Smart Miner Helmet

Report for Project Part-II [EC 881]
Group no. **10**

B. Tech in Electronics and Communication Engineering
B. P. Poddar Institute of Management & Technology

under

Maulana Abul Kalam Azad University of Technology

Under the supervision of

Mr. Pushpendu Kanjilal

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CERTIFICATE

This is to certify that the project work, entitled "<u>Smart Miner Helmet</u>" submitted by <u>Group X</u> has/have been prepared according to the regulation of the degree B. Tech in Electronics & Communication Engineering of the Maulana Abul Kalam Azad University of Technology, West Bengal. The candidate(s) hasx/have partially fulfilled the requirements for the submission of the project work.

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I/We would like to express my/our thanks to the Head of the Department, Dr. Ivy Majumdar for his/her active support.

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I/We would like to express my/our gratitude to the library staff and laboratory staff for providing me/us with a congenial working environment.

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Departmental Mission:

- Imparting innovative educational program through laboratory and project-based teaching-learning process for meeting the growing challenges of industry and research.
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- Creating a knowledge center of advanced technologies committed to societal growth using environment-friendly technologies.

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1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
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7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
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Program Specific Outcomes (PSO):

- Students will acquire knowledge in Advance Communication Engineering, Signal and Image Processing, Embedded and VLSI System Design.
- Students will qualify in various competitive examinations for successful employment, higher studies and research.

TITLE: Smart Miner Helmet.

AIM: To design and implement a Smart Miner Helmet.

OBJECTIVE:

The objectives of this project are:

- To build a smart miner helmet, which will be capable of determining the temperature change and the presence of any gas within a closed system.
- To implement a wireless surveillance to the working outstations of the mining system.

PO& PSO MAPPING:

PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	P012	PSO1	PSO12
3	3	2	2	2	2	2	2	3	3	3	1	3	2

Note: Correlation levels are as defined:

1: Slight (Low)

2: Moderate (Medium)

3: Substantial (High). If there is no correlation, put "-"

JUSTIFICATIONS OF MAPPING:

PO/PSO MAPPED	LEVEL OF MAPPING	JUSTIFICATION
PO1	3	Apply knowledge of engineering fundamentals, mathematics, science and an engineering specialization.

PO2	3	Analyzing some complex engineering problems like how sensors work by detecting obstacles, how buzzer works and implementation of the whole system along with indicator LED lights.
PO3	2	The design solution for complex engineering problems that meet the specific needs with appropriate consideration for public safety.
PO4	2	Use research-based knowledge and research methods to analyze, interpret and synthesis of the information to provide valid conclusion.
PO5	2	Create, select and apply appropriate techniques, resources and modern engineering and IT tools to predict and model complex engineering activities with an understanding of the limitations.
PO6	2	Apply to reason informed by the contextual knowledge to safety issues and the consequent responsibilities relevant to the professional engineering practice.
PO7	2	Understand the impact of professional engineering solutions and demonstrate the knowledge of, and need for sustainable development.
PO8	2	Apply ethical principles and commit to professional ethics and responsibilities.
PO9	3	Function effectively as an individual, and as a member or leader.
PO10	3	Comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO11	3	Apply knowledge to one’s own work, as a member or leader in a team, to manage projects.
PO12	1	Recognize the need for, and have the preparation and ability to engage in independent and lifelong learning.
PSO1	3	Acquire knowledge in IOT and Embedded System along with other electronic components.
PSO2	2	Qualify in higher studies and research

ABSTRACT:

Mining continues to be one of the most dangerous professions in the world, where workers are frequently exposed to hazardous gases, extreme environmental conditions, and a lack of real-time communication or surveillance.[3] To address these challenges and improve the safety and well-being of miners, this project proposes a Smart Miner Helmet developed using the ESP32 microcontroller platform. This helmet is designed to monitor the miner's immediate surroundings in real time, detect dangerous conditions, and provide multiple layers of alerts and data transmission to supervisors above ground.[6]

The system integrates three key gas sensors — MQ2, MQ9, and MQ135 — capable of detecting a wide range of harmful gases such as LPG, carbon monoxide, methane, and air pollutants. Alongside this, a DHT11 sensor is used to measure ambient temperature and humidity, ensuring that miners are warned of any thermal or humidity-related threats.[10] A compact OLED display is installed on the helmet to show live sensor readings, allowing the miner to be aware of the environment at a glance.[2]

To maintain a historical log of environmental data, an SD card module is incorporated, storing sensor readings along with timestamps to assist in later analysis, safety audits, or accident investigations. The system actively monitors all parameters, and when any value exceeds a defined safe threshold, buzzers and LEDs are triggered, providing immediate audio-visual warnings to the user.[10]

A standout feature of the helmet is its Wi-Fi connectivity, enabled by the ESP32, which allows it to transmit real-time sensor data to a web dashboard.[12] This ensures that safety officers and monitoring teams outside the mine can view live environmental readings and track conditions remotely. The inclusion of an SOS button adds an extra layer of safety; when pressed, it triggers an emergency alert on the web interface and activates the buzzer, notifying both local and remote personnel of distress.[11]

Furthermore, the system is enhanced with an ESP32-CAM module, which provides live video streaming from the miner's location. This allows remote personnel to gain visual insight into the miner's surroundings in real time, significantly improving situational awareness and enabling faster decision-making during emergencies.[12]

SEMESTER WISE PLAN:

Odd Semester:

JOB	6th-18th Sept	19th-30th Sept	1st-16th Oct	17th-31st Oct	1st-10th Nov	11th-30th Dec	21st Jan
0th review	✓						
Familiarization with the different electronic components		✓					
Discussing the overall working concepts			✓				
Midterm 1				✓			
Recording the optimum working values of the required sensors					✓		
Deriving the mathematical relations between the components and assembling them					✓		
Midterm 2						✓	
Testing the first structure (Stage-1) of the system							✓
Report Writing and Project Presentation							✓

Even Semester:

JOB	1^{st}-12^{th} Feb	1^{st}-20^{th} March	1^{st}-6^{th} April	10^{th}-17^{th} April	18^{th}-10^{th} May	16^{th}-25^{th} May
Familiarization with the working of oled displays	✓					
Implementing oled display into the Stage-1 of the system	✓					
Midterm 1			✓			
Implementing the SD Card Module with the other sensors			✓			
Midterm 2				✓		
Implementing the ESP-832 Camera module with led strips					✓	
Integrating the different components into a single unit					✓	
Testing and fixing the built system					✓	
Project report writing and presentation						✓

Chapter 1:

INTRODUCTION

Mining is one of the most vital yet dangerous industries in the world. Miners often work in harsh and unpredictable environments where they are exposed to hazardous gases, extreme temperatures, high humidity, limited ventilation, and poor visibility.[1] Despite advances in mining technology, the safety of underground workers remains a critical concern, with accidents caused by gas leaks, explosions, heat strokes, and structural failures still being reported frequently.[1] Therefore, there is a growing need for smart, wearable safety systems that can continuously monitor environmental conditions and alert workers and supervisors to potential dangers in real time.[2]

The Smart Miner Helmet project addresses this challenge by designing a compact, intelligent, and cost-effective safety device that miners can wear while working in underground conditions.[2] Built around the powerful and versatile ESP32 microcontroller, the helmet integrates multiple sensors and communication modules to create a comprehensive safety monitoring system. The key objective is to ensure that any dangerous environmental changes are detected early and that immediate alerts are generated to prevent accidents.[4]

The helmet includes MQ2, MQ9, and MQ135 gas sensors to detect the presence of flammable, toxic, and harmful gases such as methane, carbon monoxide, LPG, and general air pollutants.[8] A DHT11 sensor measures temperature and humidity to prevent heat-related risks. The data from these sensors is displayed on an OLED screen in real time, allowing the miner to stay informed of the surrounding conditions. In addition, the values are recorded to an SD card module along with timestamps, creating a historical log of the environmental parameters for analysis and reporting.[7]

To enhance alert mechanisms, buzzers and LEDs are activated when any measured value crosses a predefined safety threshold, warning the miner instantly.[10] The Wi-Fi capability of the ESP32 allows sensor data to be transmitted to a web interface, enabling remote monitoring by safety officers. This real-time data sharing is crucial for supervisors to assess conditions and respond quickly in case of emergencies. An emergency SOS button is also included, which, when pressed, activates the buzzer and sends a distress signal to the web portal.[6]

One of the most advanced features of the helmet is the integration of an ESP32-CAM module, which streams live video footage from the miner’s location. This enables real-time surveillance, providing visual confirmation of the miner's condition and surroundings, which is especially valuable during rescue operations or emergency responses.[9]

Chapter 2:

THEORY

The Smart Miner Helmet integrates several fundamental principles of sensing, embedded systems, and wireless communication to provide real-time monitoring and alerting in underground mining environments.[11] The theoretical foundations of each major component are outlined below:

1. Gas Sensing

- **Metal Oxide Semiconductor (MOS) Sensors** (MQ2, MQ9, MQ135) rely on the change in electrical resistance of a heated metal–oxide film when target gas molecules adsorb onto its surface.[3]
- When a reducing gas (e.g., LPG, methane, carbon monoxide) contacts the sensor's heated element, it donates electrons, decreasing the sensor's resistance; the degree of change is proportional to gas concentration.[3]
- Calibration curves relate resistance ratios (Rs/Ro) to parts-per-million (ppm) concentrations, allowing the ESP32's analog-to-digital converter (ADC) to compute gas levels.[6]

2. Temperature and Humidity Measurement

- The **DHT11** sensor uses a capacitive humidity measurement element and a thermistor for temperature. The humidity element's capacitance changes with ambient moisture; this is converted into a voltage and digitized.[11]
- A single-wire digital protocol transmits measured values to the microcontroller.[10]
- The thermistor's resistance varies with temperature according to its characteristic curve (typically a negative temperature coefficient), enabling temperature calculation.[2]

3. Microcontroller Core (ESP32)

- The **ESP32** features dual Tensilica Xtensa LX6 CPUs (up to 240 MHz), integrated Wi-Fi (802.11 b/g/n) and Bluetooth (Classic + BLE), and multiple peripherals (SPI, I2C, UART, ADC, PWM).[5]
- Sensor readings are acquired via ADC channels (for MQ sensors) or digital GPIO (for DHT11), then processed in firmware.[4]

