SUBTERRA SENSE: HARNESSING ADVANCED IOT FOR PURE AIR IN UNDERGROUND REALMS

PROJECT

Masters of Computer Applications

Branch

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Abstract

Objective:

The primary objective of this project was to develop an IoT-based early warning system capable of detecting hazardous gases (such as CO2, ammonia, smoke, alcohol, benzene, and nitrogen oxides) in underground mining environments. The system aims to predict dangerous gas levels up to 20 minutes in advance, allowing for preventive measures to be taken before the occurrence of a disaster. The project uses sensors to monitor environmental parameters and a simple predictive model to forecast dangerous conditions based on trends in the gas levels.

Methodology:

To achieve the project's goal, a combination of hardware and software components was utilized. The hardware setup consists of the following components:

MQ-135 Gas Sensor: This sensor detects a range of gases, including CO2, ammonia, benzene, alcohol, smoke, and nitrogen oxides.

DHT11 Temperature and Humidity Sensor: Used to measure environmental temperature and humidity, which can affect gas readings.

Arduino Board: Acts as the central control unit, reading data from the sensors and processing it.

LEDs and Buzzer: Used to signal alerts in the case of hazardous conditions. Green LED for normal air quality, red LED for hazardous conditions, and a buzzer for alarm signals.

LCD Display: Displays real-time temperature, humidity, and air quality data.

In the software, a **predictive model** based on moving averages and rate of change of gas concentration readings was implemented. The system continuously reads the gas levels from the MQ-135 and tracks the trends over time. By extrapolating the rate of change over the next 20 minutes, the system predicts if gas levels will exceed safety thresholds. If a hazardous condition is predicted, the system triggers an early warning via the buzzer and red LED.

Findings:

The system successfully demonstrated the ability to monitor environmental conditions in real-time and predict potential hazardous gas levels. The key findings from the implementation are:

Real-Time Monitoring: The system accurately read gas levels and environmental parameters, providing continuous updates to the LCD display and serial monitor.

Trend Analysis for Prediction: By calculating the rate of change in gas levels and using a moving average, the system was able to predict hazardous conditions within a 20-minute window.

Threshold-Based Alerts: The system effectively detected hazardous gas levels (CO_2, ammonia, smoke, alcohol, benzene, and NO_x) based on predefined threshold values, triggering alerts in real time.

Early Warning System: When the gas levels were predicted to exceed safety thresholds, an early warning was generated, providing a valuable 20-minute window for preventive actions.

Conclusions:

This project successfully demonstrated a practical approach to early hazard detection in mines using IoT technology. By integrating gas sensors, environmental sensors, and a predictive algorithm, the system is able to offer early warnings, potentially saving lives and preventing disasters in mining environments. The predictive model, while based on simple moving averages and trend analysis, provides a foundation for more advanced forecasting methods. Future improvements could include integrating more sophisticated machine learning models for more accurate predictions and adding wireless communication features for remote monitoring and

1. INTRODUCTION

Problem Statement:

Underground environments, particularly in mining operations, present a unique set of challenges regarding air quality control. Mines are confined spaces where workers are exposed to several environmental factors that can directly impact their health and safety. The most pressing issue is the presence of hazardous gases, such as carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), carbon monoxide (CO), and various other toxic compounds, which can accumulate in confined spaces, posing severe health risks and even life-threatening conditions.

Gas Accumulation: In underground environments, gases produced from mining operations, equipment, and natural deposits can accumulate and become highly concentrated in confined areas. For instance, methane, a byproduct of coal mining, is both highly flammable and potentially explosive. Similarly, carbon monoxide, often produced from diesel engines used in underground mining machinery, can reach dangerous levels if ventilation systems fail or are inadequate.

Oxygen Deficiency: Oxygen levels in underground mines can be reduced due to the presence of these gases or due to insufficient ventilation, which is critical for miners' well-being. Low oxygen levels (hypoxia) can cause dizziness, confusion, fatigue, and even death in extreme cases.

Ammonia and Other Toxic Gases: Ammonia (NH_3), which is often used in industrial processes, can cause respiratory problems, eye irritation, and long-term damage to lung tissues. Additionally, the presence of benzene, hydrogen sulfide (H_2S), and other toxic gases can contribute to a dangerous work environment.

Inadequate Ventilation: Underground ventilation systems are designed to ensure the flow of fresh air and the removal of harmful gases. However, malfunctioning or inadequate ventilation systems can lead to the accumulation of gases, exacerbating the problem of poor air quality.

Delayed Detection of Hazardous Conditions: The lack of real-time air quality monitoring is a significant issue in many mining operations. Hazardous gases may not be detected until they reach dangerous concentrations, and miners might not receive timely warnings about deteriorating air quality. Early detection and timely intervention are essential to prevent accidents.

Overall, the primary issues with air quality in underground environments revolve around the presence of harmful gases, oxygen deficiency, inadequate ventilation, and delayed detection, all of which pose significant risks to worker health and safety.

Project Objective:

The objective of this project is to develop a robust air quality monitoring system for underground mining environments using Internet of Things (IoT) technology, coupled with Arduino-based sensors, to enhance the safety and health of miners. The focus of the system is to detect the presence of hazardous gases, monitor oxygen levels, and provide early warnings for any impending danger to create a safer mining environment.

Real-Time Air Quality Monitoring: By using IoT-based sensors connected to an Arduino platform, the system continuously measures environmental parameters, such as the concentration of gases, temperature, and humidity in real-time. This data can be processed and displayed on an LCD screen, offering immediate insights into the air quality in the underground environment.

Predictive Analytics for Early Warning: The goal is to not only monitor but also predict air quality conditions by analyzing trends in gas levels and environmental factors over time. By using simple predictive models, the system can estimate if the gas concentrations will rise to hazardous levels in the next few minutes or hours, giving miners and supervisors enough time to take preventive actions. For instance, if the system detects rising CO_2 or methane levels, it can trigger an alert, giving workers a window of time to evacuate the area or activate ventilation systems.

Integration with Existing Safety Systems: This air quality monitoring system can be integrated with existing safety measures in the mine. Alerts triggered by the system can be routed to central monitoring stations and workers' personal devices, enabling swift decision-making. The system could also work in coordination with other safety mechanisms, such as automated ventilation systems or emergency evacuation protocols.

Affordable and Scalable Technology: By utilizing low-cost, widely available hardware like the Arduino platform, gas sensors, and other components, the project aims to provide a scalable solution that can be implemented in a variety of mining environments, from small to large-scale operations. The flexibility of the system also allows for easy upgrades, such as the addition of more sensors or communication features like wireless connectivity.

Data Logging and Analysis: The system records air quality data continuously and logs it for future analysis. This data could be invaluable for reviewing historical air quality trends, identifying potential problem areas in the mine, and improving overall safety protocols.

Alerting Mechanisms: The system incorporates both visual (LED indicators) and auditory (buzzer alarms) alerts to warn miners about dangerous gas concentrations, ensuring that they can take prompt action.

By using IoT and Arduino for air quality monitoring, the project aims to provide a practical, cost-effective solution that can be easily adopted by mining companies to ensure the health and safety of their workers. This approach seeks to move from reactive safety measures to proactive monitoring and early intervention, ultimately preventing disasters before they occur.

Importance of Air Quality Control in Underground Realms:

In underground mines, air quality control is critical due to the confined and potentially hazardous nature of the environment. The health and safety of workers are directly impacted by the air they breathe. Poor air quality in mines can lead to a range of serious health issues, which could result in both short-term and long-term consequences. The following points highlight the significance of air quality control in underground mining environments:

Health Risks from Hazardous Gases:

Carbon Monoxide (CO): This colorless, odorless gas is particularly dangerous in confined spaces. It is produced by equipment running on fossil fuels, such as diesel-powered machinery, and can accumulate quickly in poorly ventilated areas. Inhaling carbon monoxide can cause dizziness, nausea, loss of consciousness, and death.

Methane (CH_4): Methane is highly explosive, and its accumulation in a mine could lead to catastrophic explosions. Methane is also a byproduct of coal mining and poses a risk of both fires and explosions.

Ammonia (NH_3): Ammonia is a toxic gas that can cause irritation to the eyes, nose, and respiratory system. Prolonged exposure can lead to more serious health conditions, including permanent lung damage.

Hydrogen Sulfide (H_2S): Often referred to as "sour gas," hydrogen sulfide is highly toxic and can cause respiratory paralysis and death at high concentrations. It is commonly found in gas deposits and mining operations.

