 bytes. Figure 6 explains LoRa module pin components.

Figure 6. LoRa Module

IV. SYSTEM DESIGN

A. Block Diagram of the proposed models

The input and output devices used to develop the devices are divided into two types: a coal mine unit that fits on the miner's helmet and allows for movement in the mine, and a control room unit that monitors the mining operation. In the mining environment, each sensor is well organized for sensing and transmitting to the cloud for analysis.

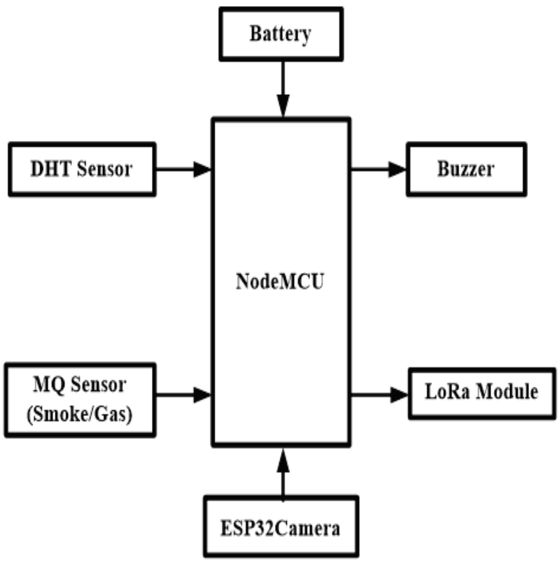

Figure 7. Block diagram of Proposed System at Transmitter

Figure 7 illustrates the proposed model for developing a perfect system, providing a framework for it. In this, all components connect with Node MCU, which control and provides instructions.

B. Control room unit

It is placed at the base station and monitors the coal mine unit. It receives the data from the transmitter unit and analyzes the data and shows it on an OLED display. Figure 8 represents the block diagram of the proposed model at the base station and gives the framework for it.

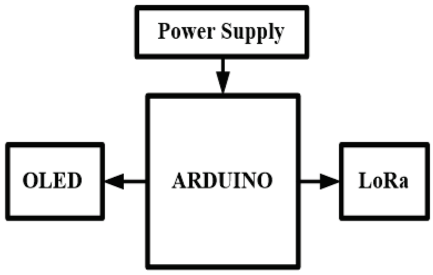

Figure 8. Block diagram of Proposed system at the Receiver

C. Circuit Diagram of Transmitter device

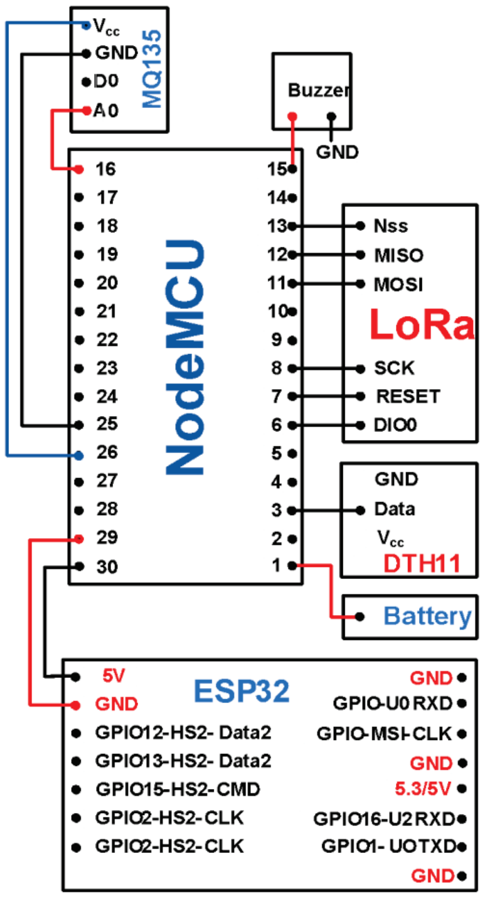

Figure 9. Circuit diagram of a Proposed System at Transmitter

Figure 9 shows the internal connections of the system on the transmitter side.

D. Circuit Diagram of Receiver Device

Figure 10 shows the internal connections of the receiver system. Their pin configuration determines how the receiver system works.