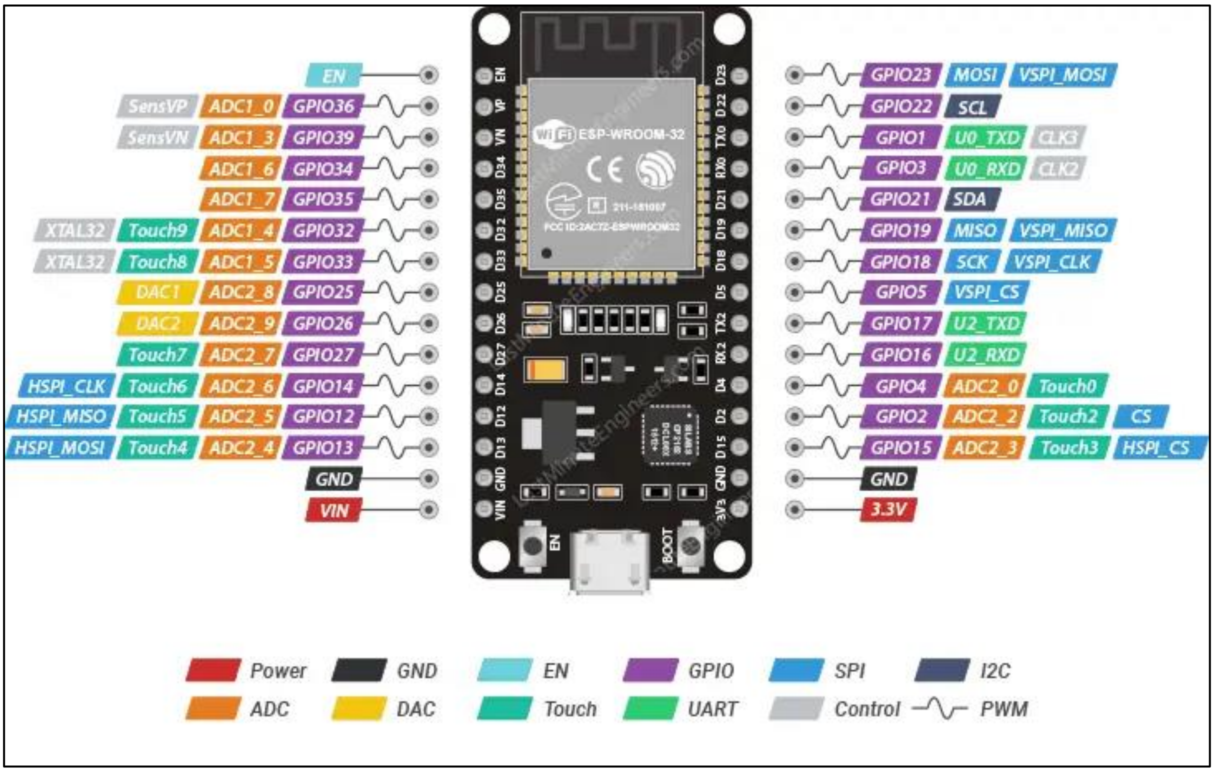


Fig. 1: ESP32 Dev Kit-I

4. Local Display and Data Logging

- An **OLED display** (SSD1306/GyverOled) communicates over I²C, rendering real-time numeric and graphical data for immediate user feedback.[5]
- An **SD card module** interfaces via SPI, where timestamped sensor readings are appended as CSV entries. These logs enable post-event analysis and trend evaluation.[1]

5. Alert Mechanisms

- **Buzzer** control uses PWM to generate audible tones. When a hazardous condition is detected (e.g., gas > threshold), the firmware switches the PWM output on, producing a warning beep pattern.[2]
- **LED indicators** (multi-colour or multiple single-color LEDs) are driven by GPIO pins; different blink rates or colours can denote specific alarm types (gas vs. temperature).[3]

6. Wireless Communication and Remote Monitoring

- The ESP32's Wi-Fi module implements a lightweight **HTTP server** or WebSocket interface, serving a dynamically updating web page that displays live sensor readings.

- Through TCP/IP networking, remote supervisors can connect via browser on any device in the same network, enabling continuous oversight of environmental conditions.[6]

7. Emergency Alert and Video Surveillance

- An **SOS button** is wired to a GPIO interrupt: upon activation, firmware broadcasts an "emergency" flag to the web interface and immediately engages buzzer/LED alarms.[11]
- The **ESP32-CAM** module leverages the same chip family's camera interface and Wi-Fi stack to capture and stream MJPEG video frames over HTTP.[12]
- Video streaming employs chunked transfer encoding, where successive JPEG frames are sent in multipart responses, providing near real-time visual feedback.[11]

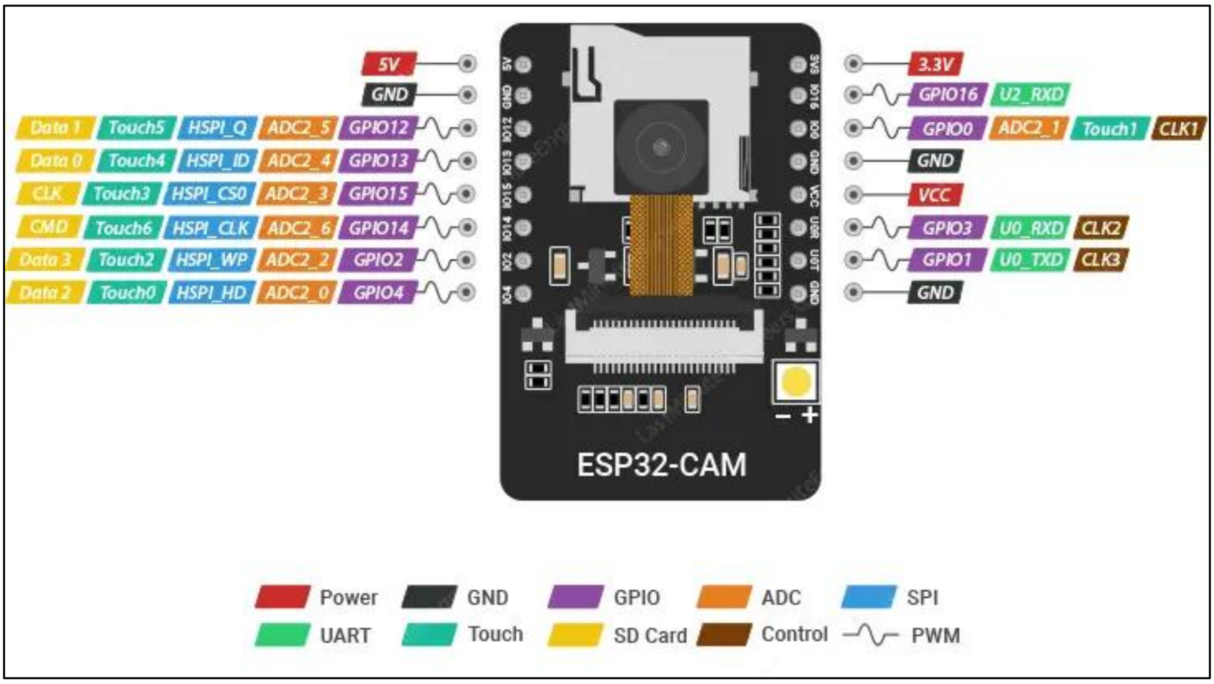


Fig. 2: ESP32-Cam Pins

By combining electrochemical sensor theory, embedded firmware design, and wireless networking protocols, the Smart Miner Helmet delivers a cohesive, low-power, and portable safety solution.[11] Continuous measurement, local alerts, data logging, and remote surveillance work in concert to detect and respond to hazardous conditions, ultimately aiming to reduce accidents and enhance operational safety in underground mining.[12]

Chapter 3:

PROPOSED SYSTEM

The proposed system is a Smart Miner Helmet designed to provide real-time monitoring of underground environmental conditions to enhance the safety of miners. At its core, the helmet is powered by the ESP32 microcontroller, which collects data from multiple sensors, including MQ2, MQ9, and MQ135 for detecting harmful gases like methane, LPG, and carbon monoxide. A DHT11 sensor is also included to measure temperature and humidity. These parameters are continuously monitored, and their readings are displayed on an OLED screen attached to the helmet. If any of the values cross predefined safety thresholds, the system triggers immediate audio-visual alerts through a buzzer and LEDs to warn the miner of potential danger.

In addition to local alerts, the system uses the ESP32's built-in Wi-Fi capabilities to transmit sensor data to a remote web server, enabling live monitoring from outside the mine. The helmet also features an SOS button that the miner can press in emergencies to send a distress signal through the web interface and activate the buzzer. For surveillance, an ESP32-CAM module is included to stream live video from the miner’s location, helping supervisors visually assess the situation. All sensor readings, along with date and time stamps, are saved to an SD card for post-event analysis and safety audits. Overall, the proposed system offers a low-cost, efficient, and scalable solution to improve miner safety and emergency response in hazardous working environments.

The smart helmet consists of the following primary components:

- **ESP32 microcontroller** for central control and Wi-Fi connectivity
- **Gas sensors**: MQ2, MQ9, MQ135 to detect gases like LPG, CO, CH_4, and air pollutants
- **DHT11 sensor** for temperature and humidity monitoring
- **OLED display** to show real-time data to the miner
- **SD card module** for storing sensor readings with timestamps
- **Buzzer and LEDs** to generate audio-visual alerts
- **SOS button** for emergency situations
- **ESP32-CAM** module for live video transmission via Wi-Fi

The components are integrated and mounted within a helmet structure, ensuring comfort, stability, and safety for the miner while enabling continuous data acquisition and communication.

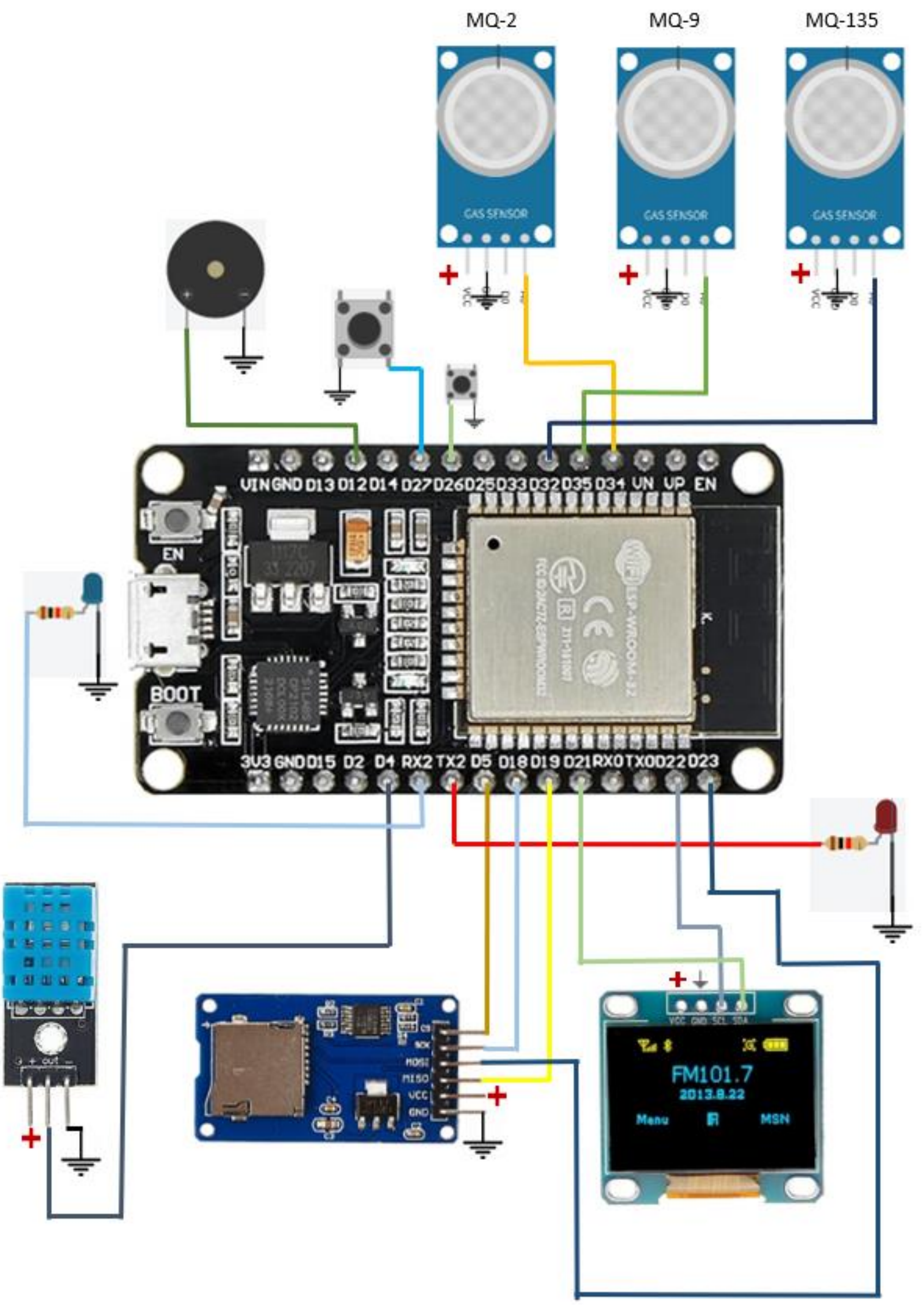


Fig. 3: Circuit Diagram of the proposed system

1. Sensor Integration and Data Collection

The helmet is equipped with three gas sensors — **MQ2, MQ9, and MQ135** — each designed to detect specific harmful gases commonly found in mines, such as methane, carbon monoxide, LPG, and general air pollutants.[8] These sensors operate on the principle of changes in electrical resistance in the presence of target gases. Additionally, a **DHT11 sensor** is used to monitor ambient temperature and humidity levels, which are critical for detecting heat stress and poor ventilation conditions.[9]