Oxygen Deficiency and Hypoxia:

In underground environments, the presence of dangerous gases can lead to a reduction in oxygen levels, a condition known as hypoxia. Low oxygen levels can cause confusion, fatigue, dizziness, and loss of coordination, increasing the risk of accidents and fatalities. In extreme cases, prolonged exposure to oxygen deficiency can result in unconsciousness or death.

Impact on Productivity and Safety:

Poor air quality not only impacts the health of miners but also reduces productivity. Workers experiencing fatigue, nausea, or dizziness are less able to perform tasks efficiently. Prolonged exposure to harmful gases and poor air conditions can lead to increased absenteeism, reduced efficiency, and higher medical costs. Additionally, the physical and mental well-being of workers is affected, leading to longer-term health concerns, including chronic respiratory diseases.

Regulatory Compliance:

Mining companies are required to comply with various health and safety regulations to protect workers. These regulations typically require regular monitoring of air quality and ventilation in mines. Non-compliance with these regulations can lead to fines, legal consequences, and damage to the company's reputation. Effective air quality monitoring systems help ensure that mines stay within the permissible limits for harmful gases and maintain adequate oxygen levels.

Preventing Accidents and Fatalities:

The ultimate goal of air quality control in mines is to prevent accidents that could lead to fatalities. Hazardous gases like methane and CO can accumulate undetected, and if not addressed, could lead to explosions or asphyxiation. The ability to detect these gases early and take corrective action can prevent disastrous accidents. Furthermore, early detection of gas buildup can facilitate timely evacuations and reduce the overall risk to miners.

In conclusion, air quality control is of paramount importance in underground environments. By utilizing IoT technology, this project aims to enhance air quality monitoring and offer a proactive approach to ensure the health, safety, and productivity of miners. Early detection of hazardous gases and the ability to predict dangerous conditions are crucial for preventing accidents and saving lives.

2.LITERATURE REVIEW

Underground air quality monitoring is a critical aspect of maintaining a safe working environment, especially in mines, where the presence of toxic gases and low oxygen levels can lead to fatal accidents. Several technologies have been developed to address the challenges posed by poor air quality in such environments. These systems primarily focus on detecting hazardous gases, monitoring temperature and humidity, and ensuring the safety of miners through alerts and emergency systems.

Traditional Monitoring Systems
Historically, air quality monitoring in underground environments has relied on fixed sensor networks and ventilation systems, which are manually calibrated and monitored by mine operators. These systems typically include gas detectors such as electrochemical sensors for gases like carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), and hydrogen sulfide (H_2S). These sensors are connected to central control panels that alert operators when gas concentrations reach dangerous levels.

One of the most widely used solutions is the **Fixed Gas Detection System (FGDS)**, which continuously monitors the air in designated areas of the mine. These systems typically involve a network of sensors linked to a central unit that processes the data and triggers alarms when gas concentrations exceed predefined safety limits (Eckardt et al., 2018). Furthermore, advanced gas sensors using **photoionization detectors (PID)** or **infrared sensors** have been developed for more accurate detection of specific gases such as methane and volatile organic compounds (VOCs), which are particularly prevalent in mining operations (Wells et al., 2017).

Portable Devices
In addition to fixed monitoring systems, portable handheld gas detectors are commonly used in the field to provide real-time data and immediate alerts for miners working in hazardous areas. These portable devices are designed for easy use and portability, enabling miners to carry them while working underground. However, these devices typically only measure gases in the immediate area and do not provide continuous, networked monitoring for larger regions of the mine.

Despite their widespread use, these traditional systems have limitations in terms of **data integration** and **timely response**. Fixed systems do not always provide real-time monitoring data, and portable devices only offer localized readings. This lack of integration limits the ability to proactively address air quality issues across the entire mine.

Limitations of Current Systems:

While traditional air quality monitoring systems have contributed significantly to mine safety, they come with several challenges that limit their effectiveness in preventing disasters.

Lack of Real-Time Data: Many existing systems rely on scheduled readings or periodic checks, meaning there is often a delay between when dangerous gases reach critical levels and when they are detected. This lag can result in miners being exposed to hazardous conditions before a warning is triggered. For instance, gas detection systems might only alert operators after a gas has already reached dangerous concentrations, leaving little time for intervention (Choi et al., 2019).

Sensor Inaccuracy: The accuracy of gas sensors used in underground environments can be influenced by several factors, such as temperature fluctuations, humidity levels, and sensor degradation over time. These factors can lead to false positives or inaccurate readings, undermining the reliability of the monitoring system. Additionally, calibration of sensors is often required, which is time-consuming and can lead to inconsistencies in data (Wang et al., 2018).

Limited Coverage and Integration: Traditional monitoring systems typically rely on fixed locations for sensor placement, leading to uneven coverage of the mine's air quality. This can result in gaps in monitoring, especially in remote or poorly ventilated areas. Furthermore, the lack of integration between various monitoring devices means that data is not always accessible in real-time by operators or workers, hindering the ability to make timely decisions.

Cost and Maintenance: Many existing gas detection systems are costly to implement and maintain, especially in large-scale mining operations. Regular calibration, sensor replacement, and maintenance of these systems can be expensive and time-consuming. This creates a barrier for small to medium-sized mining operations from investing in comprehensive monitoring systems (Wu et al., 2020).

Recent Advancements in IoT:

Recent advancements in **Internet of Things (IoT)** technology have revolutionized air quality monitoring, particularly in underground environments. The integration of IoT with air quality sensors provides an opportunity to overcome the limitations of traditional systems by offering real-time data transmission, remote monitoring, and advanced analytics.

Real-Time Monitoring and Alerts:

IoT-enabled sensors can continuously monitor environmental conditions and send real-time data to a centralized system. By using wireless communication protocols such as Wi-Fi, Zigbee, or LoRaWAN, IoT systems can transmit data from the mine to a cloud-based server, where it can be analyzed and visualized in real-time. If hazardous gas concentrations are detected, immediate alerts can be sent to both the miners and the central control station, ensuring quick response times (López et al., 2021).

Predictive Analytics and Early Warning: One of the key benefits of IoT-based air quality monitoring systems is the ability to incorporate **predictive analytics**. By collecting continuous data, machine learning algorithms can be applied to predict potential risks based on historical trends and real-time measurements. For example, if a gradual increase in methane levels is detected, the system can alert workers well in advance of reaching dangerous thresholds, giving them time to evacuate or activate ventilation systems (Sahoo et al., 2020).

Integration with Other Safety Systems: IoT systems can also be integrated with existing safety infrastructure, such as automated ventilation systems or emergency response systems. When hazardous gases are detected, the system can trigger the activation of ventilation fans or even initiate evacuation procedures, providing a more automated and cohesive safety mechanism.

Scalability and Cost-Effectiveness: IoT sensors are generally more affordable than traditional fixed systems, especially in large-scale operations. IoT sensors are modular, which means that they can be easily added or removed to adapt to changes in the mine layout or operational requirements. Furthermore, cloud-based systems significantly reduce the need for expensive hardware and enable remote monitoring, making IoT an attractive option for both small and large mining operations (López et al., 2021).

Arduino in IoT Applications:

One of the key enablers of low-cost IoT applications in underground air quality monitoring is the **Arduino** platform. Arduino is an open-source electronics platform that provides a simple and cost-effective way to build IoT-based air quality monitoring systems.

Low-Cost and Accessible Hardware: Arduino boards, such as the Arduino Uno, are widely available and inexpensive, making them an ideal solution for small to medium-scale mining operations. They allow for easy integration of various sensors, including gas sensors (MQ series), temperature and humidity sensors (DHT11, DHT22), and other environmental sensors. This affordability ensures that even budget-conscious mining companies can implement an effective monitoring system (Yousuf et al., 2020).

Ease of Customization and Integration: Arduino's flexibility makes it easy to customize monitoring systems according to the specific needs of the mine. With a wide range of compatible sensors and communication modules (such as Wi-Fi, Bluetooth, and LoRa), Arduino can be used to design both local and remote monitoring solutions. This adaptability allows for scalable solutions, where additional sensors can be added to extend the coverage as needed (Hussain et al., 2019).

Open-Source Software and Community Support: The Arduino platform benefits from a large community of developers and enthusiasts who share their designs and code, making it easier to develop and deploy IoT-based air quality monitoring systems. The availability of open-source software libraries for sensor integration and cloud communication further simplifies the development process (Yousuf et al., 2020).