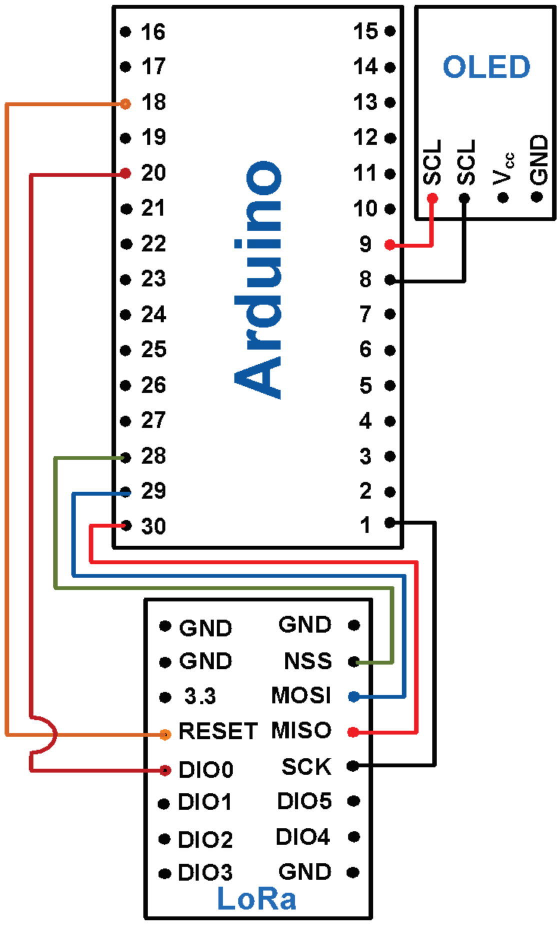

Figure 10. Circuit diagram of Proposed system at Receiver

E. Software Development

Various software techniques are utilized for the working of mine safety systems are

a) Arduino IDE

IDEs integrates code development environments. IDEs provide a wide range of tools for software developers. Computer programmers can create or test software on this device because it has all the tools they need. This environment is composed of a compiler, debugger, editor, etc.

With the Arduino IDE, code can be written quickly and uploaded directly to the board. C++ and C are open-source programming languages that can be used to program your board. All Arduino boards support these languages. USB cables (A or B plugs) are required for Arduino Nano and Node MCU.

b) Things Speak Server

Thing Speak is an IoT analytics platform that aggregates, visualizes, and analyzes real-time data streams. A device posts data to Thing Speak, and Thing Speak provides instant visualizations. Thing Speak allows you to analyze and process data as it is coming in online by executing MATLAB code. The Thing speak is often used to develop prototypes and proofs-of-concept of IoT systems requiring analytics.

An increasing number of embedded devices (things) are connecting to the Internet on the Internet of Things (IoT). These connected devices use cloud storage and computing resources to store and analyze sensor data, which provides valuable insight. Cloud services have become more affordable and widely available, driving this trend.

F. Working on the proposed system

The underground unit is powered by a rechargeable battery, which supplies power to all the components within the unit, and the underground unit is powered by the ground station unit. The system has been fully initialized. Microcontrollers receive data from sensors. Those devices generate data, which is analyzed and displayed by servers in the system. The data are displayed as charts. They are arranged accordingly. Each minute, our camera module captures images of the mining environment and sends them to the respective email address. As the internet cannot be accessed for any reason, LoRa is responsible for controlling the entire system and for transmitting and receiving data.

V. RESULT

Spreading of the spectrum is achieved in LoRa modulation by generating a chirp signal which is continuously varying in frequency. The benefit of the procedure is the time and frequency are counterbalance between transmitter and receiver so that the designing of receiver is simple. The required data are chipped at a higher data rate and modulated onto the chirp signal. The relation between the bit rate, wanted data, chip rate and symbol rate for LoRa modulation is defined as,

$$R_b = SF * \frac{1}{2^{SF}/BW} bits/sec \qquad (1)$$

$$R_s = \frac{BW}{2^{SF}} symbols/sec \qquad (2)$$

$$R_c = R_s * 2^{SF} chips\ /sec \qquad (3)$$

A variable error correction scheme provides the noiseless transmission by LoRa modulation. The nominal bit rate of the data signals as,

$$R_b = SF * \frac{\left[\frac{4}{4+CR}\right]}{\left[\frac{2^{SF}}{BW}\right]} = SF * \frac{RateCode}{\left[\frac{2^{SF}}{BW}\right]} bits/sec \qquad (4)$$