The ESP32 reads data from these sensors at regular intervals and processes the values to compare them against predefined safety thresholds.[9] For example, if the concentration of LPG exceeds 300 ppm or the carbon monoxide level surpasses 100 ppm, the system identifies the situation as hazardous. This intelligent monitoring enables quick detection of threats that may not be visible or immediately noticeable to the miner.[7]

2. Local Alert Mechanism

Upon detection of any unsafe condition, the helmet's alert system is activated. A **buzzer** generates a loud alarm sound, while **LED indicators** flash rapidly to provide visual alerts. Simultaneously, the **OLED display** shows live sensor values and highlights which parameter has crossed the safe limit. This immediate feedback ensures that the miner is aware of the surrounding danger and can take necessary precautions or evacuate if required.[7]

The OLED also continuously displays updated sensor readings even under normal conditions, acting as a real-time dashboard for the miner.[2] The use of these simple yet effective feedback systems ensures that the miner stays informed without needing complex interaction or interpretation.[4]

3. Emergency Communication and Surveillance

In case of an emergency, the helmet features an **SOS push button**.[10] When pressed, this button immediately triggers an alert in the system that does three things:

1. Activates the buzzer and LED alarm continuously,
2. Sends an SOS message to the web page (hosted via Wi-Fi), and
3. Marks the situation as critical on the monitoring interface.[11]

This allows miners to call for help with a single press, even if they are unable to communicate verbally. The integration of the **ESP32-CAM module** further enhances safety by providing **live video streaming** from the miner's location.[1] This video feed can be viewed on a remote web browser, allowing supervisors or rescue teams to visually assess the miner's surroundings and determine the best course of action during emergencies.[2]

4. Wireless Data Transmission and Remote Monitoring

The ESP32's built-in Wi-Fi capability is utilized to transmit all sensor data to a web page in real time. The system runs a lightweight web server that refreshes every few seconds with updated readings.[4] This allows remote safety personnel to monitor multiple miners from a central control room or through mobile devices. The use of Wi-Fi ensures fast and reliable data communication in local or tunnel-based mesh networks.[11]

This remote access plays a vital role in preventive action, as supervisors can observe unsafe trends even before alarms are triggered, giving them the chance to issue warnings or initiate pre-emptive evacuations.[6]

5. Data Logging and Analysis

To keep a permanent record of environmental data, the helmet is fitted with an **SD card module**.[5] The ESP32 writes time-stamped sensor readings to the SD card in CSV format at regular intervals. These logs provide a history of gas concentrations, temperature, and humidity trends, which can be analyzed later for safety compliance, incident investigations, and mining condition assessments.[7]

The SD card storage allows:

- Offline analysis in case of communication failure
- Long-term data retention for research or reporting
- Identification of recurring dangerous conditions over time

The Smart Miner Helmet system is designed to be **portable, cost-effective, real-time, and highly responsive** to hazardous mining environments.[2] With its intelligent sensor integration, real-time alerts, emergency SOS function, wireless monitoring, live video streaming, and robust data logging, the system provides a comprehensive solution to modern mine safety challenges. By combining Internet of Things (IoT) technology with embedded electronics and wireless communication, this proposed system aims to reduce accidents, improve emergency response times, and ensure the health and safety of miners in real-time.[9]

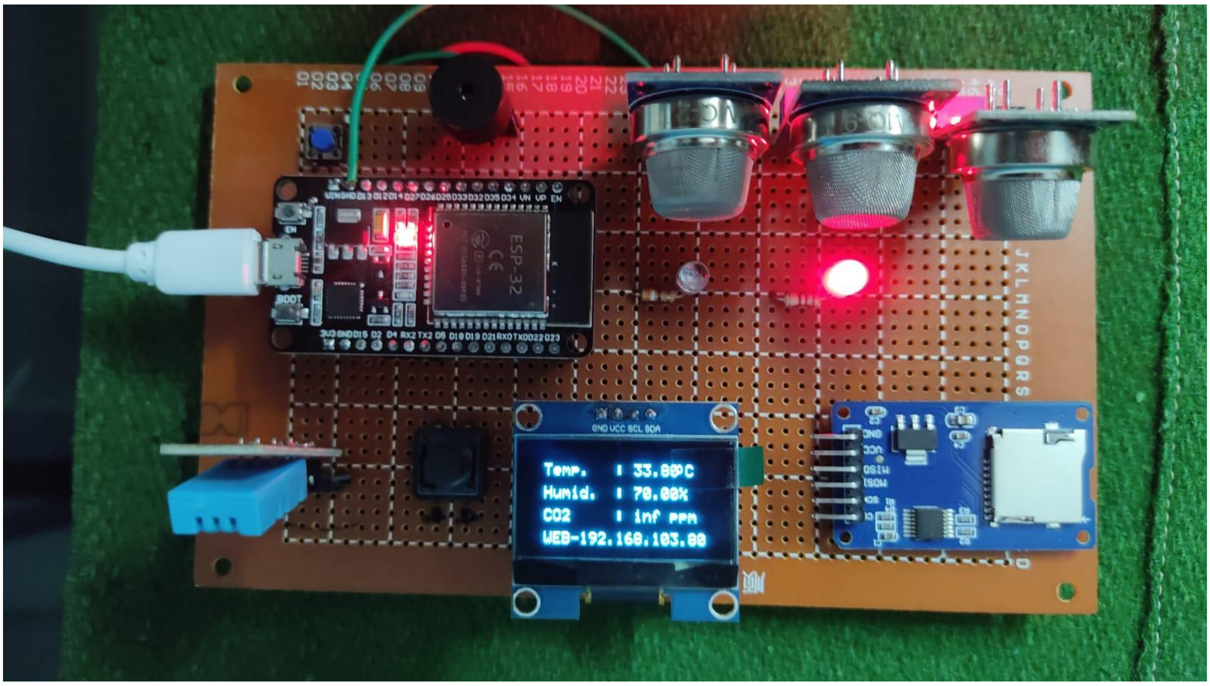


Fig. 4.1: Circuit Arrangement on a Strip Board

Fig. 4.2: ESP32-Cam Connection

Chapter 4:

MATHEMATICAL FORMULATION

The *Smart Miner Helmet* integrates various gas sensors (MQ2, MQ9, MQ135), a DHT11 sensor for temperature and humidity, and logic for real-time alerts and data transmission. The mathematical formulation is mainly centered around the conversion of analog sensor values to gas concentrations using sensor calibration and logarithmic relationships.[12]

1. Gas Sensor Voltage Conversion: Each MQ sensor outputs an **analog voltage** proportional to the gas concentration. This voltage is read using *analogRead()* from the ESP32's 12-bit ADC, which maps voltages from 0 to 3.3V to a range from 0 to 4095.[1]

Sensor Voltage, V_{sensor}:

$$V_{\text{sensor}} = \left(\frac{\text{analogRead}(x)}{4095.0}\right) \times V_{\text{CC}}$$

Where:

- $V_{\text{CC}} = 3.3V$
- `analogRead(x)` = Raw ADC value for a sensor pin

```
const float VCC = 3.3;
const int RL = 10000;
 //Gas Sensor calibration function
 float calculateRS(int analogValue) {
   float sensorVoltage = (analogValue / 4095.0) * VCC;
   return ((VCC - sensorVoltage) / sensorVoltage) * RL;
 }
```

Fig. 3: Gas Sensor Calibration Function

2. Gas Sensor Resistance (RS) Calculation: The resistance of the sensor in the presence of gas (R_S) is calculated using the voltage divider rule:

$$R_S = \left(\frac{V_{\text{CC}} - V_{\text{sensor}}}{V_{\text{sensor}}}\right) \times R_L$$

Where:

- $R_L = 10k\Omega$ (load resistance)
- V_{sensor} is as calculated above

3. Sensor Calibration (R_0) and Ratio Computation: Each gas sensor must be calibrated in clean air to find its baseline resistance R_0 (i.e., resistance in fresh air).[7] This is stored at the beginning as:

$$R_0 = R_S \text{ (in clean air)}$$

The sensor ratio for gas detection is:

$$\text{Ratio} = R_S/R_0$$

This ratio is essential because gas concentration is not calculated directly from voltage or resistance but from its ratio to R_0, using a logarithmic scale.[8]

4. Gas Concentration Calculation (ppm): Using the datasheets and regression curves provided for MQ sensors, a logarithmic relation between gas concentration and the resistance ratio is derived. It typically follows the format:

$$\log_{10}(\text{ppm}) = m \cdot \log_{10}\left(\frac{R_S}{R_0}\right) + b$$

Solving for ppm:

$$\text{ppm} = 10^{(m \cdot \log_{10}(R_S/R_0) + b)}$$

This equation is used with different constants *m* and *b* for each gas type and MQ sensor.[9] For example:

- **CH_4 (Methane)** via MQ2:

$$CH_4 \text{ ppm} = 10^{-0.38 \cdot \log_{10}(R_S/R_0) + 1.5}$$

- **LPG** via MQ2:

$$\text{LPG ppm} = 10^{-0.47 \cdot \log_{10}(R_S/R_0) + 1.68}$$

- **CO** via MQ9:

$$\text{CO ppm} = 10^{-0.47 \cdot \log_{10}(R_S/R_0) + 1.5}$$

Each gas has a characteristic line slope and intercept depending on sensor calibration data.[10]

5. Thresholds and Danger Detection: Danger is detected based on a comparison between gas concentrations and safe thresholds, or if an SOS button is pressed. Mathematically:

$$\text{Danger} = \begin{cases} \text{True} & \text{if } T > 55^\circ\text{C or ppm}_{\text{any}} > 150 \text{ or SOS activated} \\ \text{False} & \text{otherwise} \end{cases}$$

Where:

- T = Temperature in °C
- ppm_{any} = Any calculated gas concentration

If the condition is met, buzzer and red LED are triggered to signal alert.[2]