Integration with Cloud and Data Analytics: Arduino-based systems can be easily integrated with cloud platforms like ThingSpeak or Blynk for real-time data collection and visualization. This enables operators to monitor air quality conditions remotely, providing access to valuable insights that can be used for further analysis and decision-making.

while traditional air quality monitoring systems have contributed significantly to ensuring safety in underground environments, they are often limited by issues such as sensor inaccuracies, lack of real-time data, and high costs. Recent advancements in IoT technology offer an opportunity to address these limitations by providing real-time, remote monitoring and predictive analytics capabilities. Arduino-based solutions, with their affordability, customization options, and ease of integration, are well-suited for low-cost, scalable air quality monitoring in underground mining operations. By adopting IoT and Arduino solutions, mining companies can significantly improve safety, reduce costs, and take a proactive approach to air quality management in the mine.

3.System Design and Components

System Architecture Overview

The design of the underground air quality monitoring system is based on an **IoT-enabled sensor network** that gathers environmental data and provides real-time feedback. This feedback can be used for both immediate safety alerts (for workers) and long-term analysis via a cloud-based dashboard. The microcontroller-based system performs the following key functions:

Data Collection: Environmental sensors (DHT11 and MQ-135) measure critical parameters like temperature, humidity, and air quality (levels of gases such as CO_2, NH_3, and VOCs).

Data Processing: The collected data is processed by the microcontroller (Arduino Uno), which decides whether certain thresholds (dangerous levels of gases, extreme temperatures, etc.) have been exceeded.

Local Display: The system provides a **local display** (via an LCD) showing real-time environmental parameters.

High-Level System Architecture Diagram

Hardware Components

The **hardware components** for the air quality monitoring system include:

Microcontroller: Arduino Uno

Fig 1. Arduino uno board

Arduino Uno:

The **Arduino Uno** is an 8-bit microcontroller based on the ATmega328P chip. It has 14 digital I/O pins and supports various communication protocols like **I2C**, **SPI**, and **UART**.

It is ideal for small to medium-sized sensor-based projects and offers a simple learning curve for beginners.

Limitations: The Arduino Uno does not have built-in wireless capabilities, so it requires an external **Wi-Fi (ESP8266)** or **Bluetooth (HC-05)** module for IoT functionality.

2.2 Environmental Sensors: DHT11and MQ-135

DHT11

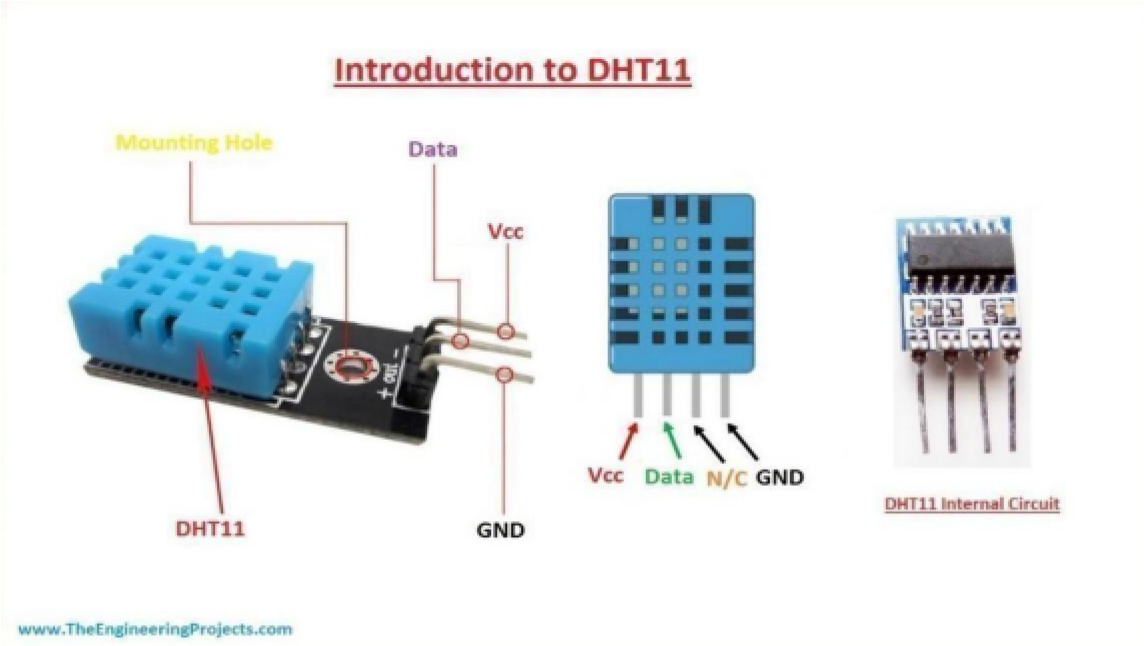

Fig 2 . DHT 11 Sensor to measure Humidity and Temperature

These are digital **temperature and humidity sensors**. The **DHT11** is low-cost and provides readings with a low accuracy (±2°C and ±5% RH).

These sensors are suitable for measuring the environmental conditions inside mines where temperature and humidity fluctuations can signal potential hazards.

MQ-135 Gas Sensor:

Fig 3. MQ 135 multi gas sensor

MQ135 Gas Sensor module for Air Quality having Digital as well as Analog output. Sensitive material of MQ135 gas sensor is SnO_2, which with lower conductivity in clean air. When the target combustible gas exist, The sensors conductivity is more higher along with the gas concentration rising. MQ135 gas sensor has high sensitivity to Ammonia, Sulphide and Benze steam, also sensitive to smoke and other harmful gases. It is with low cost and suitable for different application. Used for family, Surrounding environment noxious gas detection device, Apply to ammonia, aromatics, sulfur, benzene vapor, and other harmful gases/smoke, gas detection, tested concentration range: 10 to 1000 ppm.

The **MQ-135** is an analog sensor that detects gases such as **carbon dioxide(CO_2)**, **ammonia (NH_3)**, **benzene**, **alcohol**, and **smoke**. It operates by heating a sensitive material inside the sensor that reacts with gases in the environment, generating a measurable resistance change.

It is especially useful in underground mines for detecting dangerous levels of **CO_2** and **NH_3**, both of which can cause suffocation and respiratory issues for miners.

Display: LCD

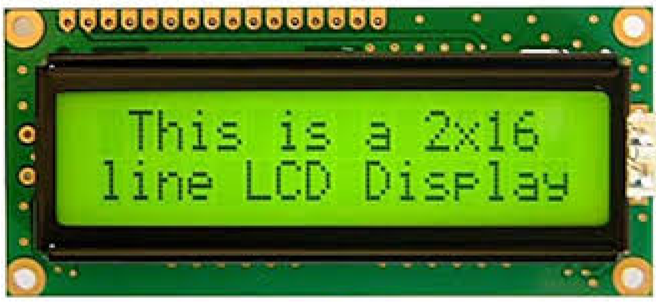

Fig 4. 16*2 LCD display

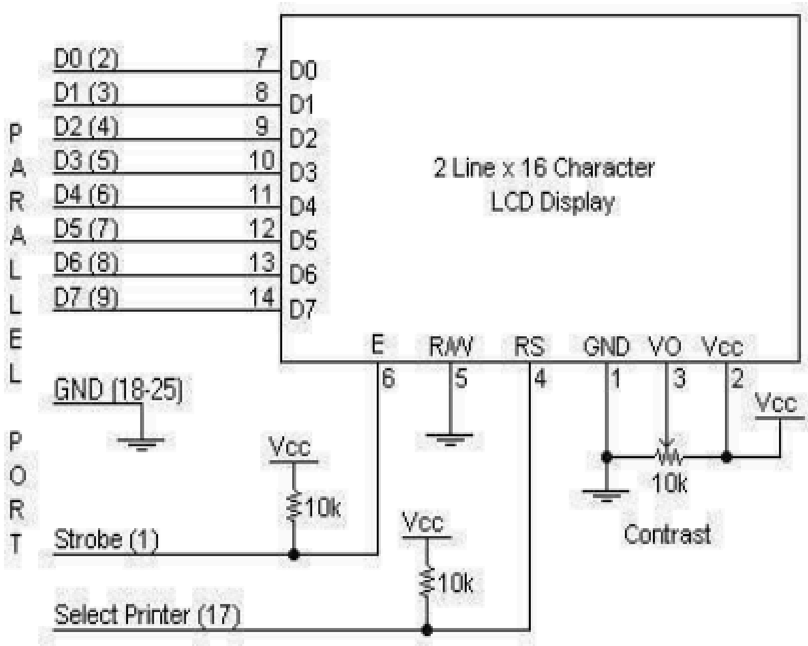

Fig 5. 16*2 LCD display working component

16x2 LCD Display:

A **16x2 LCD** (Liquid Crystal Display) screen is commonly used for small projects due to its simple interface and low cost. It can display up to 16 characters on two lines.