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Another important parameter is the receiver sensitivity is defined as,

$$RS = -174 + 10\log_{10}(BW) + NF + SNR[dBm] \quad (5)$$

Where, SF is spreading factor, BW is bandwidth (Hz), R_b is modulation bit rate, R_s is symbol rate, CR is code rate, NF is the receiver noise figure, SNR is signal-to-noise ratio and R_c is chip rate. '-174' is determined by the thermal noise in 1 Hz of bandwidth

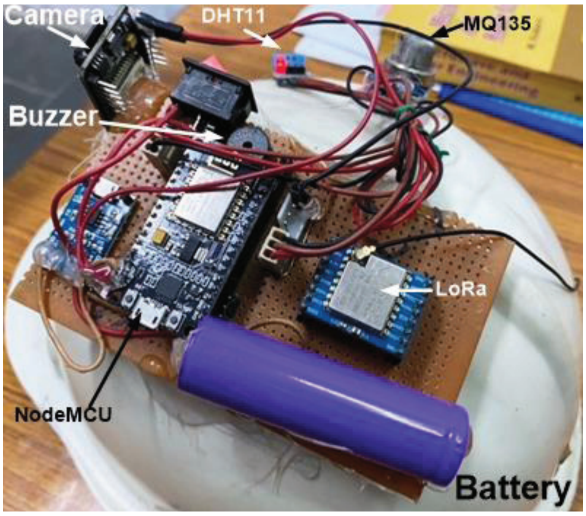

Figure 11. working of a Transmitter Device

Figure 11 illustrates the assembling of the transmitter device and it's working under the mine conditions. Tests are done to ensure that the sensors mounted on the helmet can be trusted for the specified limits and also specifically for their functions. In addition, alarms are triggered based on data from the sensors. LORA technology is used to build wireless sensor networks that enabled real-time surveillance and early warning of methane, temperature, and humidity in the mining area, thus reducing safety concerns during coal production. By installing this system in mines, can avoid the baneful, deleterious, noxious, and pernicious situation. Apart from that camera send live telecast in the mine.

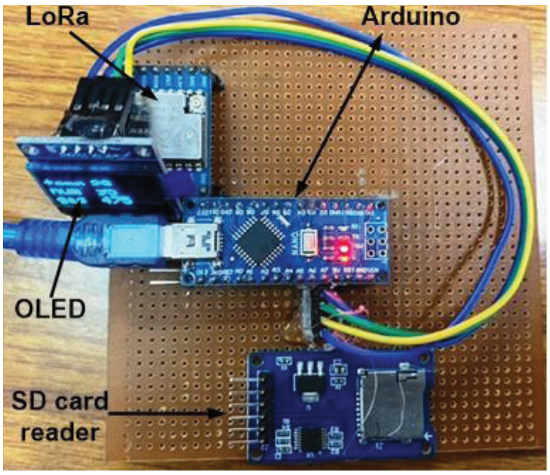

Figure 12. Working of a Receiver Device

Figure 12 illustrates the assembling of the Receiver device and its working. The receiver provides data from the transmitter and displays it. SD card reader is responsible for the collection of the data in the form of bits and stores in a memory card. If any data is lost, it is already stored in the camera module memory card as well as in the mail.