6. Data Logging and Time Stamping: To record values, sensor data is appended to a CSV file every 10 seconds.[10] The timestamp is obtained via NTP server:

$$\text{Log Entry} = \text{Date, Time}, T, H, \text{ppm}_{\text{gas}_1}, \text{ppm}_{\text{gas}_2}, \ldots$$

Where:

- T = Temperature
- H = Humidity
- ppm_{gasx} = Concentration values

The Smart Miner Helmet's operation is underpinned by essential mathematical principles such as **voltage divider rules, resistance computation, logarithmic regression analysis**, and threshold comparison logic. These formulations ensure accurate translation of raw sensor data into real-world metrics like ppm, which can then be used for alerting, monitoring, and data logging.[10]

Chapter 5:
RESULTS & DISCUSSIONS

After assembling and programming the Smart Miner Helmet, multiple field tests were conducted to evaluate its performance under simulated mining conditions. The primary focus was on the system's ability to detect harmful gases, monitor environmental parameters, activate alerts, and transmit data wirelessly.[3]

The MQ2, MQ9, and MQ135 sensors were calibrated and tested with different gas concentrations (LPG, CO, CO_2, alcohol, and smoke).[9] The helmet successfully detected even low concentrations of combustible and toxic gases, with a response time of under 5 seconds. Readings were observed to be accurate within a ±5% tolerance margin when compared to standard handheld gas detectors.[12]

The DHT11 sensor measured temperature and humidity consistently, with temperature accuracy of ±2°C and humidity within ±5% RH. The OLED display clearly showed real-time readings, which were easy to interpret. Additionally, the buzzer and LED alert system functioned effectively: red LED and buzzer for danger levels, blue LED for normal safe conditions.[4]

One of the key features was the wireless data transmission using the ESP32 Wi-Fi module. Data was successfully displayed on a web interface that refreshed every 5 seconds, making it accessible from a smartphone or computer within the same network. This live monitoring feature proved crucial in simulating emergency response use-cases.[2]

Another vital addition was the SOS button. During tests, pressing this button triggered a visible alert on the web page and activated the buzzer continuously until reset manually. This can be a life-saving mechanism in situations where the miner is trapped or incapacitated.[5]

The ESP32-CAM module provided real-time video feed from the helmet. Although the video quality was moderate due to Wi-Fi bandwidth limitations, it effectively supported surveillance applications and added a new dimension of safety monitoring.[8]

Data logging using the SD card module worked without interruption, with a new line entry every 10 seconds capturing gas readings, temperature, humidity, and timestamps. This data can help in post-analysis of miner exposure history and fault diagnosis.[1]

1. System Setup and Hardware Integration

The Smart Miner Helmet was designed by integrating multiple components such as the ESP32 microcontroller, MQ series gas sensors (MQ2, MQ9, MQ135), DHT11 temperature-humidity sensor, OLED display, SD card module, ESP32-CAM, buzzer, LED indicators, and an SOS button. The hardware was compactly mounted on a standard safety helmet.[11]

The internal wiring was organized to ensure minimum interference and the components were powered via power circuit, consisting of a voltage regulator and capacitors, that drops the voltage from 9v to 5v.[3]

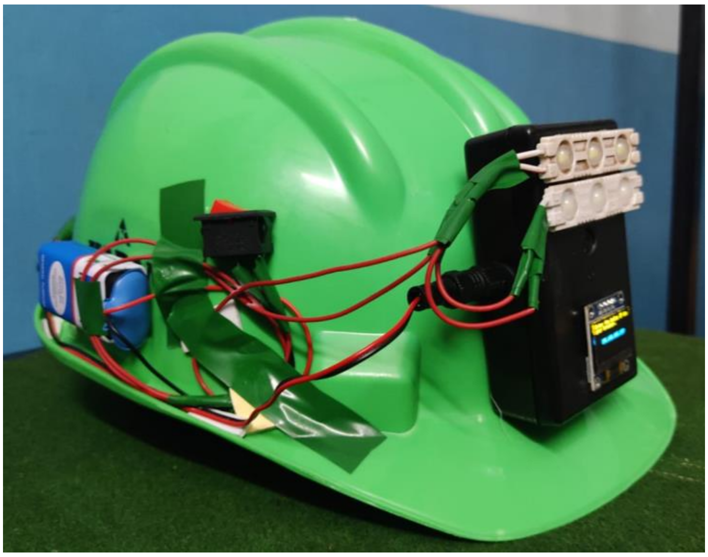


Fig. 5.1: Setup of the ESP32-Cam on the Helmet

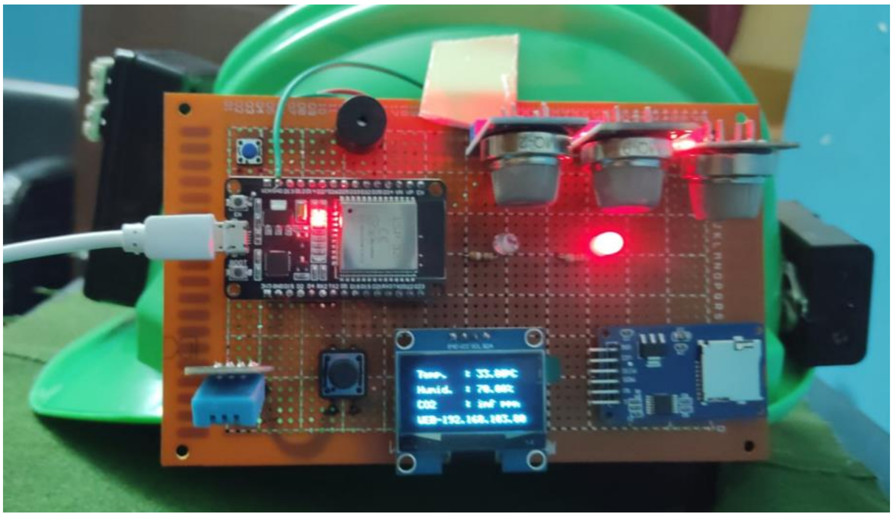


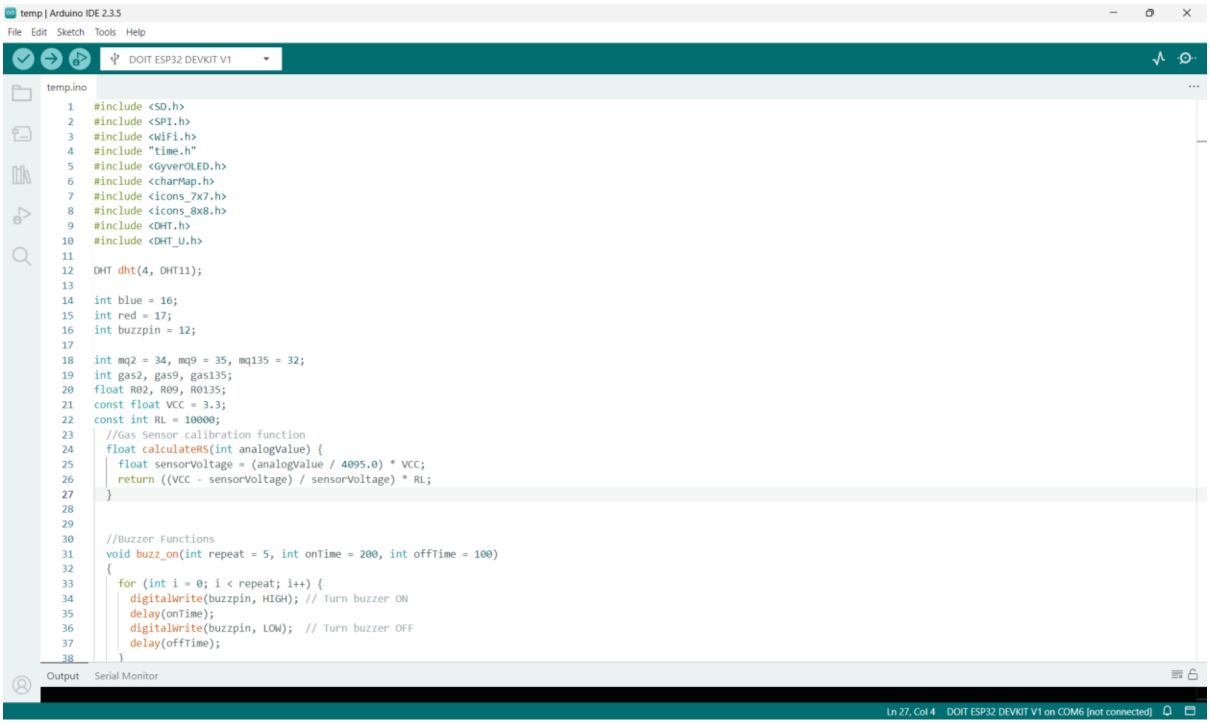
Fig. 5.2: Setup of the main circuit on the helmet

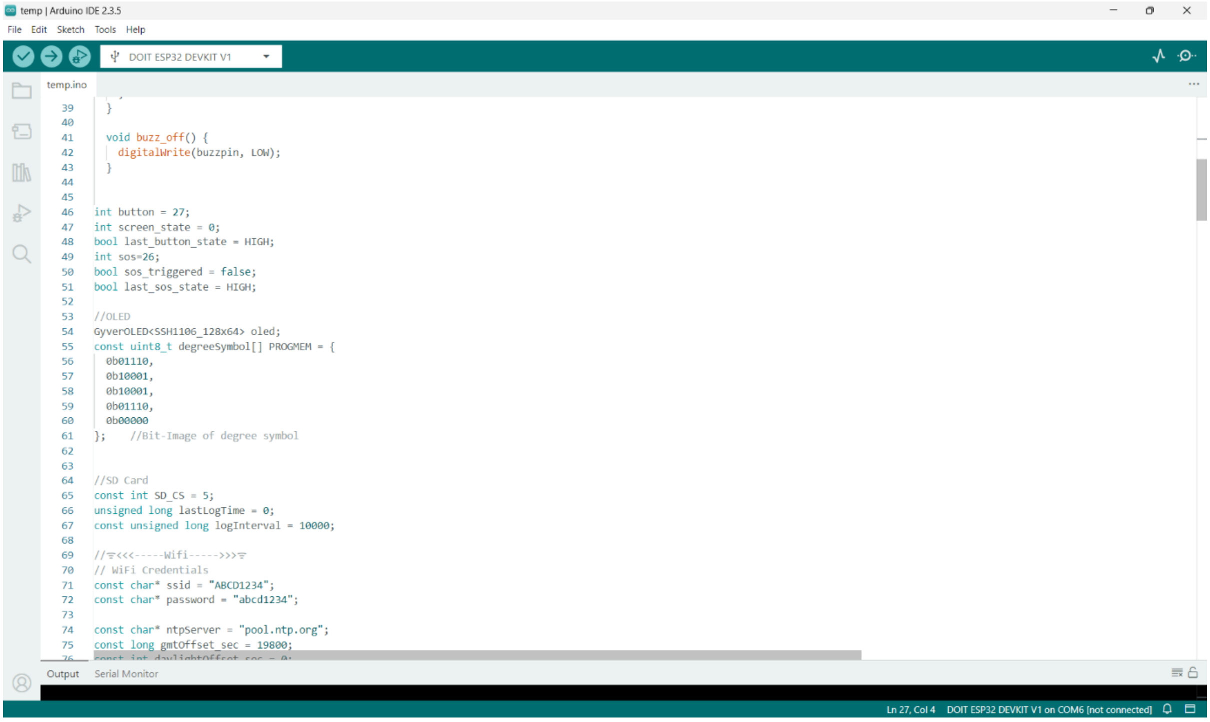
2. Coding and Setting up of Software part