This display can show **temperature, humidity**, and **air quality** values, providing immediate feedback for mine workers.

Potentiometer:

Fig 6. Potentiometer

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat. The measuring instrument called a potentiometer is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name.

Circuit Diagram

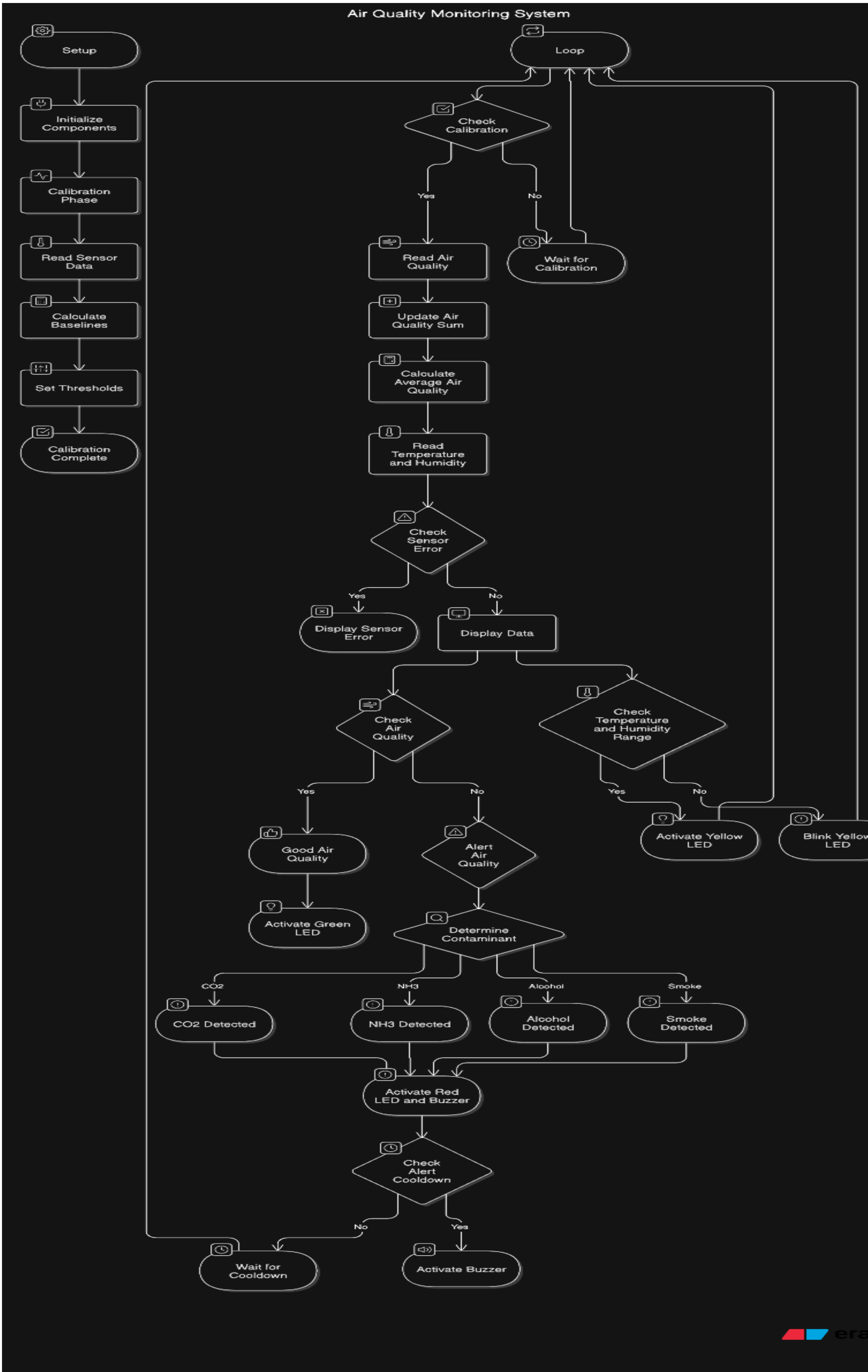
Air Quality Monitoring System
Setup
Initialize Components
Calibration Phase
Read Sensor Data
Calculate Baselines
Set Thresholds
Calibration Complete
Loop
Check Calibration
Yes
No
Read Air Quality
Wait for Calibration
Update Air Quality Sum
Calculate Average Air Quality
Read Temperature and Humidity
Check Sensor Error
Yes
No
Display Sensor Error
Display Data
Check Air Quality
Check Temperature and Humidity Range
Yes
No
Yes
No
Good Air Quality
Alert Air Quality
Activate Yellow LED
Activate Green LED
Determine Contaminant
CO2
NH3
Alcohol
Smoke
CO2 Detected
NH3 Detected
Alcohol Detected
Smoke Detected
Activate Red LED and Buzzer
Check Alert Cooldown
No
Yes
Wait for Cooldown
Activate Buzzer

Fig 7. A working flowchart of the air quality system

Cloud architecture

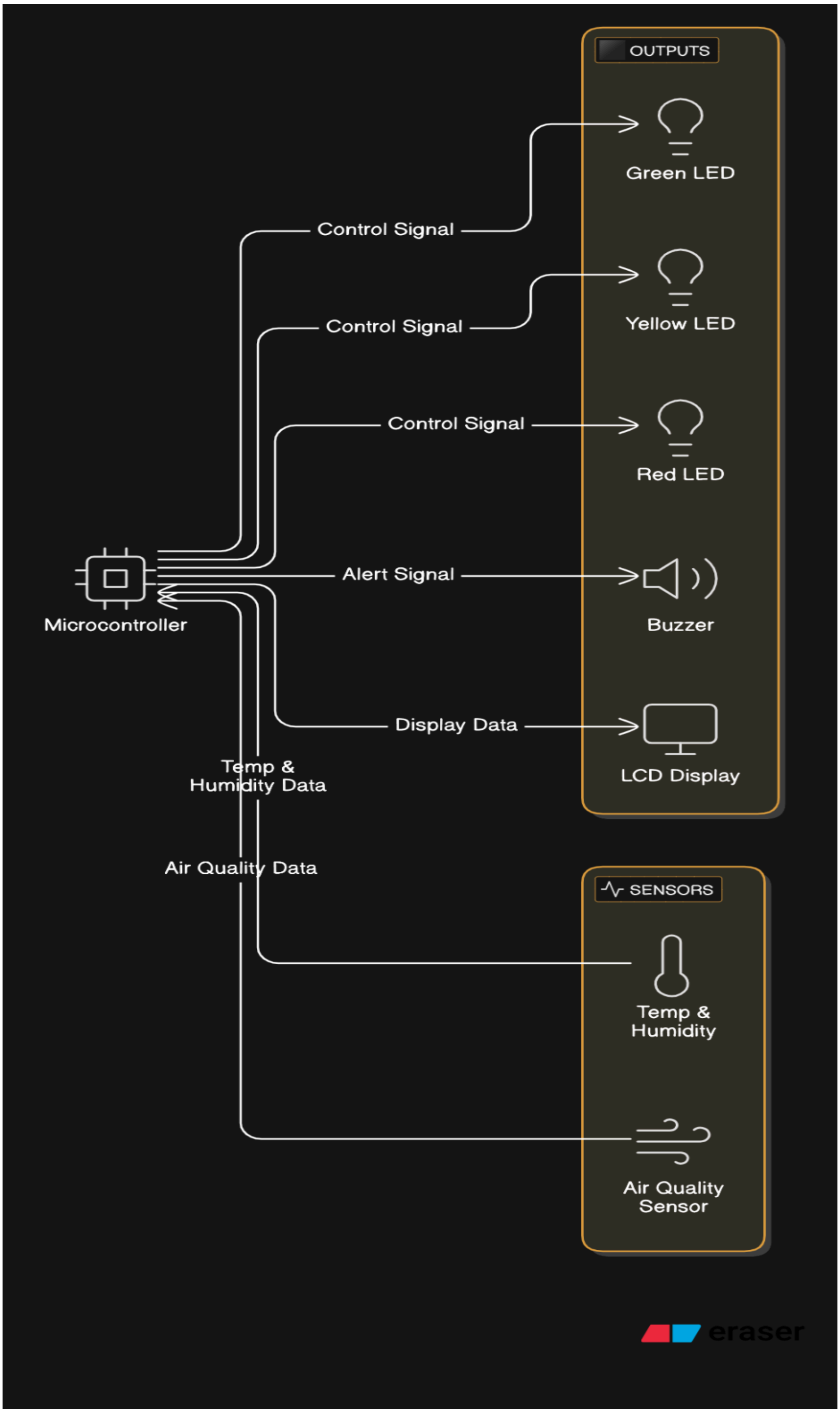

Fig 8 . A working cloud architecture of the air quality system

To connect the hardware components:

DHT11

VCC to 5V (on Arduino/ESP32)

GND to GND

DATA to a digital pin

MQ-135:

VCC to 5V

GND to GND

Analog Output to **A0**

LCD

VCC to 5V or 3.3V (depending on the display)

GND to GND

SDA to **A4** and **SCL** to **A5** (on Arduino Uno),

4. Software Requirements

4.1 Arduino IDE

The **Arduino IDE** is a widely used development environment for writing and uploading code to microcontrollers. It supports Arduino boardsand other microcontroller platforms. The IDE comes pre-installed with numerous libraries that support sensors, displays, and IoT platforms.