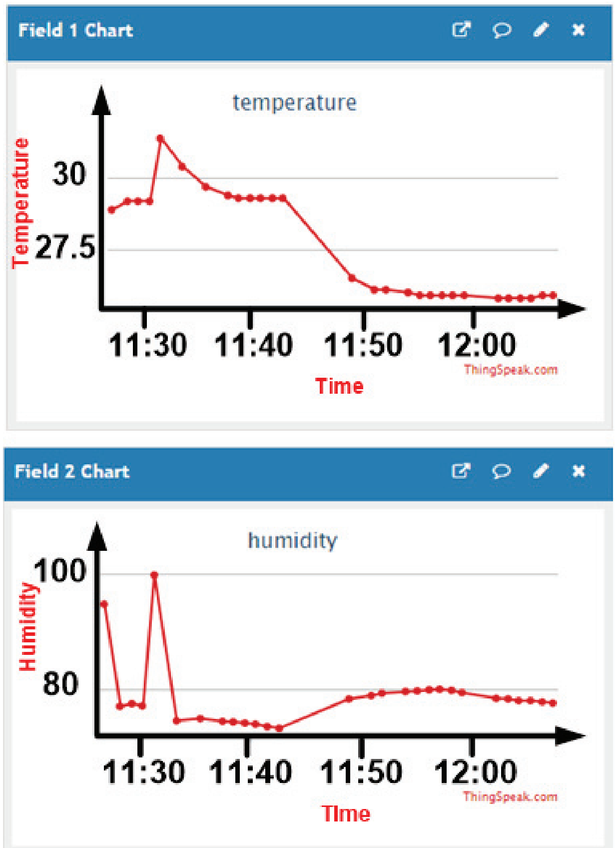

Figure 13. Variation of temperature and humidity with Time

Figure 13 displays the humidity and temperature of the environment. Taking the plot along the time axis and examining how they are related. These plots are stored in a server for analysis.

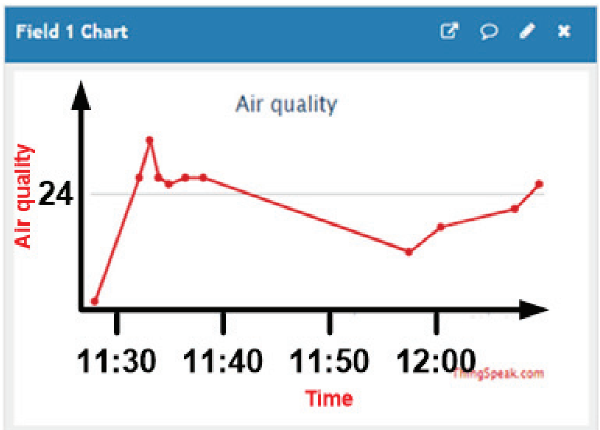

Figure 14. Variation of Air quality with Time

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Figure 14 shows the toxic content in the surroundings. It represents the quality of air around the person. A graph is plotted along the time axis and stored in a server for analysis.

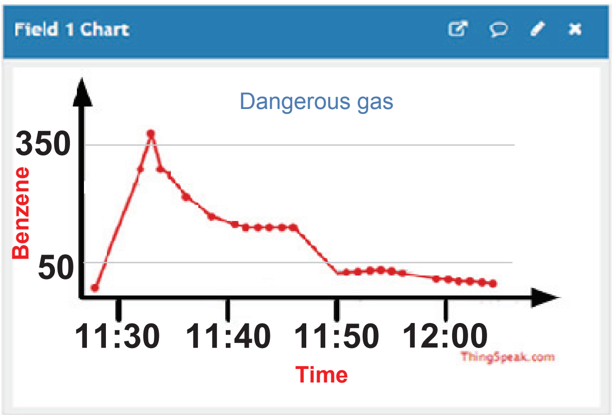

Figure 15. Variation of dangerous gas (Benzene) with Time

Figure 15 shows the sudden variation of benzene. With the analysis of the variation can find the air content in the low-lying area in the mine. By taking pre-precautions in mine can avoid the irritation of the skin, eyes, throat, and nose for the worker.

VI. Conclusions

Sometimes mine workers are facing very tough conditions like fire, flooding, the collapse of roofs and sides or walls, the emission of poisonous gases and ventilation failures while they are working in mines. Second the wireless internet connectivity is almost zero in the deep mines. For their safety, we assemble an embedded system circuit on the helmet. This system is also useful in the absence of the internet since it creates its network and sends signals from one node to another. In this system sensor and camera is installed, which is controlled by Nodemcu that continuously monitors atmospheric parameter, clips the picture and send to the control room. OLED continuously displays the live atmospheric parameter values in the control room. The control room server is connected to the internet so that any authorized person can monitor the mine conditions from anywhere in the world. If any atmospheric parameter crosses the threshold values, controller alerts the safety team and they take appropriate action to rescue the worker before any accident.

This project made use of components that were reasonably priced, durable and easily accessible. As a result, the project is affordable and easy to maintain.

VII. Future Scope

It is possible to prevent sudden flooding by measuring the moisture content of the soil mines with the moisture sensor. We

can use wireless underground networks (WSNs) to improve network infrastructure in underground mines by broadcasting and receiving data through the soil.

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