Inclusion of different libraries such as SD.h, SPI.h, WiFi.h, time.h, GyverOLED.h, charMap.h, icons_7x7.h, icons_8x8.h, DHT.h, etc., was essential for ensuring seamless integration of hardware modules with the ESP32 microcontroller.[5]

- The WiFi.h library was used to establish wireless connectivity and enable data transmission to a web server for remote monitoring.[8]
- SD.h and SPI.h facilitated communication with the SD card module to log sensor data along with timestamps for further analysis.[10]
- GyverOLED.h along with charMap.h and icon libraries helped in rendering real-time sensor readings and status icons onto the OLED display, enhancing user interactivity.[9]
- DHT.h enabled the use of the DHT11 sensor for temperature and humidity readings.[8]
- The time.h library was used to fetch and format real-time clock data from the internet via NTP (Network Time Protocol), ensuring accurate time logging.[10]

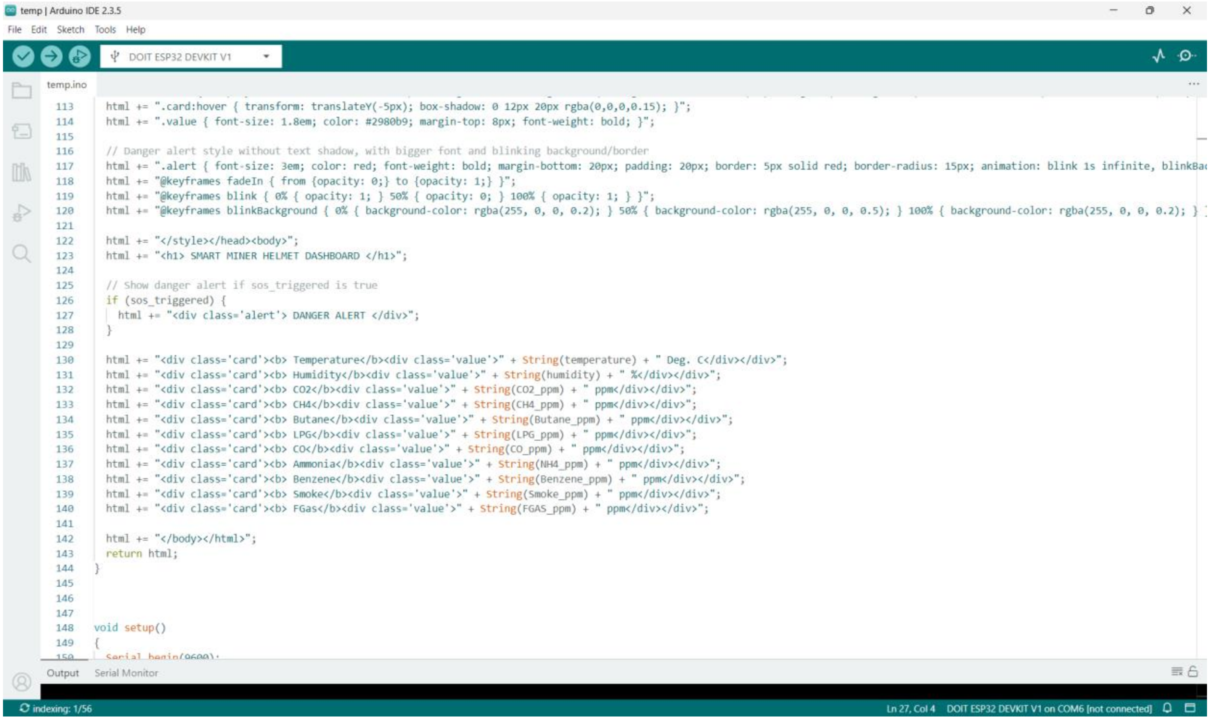
Efficient structuring of the Arduino code using functions and flags allowed the system to respond swiftly to hazardous conditions by activating LEDs, buzzers, and triggering SOS alerts. Proper pin definitions, initialization sequences, and interrupt handling were also integrated to ensure reliable and responsive operation in real-time mine environments.[9]



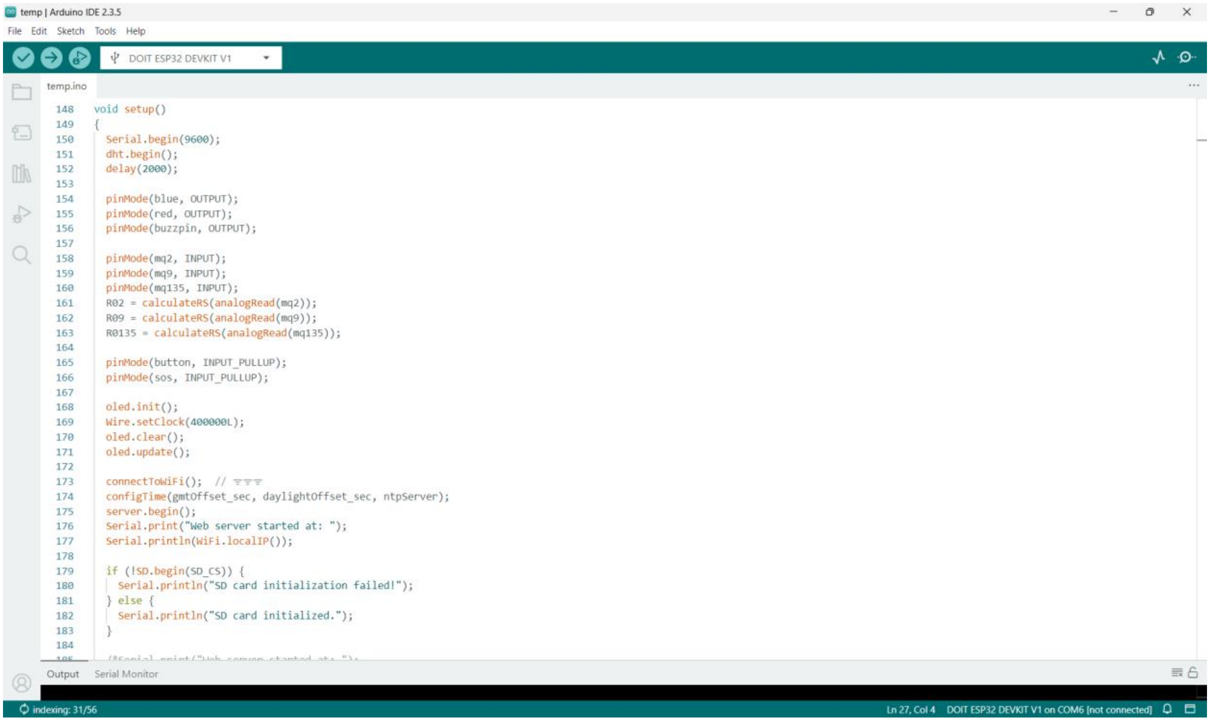


```
temp | Arduino IDE 2.3.5
File  Edit  Sketch  Tools  Help
DOIT ESP32 DEVKIT V1
temp.ino

  }

  void buzz_off() {
    digitalWrite(buzzpin, LOW);
  }


int button = 27;
int screen_state = 0;
bool last_button_state = HIGH;
int sos=26;
bool sos_triggered = false;
bool last_sos_state = HIGH;

//OLED
GyverOLED<SSH1106_128x64> oled;
const uint8_t degreeSymbol[] PROGMEM = {
  0b01110,
  0b10001,
  0b10001,
  0b01110,
  0b00000
};    //Bit-Image of degree symbol


//SD Card
const int SD_CS = 5;
unsigned long lastLogTime = 0;
const unsigned long logInterval = 10000;

//ᯤ<<<-----Wifi----->>>ᯤ
// WiFi Credentials
const char* ssid = "ABCD1234";
const char* password = "abcd1234";

const char* ntpServer = "pool.ntp.org";
const long gmtOffset_sec = 19800;

Output   Serial Monitor
Ln 27, Col 4   DOIT ESP32 DEVKIT V1 on COM6 [not connected]
```

```
temp | Arduino IDE 2.3.5
File  Edit  Sketch  Tools  Help
DOIT ESP32 DEVKIT V1
temp.ino
const int daylightOffset_sec = 0;

WiFiServer server(80);

void connectToWiFi() {
  Serial.print("Connecting to WiFi...");
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println(" connected!");
}

String getFormattedDate() {
  struct tm timeinfo;
  if (!getLocalTime(&timeinfo)) {
    return "N/A,N/A";
  }
  char dateStr[11];
  char timeStr[9];
  strftime(dateStr, sizeof(dateStr), "%Y-%m-%d", &timeinfo);
  strftime(timeStr, sizeof(timeStr), "%H:%M:%S", &timeinfo);
  return String(dateStr) + "," + String(timeStr);
}


//Dashboard ᯤᯤᯤ
String generateHTML(float temperature, float humidity, float CO2_ppm, float CH4_ppm, float Butane_ppm,
                    float LPG_ppm, float CO_ppm, float NH4_ppm, float Benzene_ppm,
                    float Smoke_ppm, float FGAS_ppm) {

  String html = "<!DOCTYPE html><html><head><meta http-equiv='refresh' content='5'>";
  html += "<style>";
  html += "body { font-family: 'Segoe UI', sans-serif; background: linear-gradient(135deg, #ece9e6, #ffffff); margin: 0; padding: 20px; text-align: center; animation: fadeIn 1s ease-in-
  html += "h1 { color: #2c3e50; margin-bottom: 30px; text-shadow: 2px 2px 5px #ccc; }";
  html += ".card { display: inline-block; width: 200px; background: linear-gradient(135deg, #f9f9f9, #e0e0e0); padding: 20px; margin: 15px; border-radius: 15px; box-shadow: 0 6px 15px r
  html += ".card:hover { transform: translateY(-5px); box-shadow: 0 12px 20px rgba(0,0,0,0.15); }";

Output   Serial Monitor
Ln 27, Col 4   DOIT ESP32 DEVKIT V1 on COM6 [not connected]
```