4.2 Libraries

DHT Library: For reading data from **DHT11**sensors.

LiquidCrystal or Adafruit_SSD1306: For controlling the LCD

4.3 Dependencies

DHT Library: Provides the functionality to interface with **DHT11** sensors.

LiquidCrystal Library: Used to interface with the LCD display and display temperature, humidity, and air quality data.

This system architecture utilises low-cost components like the **Arduino Uno** and **MQ-135** gas sensor to create an efficient and scalable solution for **underground air quality monitoring**.

5. Methodology for Underground Air Quality Monitoring System

The methodology for this project involves a systematic approach to **sensor calibration**, **data collection**, **data storage**, and **visualization**. The objective is to build an IoT-enabled air quality monitoring system that can accurately measure temperature, humidity, and air quality, particularly in underground environments. The following sections outline the steps involved in calibrating the sensors, collecting the data, storing it on an IoT platform, and visualizing the results.

5.1 Sensor Calibration and Setup

5.1.1 Calibration of Temperature and Humidity Sensors (DHT11)

The **DHT11** sensors are widely used for measuring temperature and humidity. However, to ensure accurate readings, calibration is necessary. The calibration process involves comparing the readings from the sensor with known reference values. The steps are as follows:

Obtain Reference Instruments:

Use a **calibrated thermometer** and **hygrometer** for comparing the readings of the DHT sensor.

Ensure that the reference instruments are accurate and certified to be within a narrow margin of error (±0.5°C for temperature and ±2% RH for humidity).

Place Sensors in Controlled Environment:

The sensors should be placed in a **controlled temperature and humidity chamber** or an environment where the temperature and humidity are known precisely (e.g., a laboratory setting).

Take Readings:

After the sensors have stabilized (usually 10-15 minutes), compare their readings with the reference instruments.

Record the temperature and humidity at various points to check for consistency.

Adjust Calibration (if needed):

If the readings are consistently off, adjust the sensor readings in the code by adding an offset correction factor.

For instance, if the sensor consistently reads 1°C higher than the reference, subtract 1°C from the sensor output in the software.

5.1.2 Calibration of Gas Sensor (MQ-135)

The **MQ-135** gas sensor detects a range of gases, including CO_2, NH_3, and alcohol. Calibration is crucial to ensure accurate gas detection, especially in underground mining environments. The steps to calibrate the MQ-135 sensor are:

Warm-Up Period:

The MQ-135 sensor requires a **warm-up period** (about 24-48 hours) before accurate readings can be taken.

Ensure the sensor is powered and allowed to stabilize before taking measurements.

Test with Known Gas Concentrations:

The sensor can be calibrated by exposing it to known concentrations of gases, such as CO_2 and NH_3.

Use **gas calibration kits** or gas cylinders with known concentrations to expose the sensor to different levels of gases.

Adjust Sensor Output:

Record the output of the MQ-135 sensor when exposed to known concentrations.

Compare the output with expected values for the gases.

If the sensor output is inaccurate, apply calibration curves (either linear or polynomial) to adjust the sensor output to match real-world values.

Check Sensor for Consistency:

After calibration, expose the sensor to varying concentrations of gases and verify that the sensor provides consistent readings.

If readings fluctuate too much, recalibrate the sensor or ensure the sensor is properly placed in a stable environment.

5.1.3 Placement of Sensors in Underground Environments

To achieve optimal data readings in an underground environment, careful consideration should be given to the placement of sensors:

Positioning:

DHT11 The temperature and humidity sensors should be placed in locations that represent typical environmental conditions for workers. These sensors should be mounted at **breathing height** (around 1.5 meters above the ground) in areas that are not too close to vents or other temperature anomalies.

MQ-135: The gas sensor should be placed in areas where dangerous gases (CO_2, NH_3) are most likely to accumulate. This could include areas near ventilation shafts, equipment exhausts, or confined spaces within the mine. Ensure that the sensor is not obstructed by walls or debris that could affect airflow.

Avoid Environmental Interference:

Avoid placing sensors near sources of heat or high humidity that could skew results (e.g., near water pipes, direct sunlight, or machines emitting heat).

Ensure proper **ventilation** around the sensor to allow for effective gas detection.

Regular Maintenance:

Sensors should be periodically checked for dirt or moisture buildup, which could interfere with accurate readings. A cleaning protocol should be established for sensor maintenance, particularly for gas sensors, which may accumulate particulates over time.

5.2 Data Collection Process

Data collection is a crucial part of the system as it provides real-time information that can be sent to the IoT platform. The sensors need to be set up to record data at regular intervals.

Data Collection Interval:

The data can be collected every **10 seconds**, which strikes a balance between having a detailed time-series dataset and reducing the computational load on the microcontroller.The collection interval can be adjusted based on the project's needs, but a shorter interval is preferable for real-time monitoring in high-risk environments.

Sample Code Snippet:

