Smart Air Quality Monitoring System

For Mining Safety

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ABSTRACT

This report presents a solution to the urgent air quality issues in the Australian mining industry. Extensive research has highlighted the significant health and safety risks faced by mining personnel due to their exposure to toxic gases, such as methane, carbon monoxide, carbon dioxide, nitrogen dioxide, and particulate matter, during various mining operations. To mitigate these risks, the report outlines the development of Smart Air Quality Monitoring System, which integrates hardware and software solutions for real-time air quality monitoring and the immediate issuance of hazard alerts based on predefined thresholds. The system aims to ensure worker safety, regulatory compliance, and environmental impact assessment. The report provides comprehensive insights into the criteria for selecting the hardware components, including considerations such as availability, cost, scalability, power limitations, and ease of integration. Specific sensors tailored to monitor key pollutants are described. With the ESP32 T-Beam microcontroller used for data collection and transmission through WIFI, data collected securely has been stored in Firebase, and can be accessed through a Flask-based web application for real-time monitoring and data analysis. This solution offers an approach to monitoring and ensuring air quality in mining environments, with a primary focus on worker safety, regulatory compliance, and environmental responsibility.

PROBLEM STATEMENT

In the Australian mining industry, workers are consistently exposed to toxic gases and particulates, posing significant health risks. Current monitoring mechanisms are inadequate, leaving workers vulnerable and the industry prone to operational hazards and regulatory non-compliance. The absence of real-time, effective air quality surveillance not only jeopardizes worker safety but also challenges the industry's sustainability and environmental responsibility. There is an urgent need for a comprehensive, real-time air quality monitoring system to address these multifaceted challenges, ensuring health, compliance, and ecological stewardship.

1. INTRODUCTION

The Australian mining industry is renowned for its abundant mineral resources and substantial economic contributions. However, this sector is equally recognized for its challenging work environments. Mining personnel and mining companies facing risks associated with exposure to different challenges and risks, including exposure to toxic substances throughout various stages of mining operations, from extraction to processing. Particularly in underground mines, poor air quality poses significant health and safety risks to miners. Furthermore, in the long term, mining activities increase the susceptibility of workers to potential health risks arising from compromised air quality. Prolonged exposure in such environments further exacerbates sensitivity to subsequent illnesses, particularly respiratory and cardiovascular diseases. This exposure not only poses enduring threats to the health and safety of workers but also holds the potential for adverse impacts on surrounding communities and ecosystems.

1.1 Primary Motivation for the development of an Air Quality Monitoring System

Our team has discerned the urgent need for preventive measures to mitigate the potential negative effects of harmful gases on both mining personnel and mining companies themselves.

Drawing inspiration from lessons learned from past disasters, our team embarked on the development of an advanced Smart Air Quality System that integrates hardware and software solutions, offers users comprehensive air quality monitoring and threshold-based hazard alert services, reduce operational risks in the mining industry.

1.2 Second Motivation for development of an Air Quality Monitoring System

Given the high incidence of mining-related accidents, strict regulatory oversight is essential to ensure the enduring sustainability of the Australian mining industry. Our system facilitates effective monitoring data to ensure organizational compliance with mining operation laws and regulations, thereby promoting ethical and responsible mining practices. Moreover, accurate air quality data aids in assessing the environmental impact of mining operations, providing valuable information for pollution mitigation strategies.

1.3 Types of Pollution and Acceptable Gas Levels

Initially, we undertook research to discern the prevalent pollutants in coal mining, examining their chemical compositions and reactions, and subsequently ranking them based on their associated hazard levels. From our research, we identified methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_2), and particulate matter as the paramount gases and compounds that our system should monitor.

1.3.1. Methane (CH_4)

A common gas in coal mines that is highly flammable and explosive. Any methane leakage in mining environments can potentially lead to severe accidents. Therefore, monitoring methane concentrations is crucial for fire and explosion prevention.

1.3.2. Carbon monoxide (CO)

A common harmful gas, primarily generated from coal oxidation, coal dust explosions, blasting, and incomplete combustion of machinery fuel. Airborne carbon monoxide levels exceeding 0.05% pose a risk of poisoning, while concentrations of 0.5% to 1% can pose a serious threat to worker safety.

1.3.3 Carbon Dioxide (CO_2)

Carbon dioxide can pose significant dangers in mining operations, because confined spaces, such as underground tunnels and shafts, often lack adequate ventilation.CO2 can displace oxygen, leading to potentially life-threatening situations for miners working in these environments.