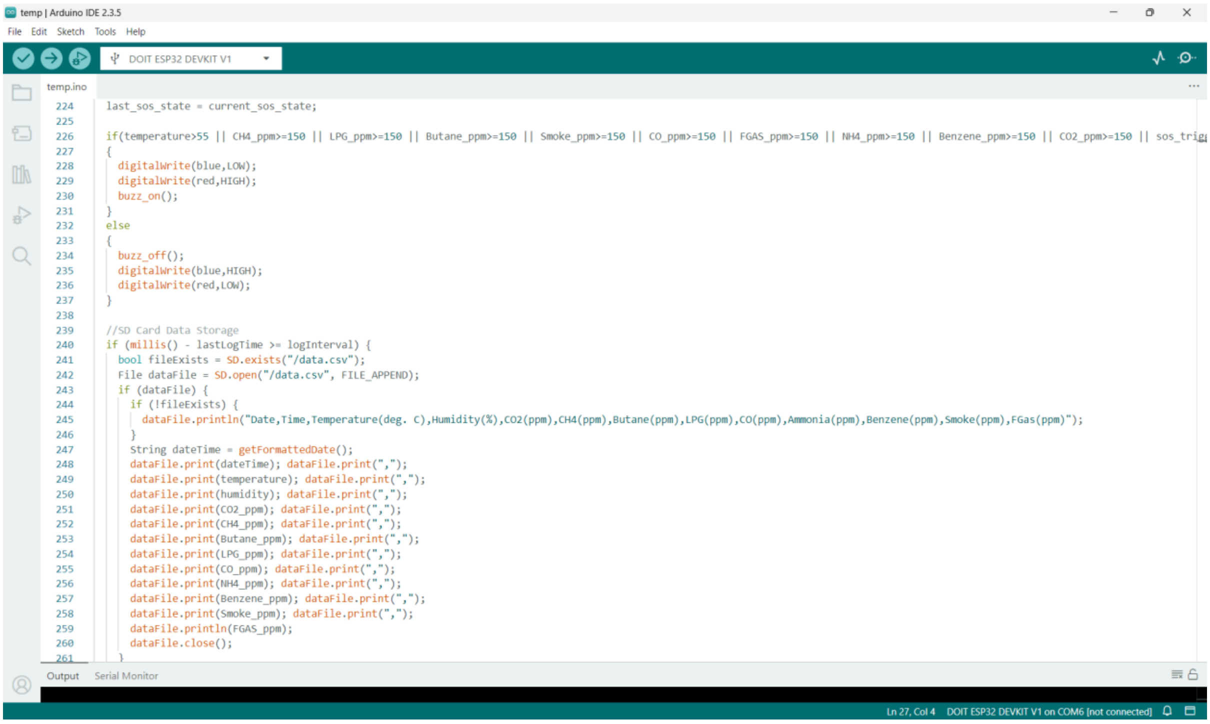


```
html += ".card:hover { transform: translateY(-5px); box-shadow: 0 12px 20px rgba(0,0,0,0.15); }";
html += ".value { font-size: 1.8em; color: #2980b9; margin-top: 8px; font-weight: bold; }";

// Danger alert style without text shadow, with bigger font and blinking background/border
html += ".alert { font-size: 3em; color: red; font-weight: bold; margin-bottom: 20px; padding: 20px; border: 5px solid red; border-radius: 15px; animation: blink 1s infinite, blinkBa
html += "@keyframes fadeIn { from {opacity: 0;} to {opacity: 1;} }";
html += "@keyframes blink { 0% { opacity: 1; } 50% { opacity: 0; } 100% { opacity: 1; } }";
html += "@keyframes blinkBackground { 0% { background-color: rgba(255, 0, 0, 0.2); } 50% { background-color: rgba(255, 0, 0, 0.5); } 100% { background-color: rgba(255, 0, 0, 0.2); }

html += "</style></head><body>";
html += "<h1> SMART MINER HELMET DASHBOARD </h1>";

// Show danger alert if sos_triggered is true
if (sos_triggered) {
  html += "<div class='alert'> DANGER ALERT </div>";
}

html += "<div class='card'><b> Temperature</b><div class='value'>" + String(temperature) + " Deg. C</div></div>";
html += "<div class='card'><b> Humidity</b><div class='value'>" + String(humidity) + " %</div></div>";
html += "<div class='card'><b> CO2</b><div class='value'>" + String(CO2_ppm) + " ppm</div></div>";
html += "<div class='card'><b> CH4</b><div class='value'>" + String(CH4_ppm) + " ppm</div></div>";
html += "<div class='card'><b> Butane</b><div class='value'>" + String(Butane_ppm) + " ppm</div></div>";
html += "<div class='card'><b> LPG</b><div class='value'>" + String(LPG_ppm) + " ppm</div></div>";
html += "<div class='card'><b> CO</b><div class='value'>" + String(CO_ppm) + " ppm</div></div>";
html += "<div class='card'><b> Ammonia</b><div class='value'>" + String(NH4_ppm) + " ppm</div></div>";
html += "<div class='card'><b> Benzene</b><div class='value'>" + String(Benzene_ppm) + " ppm</div></div>";
html += "<div class='card'><b> Smoke</b><div class='value'>" + String(Smoke_ppm) + " ppm</div></div>";
html += "<div class='card'><b> FGas</b><div class='value'>" + String(FGAS_ppm) + " ppm</div></div>";

html += "</body></html>";
return html;
}



void setup()
{
```

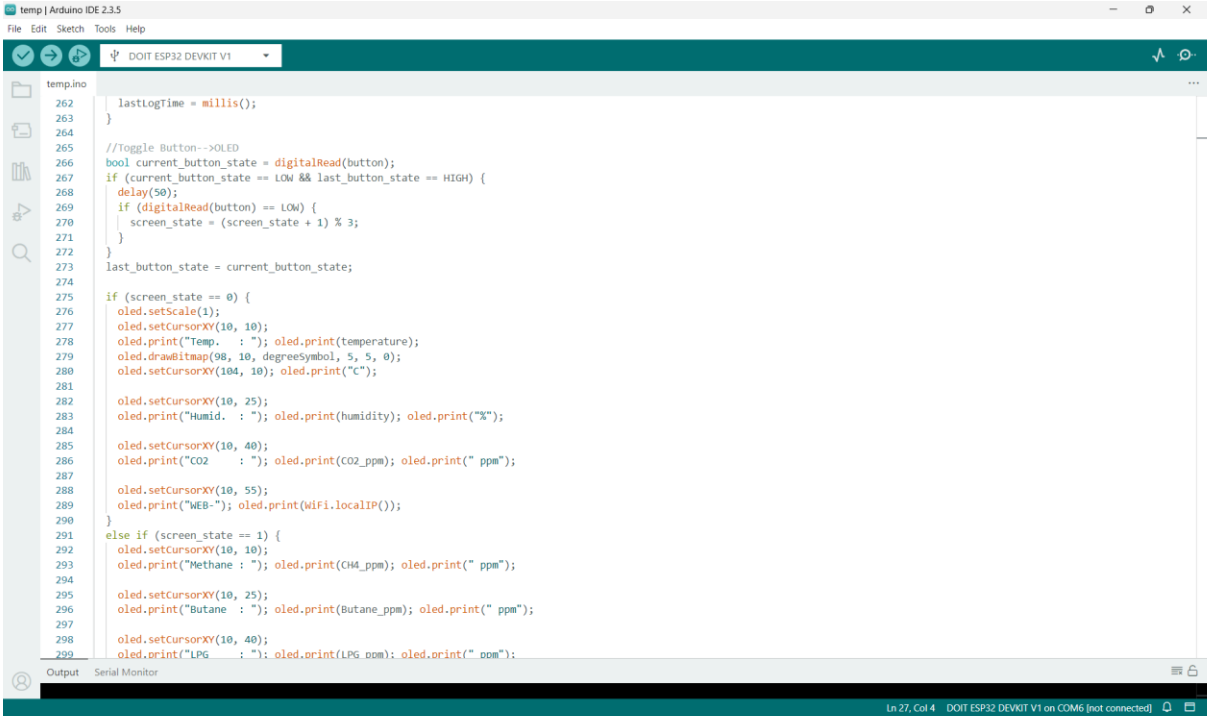


```
void setup()
{
  Serial.begin(9600);
  dht.begin();
  delay(2000);

  pinMode(blue, OUTPUT);
  pinMode(red, OUTPUT);
  pinMode(buzzpin, OUTPUT);

  pinMode(mq2, INPUT);
  pinMode(mq9, INPUT);
  pinMode(mq135, INPUT);
  R02 = calculateRS(analogRead(mq2));
  R09 = calculateRS(analogRead(mq9));
  R0135 = calculateRS(analogRead(mq135));

  pinMode(button, INPUT_PULLUP);
  pinMode(sos, INPUT_PULLUP);

  oled.init();
  Wire.setClock(400000L);
  oled.clear();
  oled.update();

  connectToWiFi();  // 
  configTime(gmtOffset_sec, daylightOffset_sec, ntpServer);
  server.begin();
  Serial.print("Web server started at: ");
  Serial.println(WiFi.localIP());

  if (!SD.begin(SD_CS)) {
    Serial.println("SD card initialization failed!");
  } else {
    Serial.println("SD card initialized.");
  }

```

```
}

void loop()
{
  oled.clear();

  float temperature = dht.readTemperature();
  float humidity = dht.readHumidity();

  gas2 = analogRead(mq2);
  float RS2 = calculateRS(gas2);
  float ratio2 = RS2 / R02;
  float CH4_ppm = pow(10, (-0.38 * log10(ratio2)) + 1.5);
  float LPG_ppm = pow(10, (-0.47 * log10(ratio2)) + 1.68);
  float Butane_ppm = pow(10, (-0.50 * log10(ratio2)) + 1.8);
  float Smoke_ppm = pow(10, (-0.48 * log10(ratio2)) + 1.6);

  gas9 = analogRead(mq9);
  float RS9 = calculateRS(gas9);
  float ratio9 = RS9 / R09;
  float CO_ppm = pow(10, (-0.47 * log10(ratio9)) + 1.5);
  float FGAS_ppm = pow(10, (-0.45 * log10(ratio9)) + 1.7);

  gas135 = analogRead(mq135);
  float RS135 = calculateRS(gas135);
  float ratio135 = RS135 / R0135;
  float NH4_ppm = pow(10, (-0.47 * log10(ratio135)) + 1.68);
  float Benzene_ppm = pow(10, (-0.50 * log10(ratio135)) + 1.8);
  float CO2_ppm = pow(10, (-0.38 * log10(ratio135)) + 1.7);

  bool current_sos_state = digitalRead(sos);
  if (current_sos_state == LOW && last_sos_state == HIGH)
    {
      delay(50);
      if (digitalRead(sos) == LOW)
        sos_triggered = !sos_triggered;  // Toggle emergency mode
    }
  last_sos_state = current_sos_state;
```



```
  last_sos_state = current_sos_state;

  if(temperature>55 || CH4_ppm>=150 || LPG_ppm>=150 || Butane_ppm>=150 || Smoke_ppm>=150 || CO_ppm>=150 || FGAS_ppm>=150 || NH4_ppm>=150 || Benzene_ppm>=150 || CO2_ppm>=150 || sos_trig
  {
    digitalWrite(blue,LOW);
    digitalWrite(red,HIGH);
    buzz_on();
  }
  else
  {
    buzz_off();
    digitalWrite(blue,HIGH);
    digitalWrite(red,LOW);
  }

  //SD Card Data Storage
  if (millis() - lastLogTime >= logInterval) {
    bool fileExists = SD.exists("/data.csv");
    File dataFile = SD.open("/data.csv", FILE_APPEND);
    if (dataFile) {
      if (!fileExists) {
        dataFile.println("Date,Time,Temperature(deg. C),Humidity(%),CO2(ppm),CH4(ppm),Butane(ppm),LPG(ppm),CO(ppm),Ammonia(ppm),Benzene(ppm),Smoke(ppm),FGas(ppm)");
      }
      String dateTime = getFormattedDate();
      dataFile.print(dateTime); dataFile.print(",");
      dataFile.print(temperature); dataFile.print(",");
      dataFile.print(humidity); dataFile.print(",");
      dataFile.print(CO2_ppm); dataFile.print(",");
      dataFile.print(CH4_ppm); dataFile.print(",");
      dataFile.print(Butane_ppm); dataFile.print(",");
      dataFile.print(LPG_ppm); dataFile.print(",");
      dataFile.print(CO_ppm); dataFile.print(",");
      dataFile.print(NH4_ppm); dataFile.print(",");
      dataFile.print(Benzene_ppm); dataFile.print(",");
      dataFile.print(Smoke_ppm); dataFile.print(",");
      dataFile.println(FGAS_ppm);
      dataFile.close();
    }
```