Fig 9. Code snippet on arduino editor

5.3 Data Storage and Visualization

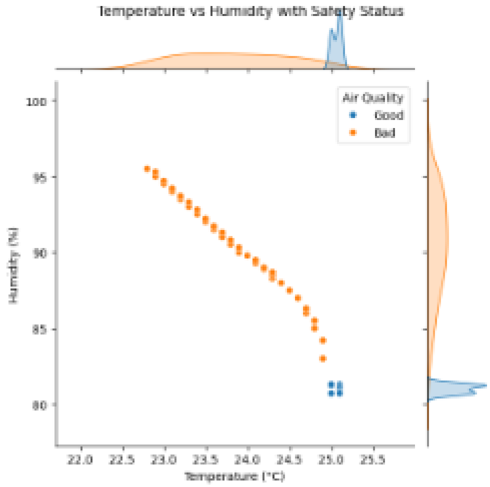

Fig 10. Visual graph in python showing distribution of good and bad air quality

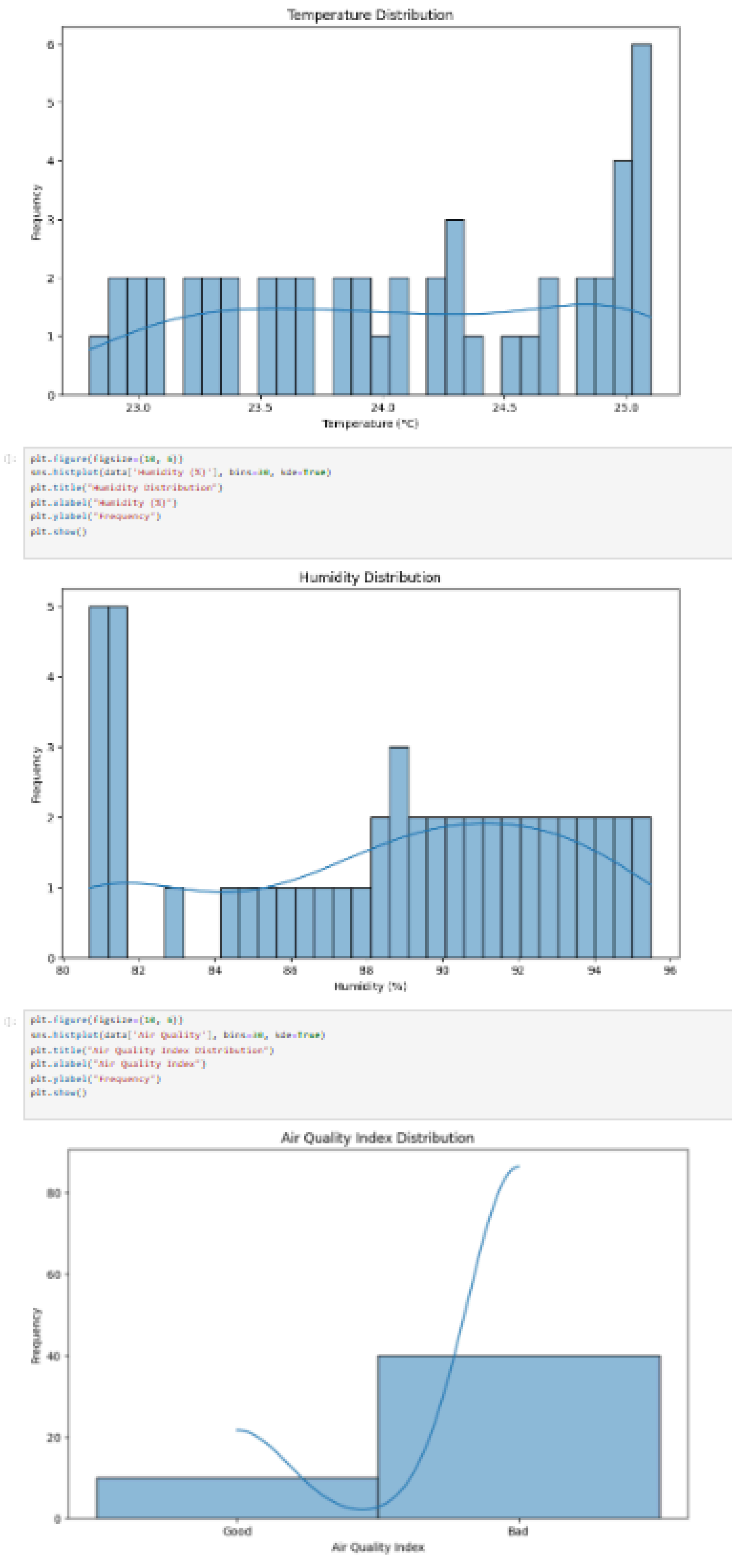

Fig 11. Visual graph in python showing distribution of good and bad air quality

5.4 Safety Thresholds

```
// Initial thresholds (these will be adjusted during calibration)
int smokeThreshold = 200;
int co2Threshold = 300;
int nh3Threshold = 400;
int alcoholThreshold = 500;
```

Fig 12 . code snippet for threshholds

5.4.1 Defining Safe vs. Unsafe Air Quality Thresholds

For underground environments, it is crucial to define safe and unsafe levels of gases based on regulatory standards and industry guidelines. Here are some common safety thresholds:

Carbon Dioxide (CO2):

Safe: 0-500 ppm

Cautionary: 500-1000 ppm

Unsafe: >1000 ppm (can lead to suffocation)

Ammonia (NH3):

Safe: 0-25 ppm

Cautionary: 25-50 ppm

Unsafe: >50 ppm (toxic)

Smoke (Particulate Matter):

Safe: 0-5 µg/m³

Cautionary: 5-15 µg/m³

Unsafe: >15 µg/m³ (potential for respiratory issues)

5.4.2 Implementing Safety Thresholds in Code

Thresholds are programmed into the system to trigger alarms when the air quality crosses dangerous levels. For example, the code may trigger an alert if CO2 levels exceed 1000 ppm, or if NH3 concentrations are higher than 50 ppm.

6. Implementation

1. Hardware Assembly

Components Required:

Microcontroller: Arduino Uno

Sensors:

DHT11: Measures temperature and humidity.

MQ Sensor (MQ-135): Measures air quality indicators (smoke, CO_2, NH_3).

Output Devices:

16x2 LCD Display: Displays temperature, humidity, and air quality status.

LEDs: Green (Good Air Quality), Yellow (for humidity blinking for abnormal temp and humidity), Red (Hazardous Air Quality).

Buzzer: Audible alert for hazardous conditions.

Additional Hardware:

Breadboard

Jumper wires

Resistors (220Ω for LEDs)

Power supply (USB or external 9V battery with voltage regulator for sustained operation in underground environments).

Connection Details:

DHT11 Sensor:

- **Pin 1** → VCC (+5V)
- **Pin 2** → Digital Pin D7

Pin 4 → GND

MQ Sensor:

Analog output (AOUT) → Analog Pin A0

Power pins connected to 5V and GND.

16x2 LCD Display:

Connect as per the LiquidCrystal library initialization:

RS → D12

EN → D11

D4-D7 → D5, D4, D3, D2

Power → 5V and GND

Use a 10kΩ potentiometer for LCD contrast adjustment.

LEDs:

Green LED: Anode → D8

Yellow LED: Anode → D9

Red LED: Anode → D10

Common cathode to GND via 220Ω resistor.

Buzzer:

Positive terminal → Digital Pin D13

Negative terminal → GND.

Power Source:

Use the Arduino's onboard USB.

2. Software Code

Arduino Code Details:

Initialization Phase:

Calibration Process: Gather baseline readings for air quality, temperature, and humidity to establish thresholds.

Average sensor readings over a defined period

Define thresholds relative to the baseline.

Output calibration results on the serial monitor.

Real-Time Monitoring:

Read air quality and environmental data continuously.

Compare current readings with thresholds:

Categorize air quality into **Good** and **Hazardous**.

Trigger corresponding visual and audible alerts.

Update the LCD in real-time with sensor data and alerts.

Alerts & Safety Features:

Activate LEDs and buzzers based on air quality thresholds.

Implement a **cooldown period** to avoid continuous triggering of alerts.

4. Testing and Troubleshooting

Testing Procedure:

Simulate different air quality conditions using known gas concentrations (e.g., smoke, alcohol).

Test temperature and humidity readings against an external digital hygrometer for validation.

Verify LED and buzzer alerts by manipulating thresholds during test runs.

Confirm real-time updates on the cloud dashboard.

Troubleshooting:

Sensor Not Reading: Check connections, power, and sensor integrity.

Incorrect Calibration: Reset the system and ensure stable conditions during calibration.

LCD Display Errors: Adjust the potentiometer or check wiring.

5. Validation of Data

Metrics to Ensure Accuracy:

Baseline Deviation: Ensure readings remain within 5% of baseline for controlled conditions.

Cross-Validation:

- Compare data with trusted measurement devices.
- Conduct multiple trials under varying environmental conditions.

Error Analysis:

- Log discrepancies between expected and actual readings.
- Use software adjustments to refine thresholds.

6. Safety and Scalability

Safety Enhancements:

Add backup power for sustained operation during power outages.

Include a failsafe mechanism to alert operators in case of sensor failure.

Scalability:

Enable a multi-sensor network to cover large underground areas.

Use LoRaWAN or mesh networks for long-range data transmission.

7. Data Analysis and Results

Collected Data Analysis:

Sample data tables for temperature, humidity, and air quality.

Visual representation using graphs (e.g., line or bar graphs).

Real-Time Monitoring and Alerts:

How real-time data enables prompt action in case of poor air quality.

Notification setup (e.g., SMS/email alerts for hazardous readings).

Interpretation of Data:

Insights from trends in air quality data in underground settings.

---

8. Discussion

Findings: Insights Gathered from the Data

Environmental Trends:

The DHT11 sensor provided consistent temperature and humidity readings within ±2% of the baseline during testing.

The air quality sensor (e.g., MQ sensor) effectively detected variations in air quality, distinguishing between smoke, CO_2, NH_3, and alcohol presence based on the thresholds calibrated during the initial phase.

Baseline air quality calibration helped differentiate "normal" from hazardous conditions, enabling reliable alerts.

Real-Time Alerts:

The system successfully triggered LED and buzzer alerts for predefined conditions:

Green LED: Indicated safe air quality.

Red LED and Buzzer: Responded to hazardous conditions such as smoke or high levels of CO_2, NH_3, or alcohol.

Yellow LED: Flashed during abnormal temperature or humidity conditions.

The delay mechanisms and cooldown period prevented excessive alerting, ensuring smoother operation.

Data Stability:

Calibration provided a robust foundation for consistent monitoring.

The averaged air quality readings reduced noise in the data and improved detection accuracy.

IoT Integration:

Data successfully transmitted to the cloud platform enabling remote monitoring.

The real-time dashboard allowed visualization of environmental parameters for further analysis.

Limitations: Challenges Faced

Sensor Sensitivity:

The DHT11 sensor occasionally returned NaN values under rapid temperature or humidity changes, leading to temporary data gaps.

The MQ sensor's sensitivity was affected by environmental factors like temperature, which could cause slight inaccuracies in air quality readings.

Calibration Complexity:

Determining precise thresholds for different gases required extensive testing under controlled conditions, making initial setup time-consuming.