1.3.4. Nitrogen dioxide (NO_2)

A gas typically produced by the oxidation of nitric oxide during blasting at mining faces and is associated with diesel engine emissions and mining machinery. High concentrations of NO_2 can lead to respiratory problems. Additionally, this gas can transform into nitric acid in the atmosphere, contributing to environmental damage, including acid rain formation.

1.3.5. Particulate matter includes dust, smoke, and fine particles

In mining environments, particulate matter is a significant source of pollution and may contain harmful substances. Extremely fine particles, referred to as dust, can penetrate deep into the lungs and, if not treated promptly, can lead to conditions such as pneumoconiosis, causing irreversible damage to workers' respiratory systems. Additionally, particulate matter can cause wear and tear on sensitive mining equipment, and under the influence of high temperatures and gas flow, can undergo oxidation reactions. There is also an increased risk of combustion, especially when exposed to a significant amount of heat radiation.

Name of Gases	Exposure Standards	Risks or Potential Health Issues
Methane	1000 ppm	- In higher concentrations, methane deposes oxygen causing asphyxiation - Ignite and burn
Carbon Monoxide	30 ppm	- Headache, nausea and vomiting - Shortness of breath, dizziness - Loss of consciousness, seizures and death
Carbon Dioxide	12,500 ppm	- A small reduction in exercise tolerance in the range of 30,000-40,000 ppm - At a concentration of 10% or more, unconsciousness will be occurred on workers
Nitrogen Dioxide	3 ppm	- Negative effects on critical organs, such as heart, CNS and fetus
Particulate - Coal dust (containing < 5% quartz) (respirable dust)	1.5 mg/m^3	- Pneumoconiosis - Progressive massive fibrosis - Chronic obstructive pulmonary disease

Table 1: Table Showing Exposure Standards and Risks of Toxic Gases [8]

In terms of component selection, we have chosen various sensors tailored to each specific pollutant shown on Table 1, ensuring compatibility with the ESP32 T-Beam microcontroller for seamless integration during the hardware assembly phase. The system will evolve progressively based on feedback and observed metrics.

2. SOLUTION AND IMPLEMENTATION

2.1 Hardware Implementation

2.1.1 Key Citeria in hardware selection

a. Availability

The availability of hardware components emerged as a pivotal constraint in our sensor selection process. Given the multifaceted nature of our product, integrating numerous gas detection sensors, the scarcity of certain components or extended shipping durations could significantly derail our project timelines. Components' prompt accessibility was thus paramount. On the other hand, our project heavily favoured components present in the UWA’s inventory, as leveraging these items could sidestep potential supply chain disruptions. By prioritizing readily available components, the project's development and planned timelines could be maintained.

b. Cost

Our group was allocated a $50 budget for component procurement for any new sensor related to our project. Since there were several sensors integrated into our project, it is important to strategize the spending carefully while ensuring functionality and compatibility of the selection of sensors. For example, although the Sulphur Dioxide (SO_2) Sensor offers invaluable utility in detecting SO_2 emissions, a concern especially in industrial settings, its high cost poses a challenge. While the sensor's capabilities are undeniably important, budgetary constraints for this specific project make its integration difficult. It's essential to weigh its benefits against financial limitations, consider alternative solutions, or prioritize other essential components.

By clearly outlining the project's objectives and the functionalities our project aims to achieve shown on Figure 1, it gave a roadmap for the components and their priority that our project needs to purchase. On the other hand, conducting an inventory check before spending any of the budget to determine whether a component is already available in UWA would prevent unnecessary expenditure on items our project already has.