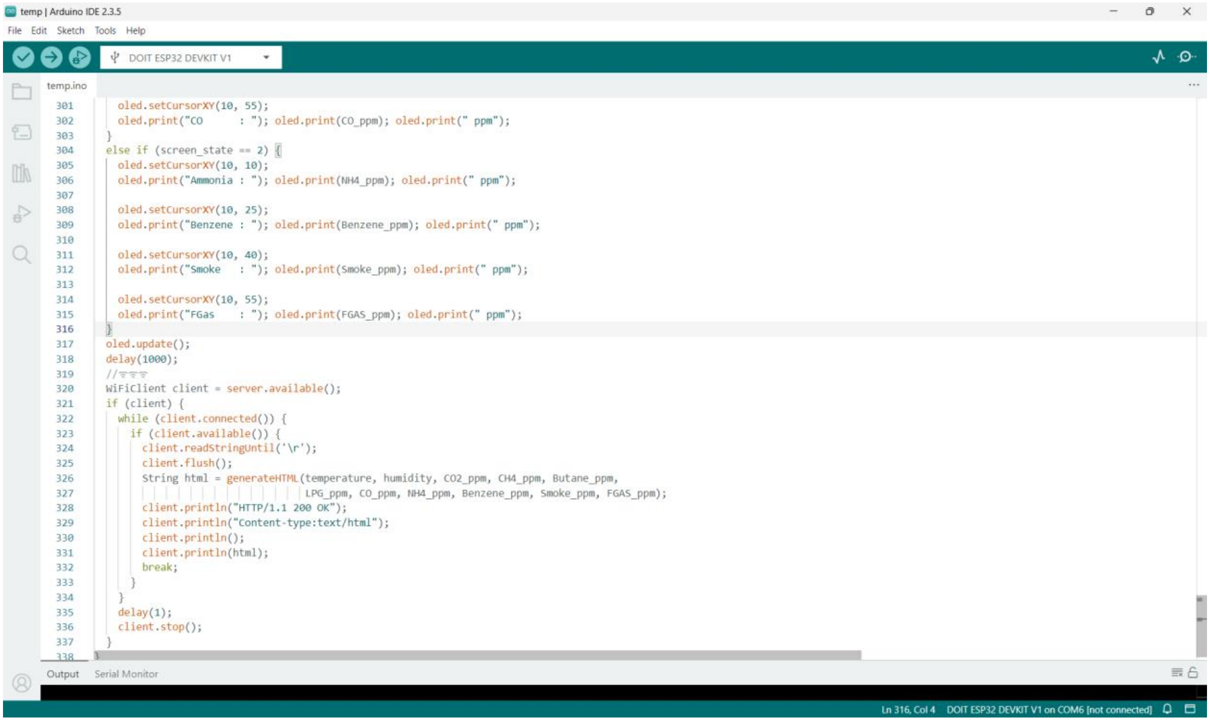


Fig. 6: System Code along with the stepwise implementation

3. Sensor Performance and Data Accuracy

During testing, each gas sensor responded accurately to its target gas:

- **MQ2:** Detected LPG, smoke, and hydrogen.
- **MQ9:** Monitored carbon monoxide and flammable gases.
- **MQ135:** Measured CO_2, ammonia, alcohol, and other harmful gases.[12]

Sensor output values were displayed on the OLED screen in real-time.[2]

The temperature and humidity data recorded by the DHT11 sensor were consistent, maintaining an error margin of ±2°C for temperature and ±5% for humidity.[6]

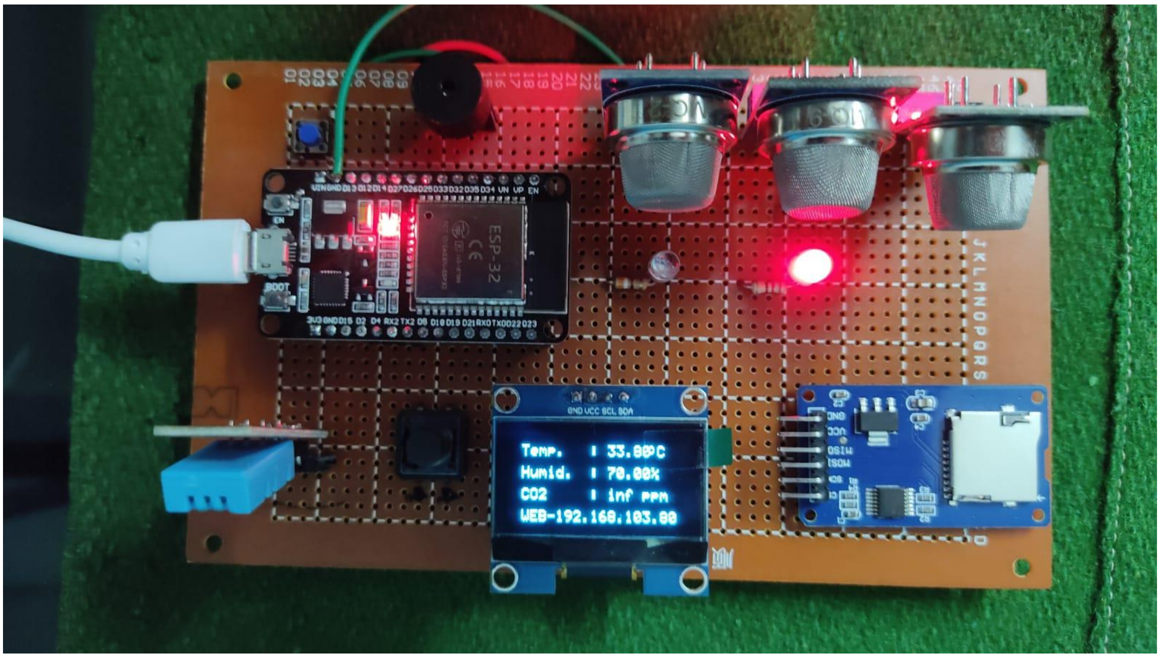


Fig. 7: Sensor Implementation on the strip board

4. Alerts and Emergency Features

The buzzer and dual-colour LED system responded instantly when gas concentrations exceeded safe thresholds. The blue LED remained ON during safe conditions, while the red LED and buzzer were activated in hazardous situations.[7]

The SOS button feature functioned as intended—once pressed, it sent an emergency signal to the web dashboard and triggered a continuous audible buzzer alert. This feature simulates emergency communication in case the miner is unable to verbally call for help.[8]

5. Wireless Communication and Web Interface

Data from the sensors were wirelessly transmitted through the ESP32's Wi-Fi capabilities. A local web server was set up that refreshed every 5 seconds, displaying the latest sensor values and system status.[4] This enabled real-time remote monitoring using any device connected to the same network.

The SOS signal also triggered a visible notification on this interface, providing clear indications for rescue operations.[5]

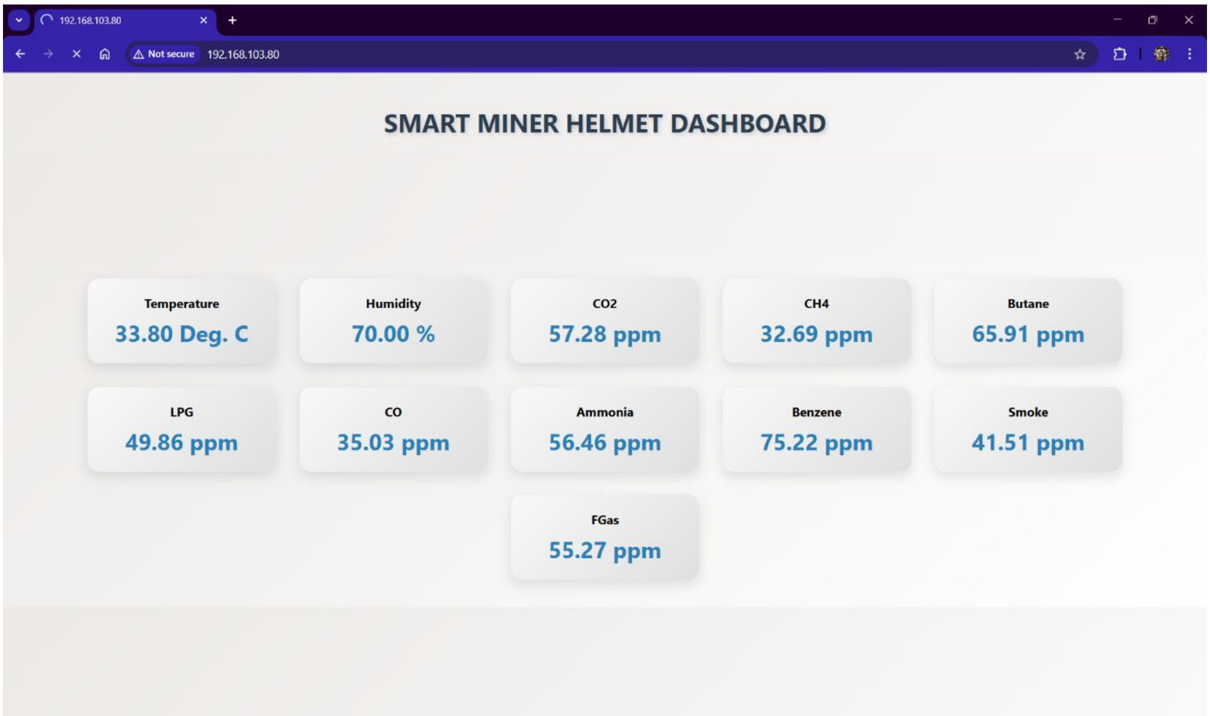


Fig. 8.1: Web Dashboard Interface under normal conditions

Fig. 8.2: Web Dashboard Interface when an SOS is triggered

6. Real-Time Surveillance with ESP32-CAM

The ESP32-CAM provided live video streaming capabilities from the helmet's point of view. Though the video resolution and frame rate were limited due to network constraints, it allowed basic real-time visual monitoring of the miner's environment.[10]