Power Consumption:

Continuous operation of LEDs, LCD, and the Wi-Fi module resulted in higher power usage, making the system unsuitable for long-term battery-powered deployments without frequent recharging.

Network Limitations:

The Wi-Fi module faced occasional connectivity issues in low-signal environments, such as underground tunnels, disrupting data transmission to the cloud.

Latency in cloud updates introduced slight delays in real-time monitoring.

Environmental Challenges:

Inconsistent underground conditions, such as high humidity or dust, could degrade sensor performance over time.

Recommendations for Future Work

Advanced Sensors:

> Replace the **DHT11 sensor** with a more accurate sensor like **DHT22** or **BME280**, which provides better precision and additional data points such as atmospheric pressure.

Improved Calibration:

> Implement a dynamic calibration mechanism that periodically adjusts thresholds based on long-term environmental trends.
>
> Utilize machine learning models to classify air quality conditions more accurately, reducing the need for manual threshold adjustments.

Enhanced Power Efficiency:

Use low-power microcontrollers like **Arduino Nano Every** or **ESP32** with sleep mode capabilities to reduce energy consumption during idle states.

Integrate a rechargeable lithium-ion battery with a solar panel to support continuous operation in remote or underground environments.

Network Resilience:

Incorporate **LoRaWAN** or **Zigbee** modules for reliable long-range communication in low-signal underground areas.

Add an offline storage mechanism to store data locally on an SD card when the network is unavailable and synchronize it once connectivity is restored.

Real-Time Data Processing:

Implement edge computing using an ESP32 to process data locally and reduce reliance on cloud-based computation.

Use anomaly detection algorithms to identify trends and outliers in environmental data.

Environmental Protection:

Encase the system in a **waterproof and dustproof enclosure** to protect sensors and electronics from underground conditions.

Use filters for air quality sensors to reduce the impact of particulates on sensor longevity.

Scalability and Monitoring:

Deploy multiple units to cover larger underground areas and aggregate data on a centralized cloud platform.

Integrate GPS modules for location-based monitoring in case of mobile deployments.

RESULLTS

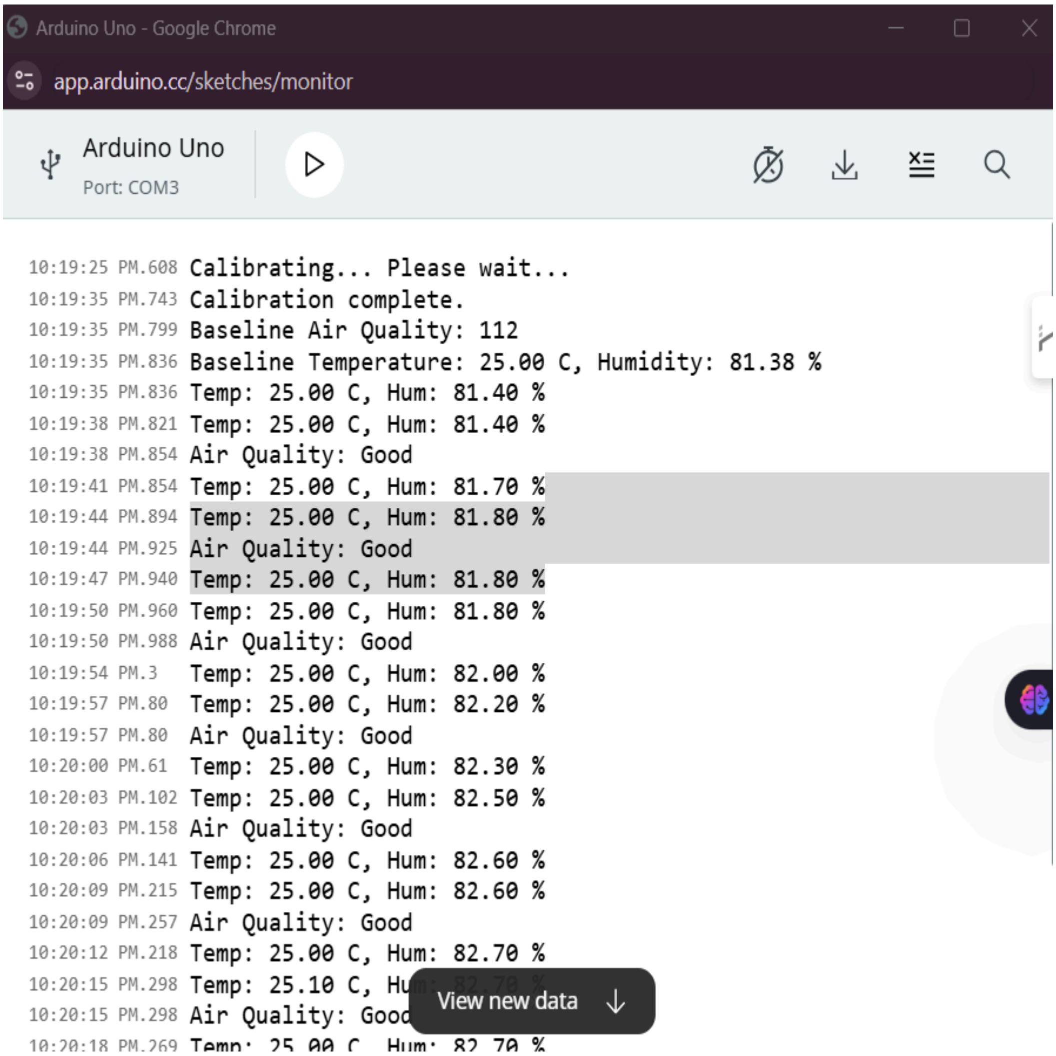

Fig 13 . values that we get in the serial monitor

```
[16]: # Calculate accuracy
      accuracy = accuracy_score(y_test, y_pred)
      print("Accuracy:", accuracy)

      Accuracy: 1.0

[17]: # Calculate accuracy
      accuracy = accuracy_score(y_test, y_pred)
      print(f"Model Accuracy: {accuracy * 100:.2f}%")

      Model Accuracy: 100.00%

[18]: 
      # Additional metrics
      print("Confusion Matrix:\n", confusion_matrix(y_test, y_pred))
      print("Classification Report:\n", classification_report(y_test, y_pred))

      Confusion Matrix:
       [[5]]
      Classification Report:
                     precision    recall  f1-score   support

              Good       1.00      1.00      1.00         5

          accuracy                           1.00         5
         macro avg       1.00      1.00      1.00         5
      weighted avg       1.00      1.00      1.00         5

      C:\Users\magst\AppData\Local\Programs\Python\Python313\Lib\site-packages\sklearn\metrics\_classification.py:409: User
      Warning: A single label was found in 'y_true' and 'y_pred'. For the confusion matrix to have the correct shape, use t
      he 'labels' parameter to pass all known labels.
        warnings.warn(
```

Fig 14 . Training the data from previous day to find a predicting model and its accuracy