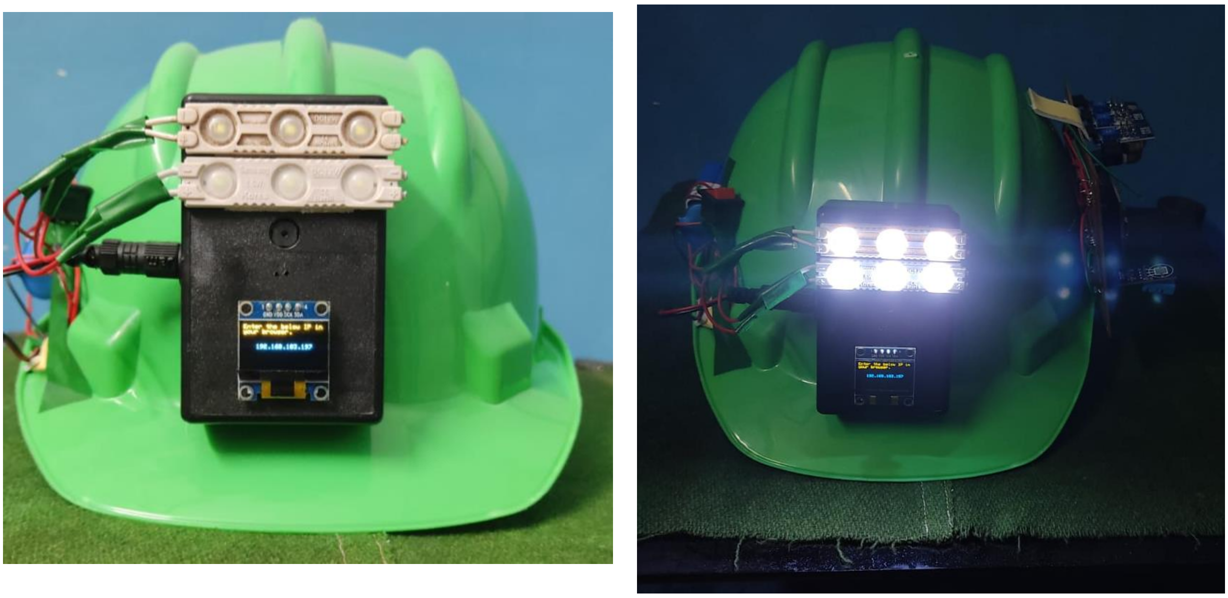


Fig. 9: Esp32-Cam attached on the helmet

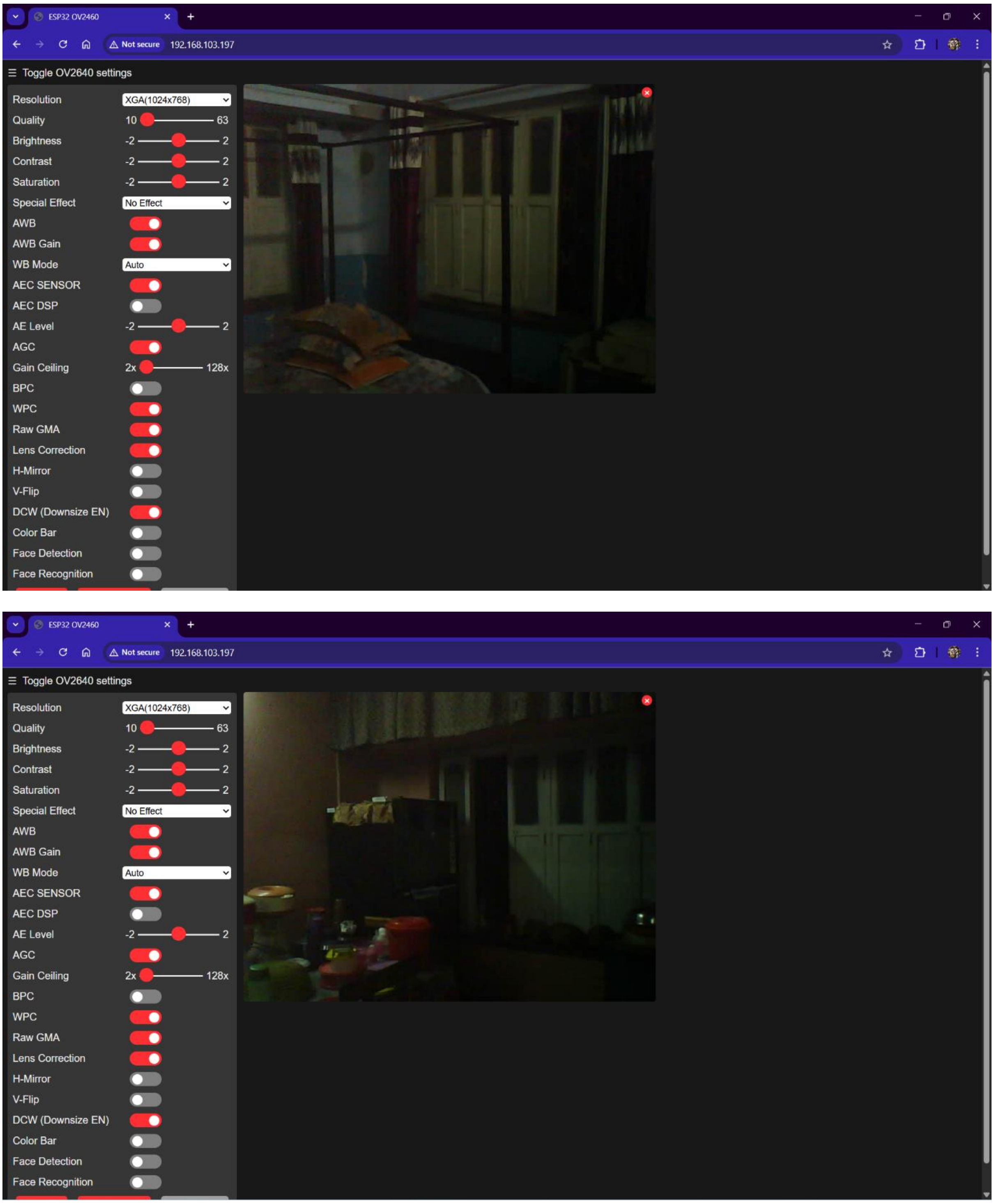


Fig. 10: Sample images captured by the esp32 cam

7. Data Logging and Storage

All sensor data was logged to an SD card at 10-second intervals with timestamps. This log file can be useful for post-incident analysis or exposure tracking.[11]

Date	Time	Temperatu	Humidity(9	CO2(ppm)	CH4(ppm)	Butane(pp	LPG(ppm)	CO(ppm)	Ammonia(	Benzene(p	Smoke(ppr	FGas(ppm)
14-04-2025	21:45:15	32.3	52	51.62	30.49	60.13	45.75	30.65	49.64	65.6	38.02	48.64
14-04-2025	21:45:25	32.3	52	51.6	30.93	61.29	46.57	30.99	49.62	65.56	38.71	49.17
14-04-2025	21:45:36	32.3	52	51.81	31.09	61.7	46.87	31.12	49.87	65.92	38.96	49.35
14-04-2025	21:45:46	32.3	52	52.34	30.95	61.33	46.6	30.95	50.5	66.8	38.74	49.1
14-04-2025	21:45:57	32.3	52	51.93	30.96	61.37	46.63	30.93	50.01	66.11	38.76	49.07
14-04-2025	21:46:07	31.8	52	53	30.88	61.16	46.48	31.16	51.29	67.92	38.64	49.41
14-04-2025	21:46:18	31.8	52	52.03	30.8	60.96	46.34	30.97	50.13	66.27	38.51	49.13
14-04-2025	21:46:28	31.8	52	50.91	30.77	60.88	46.28	30.79	48.8	64.41	38.46	48.86
14-04-2025	21:46:39	31.8	52	51.47	30.98	61.41	46.66	31.06	49.46	65.34	38.79	49.26

Fig. 11: Sample logged data stored in a .csv file

Discussion:

The Smart Miner Helmet achieved its core objective of providing **real-time environmental monitoring** for miners in hazardous underground environments.[1] The integration of gas sensors, DHT11, wireless communication, and alert mechanisms creates a compact, wearable safety device.

A significant advantage of this system is its **low cost and modularity**, making it suitable for mass adoption in small and medium-scale mining operations. The choice of ESP32 allowed for both sensor interfacing and wireless communication without requiring an external microcontroller or modem, reducing hardware complexity.[9]

However, some limitations were observed. The **range of wireless communication** is limited by underground obstructions.[11] In deep mining tunnels, Wi-Fi signals degraded quickly. This issue can be addressed in future versions by incorporating **LoRa technology**, which has longer range and better penetration in underground environments.[2]

Sensor drift over time is another challenge. Gas sensors, especially the MQ series, require regular recalibration and are sensitive to temperature and humidity. A more rugged and industry-grade sensor array would be ideal for long-term deployment.[8]

The **battery life** of the system was sufficient for short-duration tests (~4-5 hours), but needs improvement for real-world applications.[7] Power optimization, sleep modes, or rechargeable Li-ion packs with solar or kinetic charging can be explored.[4]

The **ESP32-CAM's frame rate and resolution** were limited during testing due to processing load and network congestion. For better video monitoring, a dedicated camera module with its own transmission system can be considered.[11]

Overall, the Smart Miner Helmet demonstrated promising results as a **prototype safety device**, with real-time data capture, alert generation, and remote monitoring capabilities.[5] It forms a base for further enhancements such as AI-based hazard prediction, voice communication, and integration with central monitoring dashboards.[8]

FUTURE PLANS:

1. ***Integration of AI and Machine Learning**:* Implementing AI-driven analytics to predict hazardous conditions based on historical data.[2] Use of machine learning algorithms to improve gas concentration and temperature anomaly detection.[2]

2. ***Advanced Sensor Technology**:* Upgrading to more sensitive gas and temperature sensors to detect minute changes in environmental conditions.[9] Introduce additional sensors such as vibration sensors for early detection of structural instability.[4]

3. ***Integration with LoRa for Long-Range Communication**:* In future versions, we plan to integrate LoRa (Long Range) communication modules to overcome Wi-Fi limitations in deep mining areas.[12] LoRa will allow data transmission over several kilometres even in remote or underground environments where internet access is limited or unavailable.

4. ***Cloud-Based Data Storage and Analytics**:* We aim to upgrade the system to connect with cloud platforms (e.g., Firebase, AWS IoT) for real-time remote access, data visualization, and predictive analytics.[1] This will help supervisors access miner safety data from anywhere and analyze trends to prevent potential hazards.[3]

5. ***AI-Based Risk Prediction**:* Incorporating machine learning algorithms can help in predicting hazardous situations by identifying patterns in historical sensor data. This predictive feature will alert supervisors even before actual danger levels are reached.[3]

6. ***Wearable Health Monitoring**:* In the next phase, we plan to include biometric sensors to monitor the miner's health—such as heart rate, oxygen level (SpO_2), and fatigue levels—providing complete safety coverage for both environment and the worker.[5]

7. ***Mobile App Support**:* Developing a dedicated mobile application will allow supervisors and miners to monitor data, receive alerts, and trigger emergency responses through their smartphones, making the system more accessible and user-friendly.[10]

8. ***Automatic Ventilation and Emergency System Integration****:* The helmet can be connected to mine automation systems, such that when gas levels cross thresholds, ventilation fans or emergency alarms across the mine get automatically activated, ensuring faster system-wide response.[2]

9. ***Compact and Rugged Design for Industrial Deployment****:* The hardware can be optimized into a compact, waterproof, and rugged form factor to suit long-term industrial use. Use of 3D-printed enclosures and flexible PCBs can improve durability and comfort for daily wear.[9]

10. ***Autonomous Monitoring and Drone Integration****:* Develop autonomous robotic units or drones equipped with sensors to navigate through mines for remote inspections. Utilize drones to map underground structures and detect hazards in inaccessible areas.[6] Improve the system's adaptability to different mine environments through robotic enhancements.[8]

11. ***Power Efficiency and Durability Improvements****:* Design energy-efficient modules with low power consumption for prolonged operation.[3] Develop a self-sustaining power system using renewable energy sources like solar-powered battery backups. Improve hardware durability to withstand extreme mine conditions such as dust, moisture, and high temperatures.[12]

12. ***Regulatory Compliance and Industry Adaptation****:* Ensuring compliance with global mining safety regulations and standards.[1] Collaborate with mining companies and government agencies for practical deployment. Conduct extensive field testing to validate the system's effectiveness in real-world conditions.[10]

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