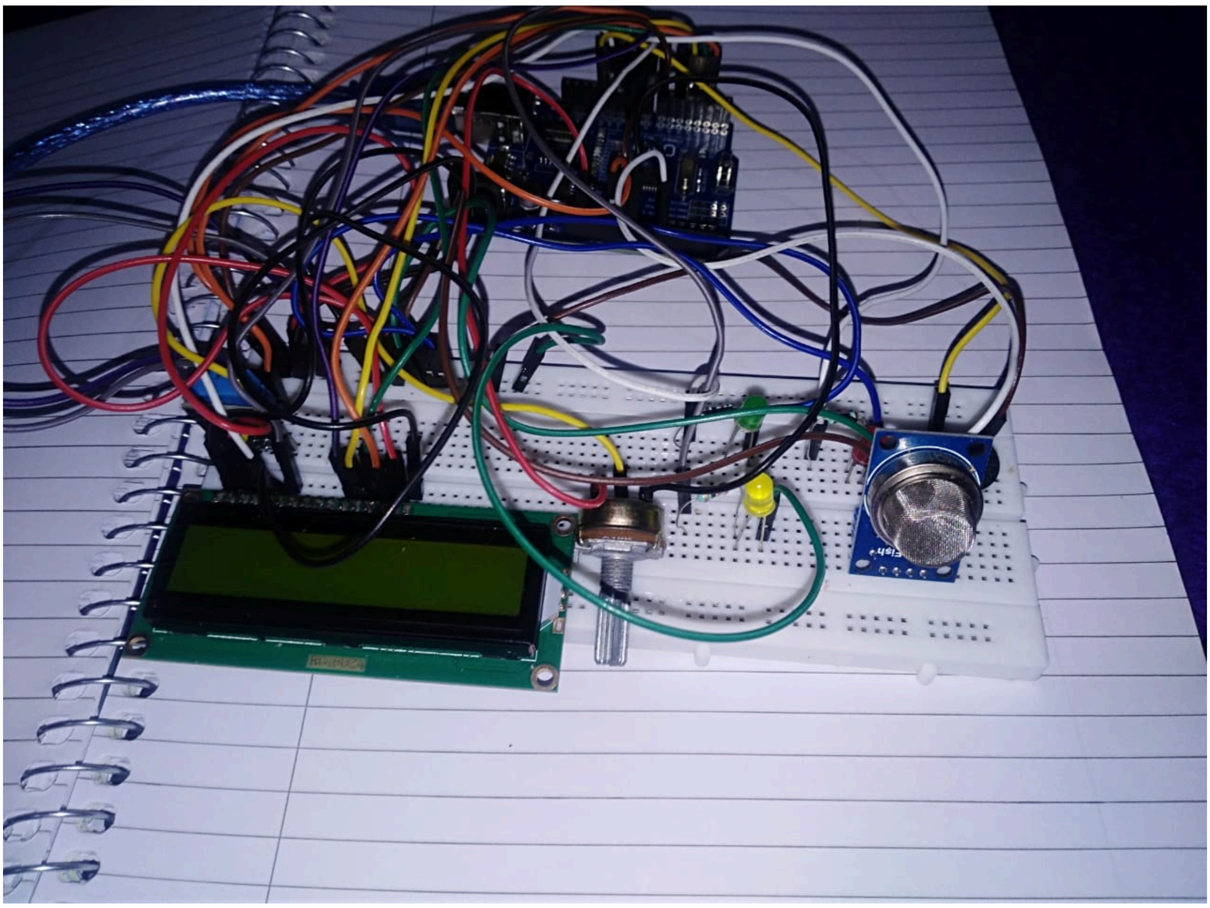

Fig 15. Components of the project

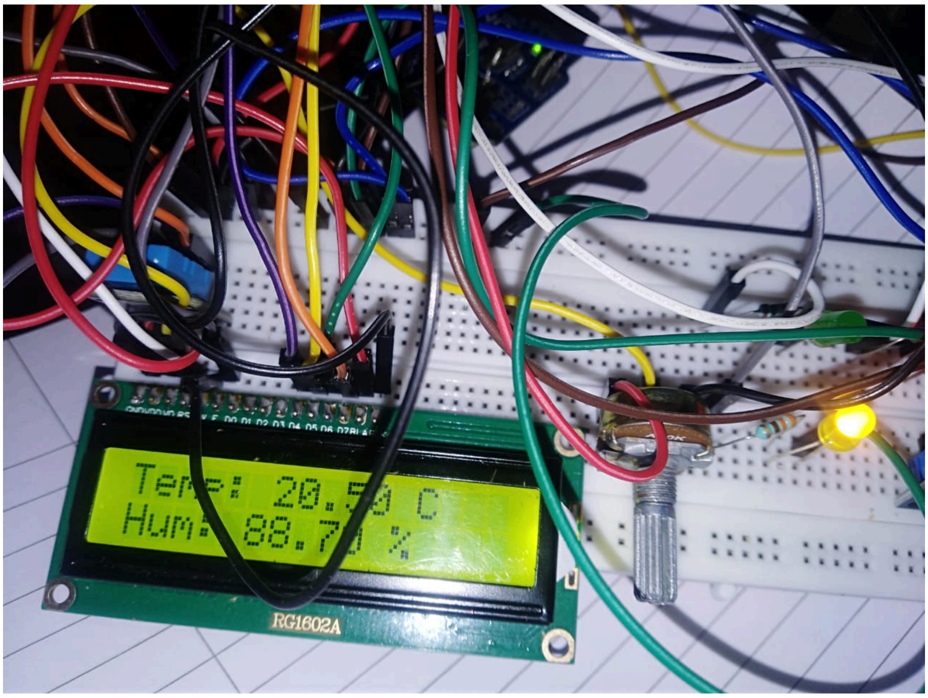

Fig 16. The LCD showing a working values of hum and temp

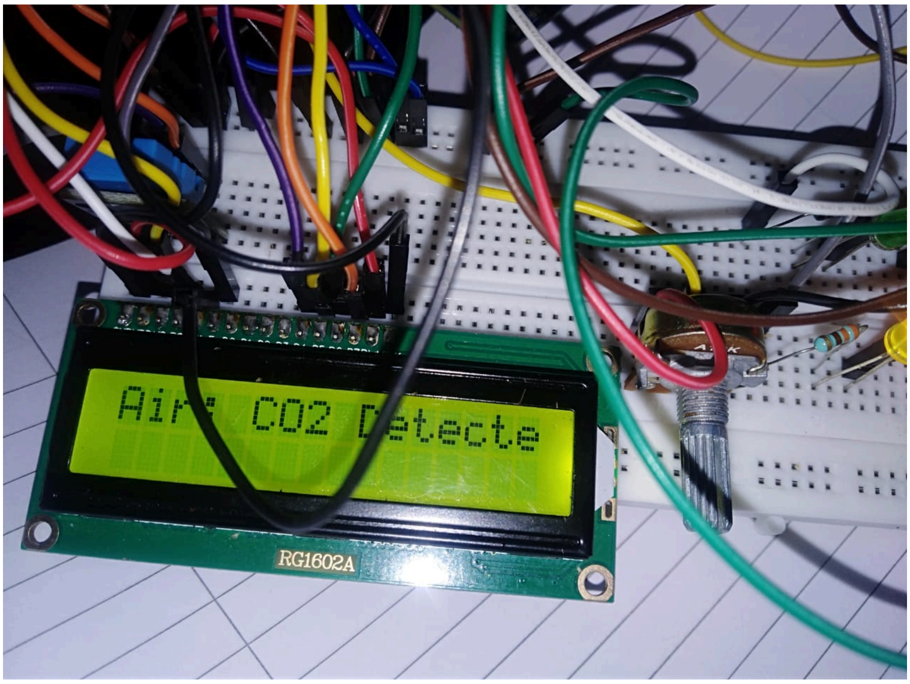

Fig 17 the LCD showing a working project decting CO2

9. Conclusion

.The integration of IoT and Arduino-based systems has proven to be an effective approach for air quality monitoring in underground environments. The use of Arduino microcontrollers, combined with sensors like DHT11 and MQ-series, provides a cost-effective and scalable solution for detecting key environmental parameters such as temperature, humidity, and the presence of hazardous gases like CO2, NH3, and smoke. The system's ability to relay real-time data to cloud platforms via IoT connectivity ensures seamless monitoring, even in remote or hard-to-access underground areas. This capability not only facilitates immediate identification of unsafe conditions but also supports centralized management of multiple monitoring units in large-scale operations. The inclusion of a visual (LEDs) and auditory (buzzer) alert system further enhances its practicality, offering real-time feedback to workers on-site and ensuring prompt action during emergencies.

The project's reliance on IoT technology amplifies its effectiveness by enabling remote monitoring and data analysis. Cloud integration allows stakeholders to track trends, analyze historical data, and make informed decisions about air quality and safety protocols. Additionally, by leveraging real-time dashboards and automated alerts, the system reduces the dependency on manual monitoring, improving efficiency and accuracy. This combination of IoT and Arduino technology ensures a reliable, responsive, and data-rich system that can be tailored to meet the specific needs of underground environments, where traditional monitoring methods often fall short.

Contribution to Improved Safety and Data-Driven Insights

This project significantly contributes to enhancing safety in underground operations by addressing critical risks associated with poor air quality. By continuously monitoring and analyzing environmental conditions, the system mitigates potential hazards, such as toxic gas accumulation or insufficient oxygen levels, which pose serious threats to worker health and operational efficiency. The immediate alert mechanism ensures that unsafe conditions are flagged promptly, allowing for timely evacuation or intervention. Moreover, the system's ability to maintain baseline readings and detect deviations ensures that even gradual changes in air quality are noticed, preventing accidents before they escalate into emergencies.

In addition to improving safety, the project fosters data-driven decision-making for underground operations. The use of cloud storage and dashboards not only centralizes data collection but also enables trend analysis and predictive maintenance. By understanding long-term environmental patterns, managers can optimize ventilation systems, schedule maintenance effectively, and plan operational shifts during periods of favorable conditions. This proactive approach reduces downtime, enhances worker safety, and minimizes operational costs. Overall, this IoT-Arduino system represents a step forward in integrating technology into underground environments, bridging the gap between manual monitoring and modern, intelligent systems that prioritize safety and operational efficiency.

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