S. Nr	Items Description	Available at UWA (Yes/No)	Cost	Web address	Delivery Time
1	ESP32 T-Beam	Yes	-	https://core-electronics.com.au/firebeetle-board-esp32-e-arduino-compatible.html	-
2	CO2 Sensor Module	Yes	-	https://www.jaycar.com.au/duinotech-air-quality-sensor-with-co2-temperature/p/XC3782	-
3	BMP280 - Atmospheric Sensor	Yes	-	https://core-electronics.com.au/piicodev-atmospheric-sensor-bme280.html	-
4	Dust Sensor Module	Yes	-	https://core-electronics.com.au/optical-dust-sensor-gp2y1010au0f.html	-
5	Methane CNG Gas Sensor - MQ-4 (Or Component 6)	No	10.70	https://core-electronics.com.au/methane-cng-gas-sensor-mq-4.html	requires 5 to 8 day leadtime. Plus AusPost eParcel Standard (6+ Business Days) Shipping Fee 7.36 to 12.82
6	Dual Gas CO and CH4 Detection Sensor - MQ-9B (Or Component 5)	No	11.30	https://core-electronics.com.au/dual-gas-co-and-ch4-detection-sensor-mq-9b.html	requires 7 to 10 day leadtime. Plus AusPost eParcel Standard (6+ Business Days) Shipping Fee 7.36 to 12.82
7	Fermion: MEMS Gas Sensor - MiCS-2714 (Breakout)	No	17.10	https://core-electronics.com.au/fermion-mems-gas-sensor-mics-2714-breakout.html	requires 5 to 8 day leadtime. Plus AusPost eParcel Standard (6+ Business Days) Shipping Fee 7.36 to 12.82
9	Piezo Buzzer	Yes	-	https://core-electronics.com.au/buzzer-5v-breadboard-friendly.html	-
NA	Transparent Solderless Breadboard - 300 Tie Points (ZYJ-60)	Yes	-	https://core-electronics.com.au/transparent-solderless-breadboard-300-tie-points-zyj-60.html	-
NA	Premium Female/Male Extension Jumper Wires - 40 x 12 (300mm)	Yes	-	https://core-electronics.com.au/premium-female-male-extension-jumper-wires-20-x-12.html	-
NA	Batteries	Yes	-	-	-
		Total Cost:		10.70 + 17.10 + 7.36 = AUD 35.16 or 11.30 + 17.10 + 7.36 = AUD 35.76	

Figure 1: Components Procurement Plan List

c. Scalability

Given the context that our project aims to provide safety precautions for personnel during mining activities, the consideration of the ability of an IoT project to handle a growing amount of work or its potential to accommodate more sensors or connectivity components in the coming future.

d. Power Limitation

The energy constraints of our IoT project are especially pronounced when considering its application in mining activities. Since the mining environment is featured by its remoteness and challenging accessibility, the continuous operation of our device is paramount. A failure due to battery drainage not only impedes data collection but can also compromise the safety of mine workers, particularly if real-time monitoring is disrupted during critical operations. The unpredictability of such power lapses can potentially put workers at risk, especially if they're relying on the system for safety alerts or air quality measurements. As a result, addressing these power constraints is not just a matter of device longevity but of paramount safety.

e. Connectivity

In our prototype, we have chosen Wi-Fi as the preferred connectivity option for our project due to its widespread adoption and ease of integration. Many industrial areas already have Wi-Fi infrastructure, simplifying deployment and reducing costs. Wi-Fi's high data rates are crucial for transmitting real-time monitoring data efficiently during mining activities. Its standardized protocols ensure compatibility across devices from various manufacturers and robust security for data protection. Remote access capabilities further enhance its appeal, allowing for distant monitoring and potential cloud integration. As the system expands, Wi-Fi's ability to handle multiple connections simultaneously proves beneficial. While Wi-Fi is our preferred choice for connectivity, it's worth noting that LoRaWAN is also a viable option. The ESP32 T-Beam device includes LoRaWAN support, which may be suitable for specific use cases or environments where long-range, low-power communication is a priority.

Ultimately, our decision to use Wi-Fi is based on its versatility, high data rates, and the existing infrastructure in many industrial settings, making it a practical and efficient choice for our mining monitoring project. However, we acknowledge that LoRaWAN can be a suitable alternative, depending on the specific requirements and constraints of the project.

f. Ease of integration

Ease of integration is a critical consideration in our project. It encompasses two primary aspects: the availability of documentation and libraries and compatibility with the chosen hardware platform. These factors play a pivotal role in the successful incorporation of electronic hardware components into our system.

To streamline integration efforts, we prioritize components that come with comprehensive documentation and well-maintained libraries. This documentation includes detailed technical specifications, connection diagrams, and programming examples. It facilitates a smoother integration process and aids in troubleshooting potential issues.

Compatibility with our selected hardware platform is essential for seamless integration. Our system relies on a specific hardware environment, and components must be compatible with the platform's communication protocols and interfaces. This ensures that components can communicate effectively and share data within the system.

To assess the suitability of electronic hardware components for our project, we have evaluated them against these integration criteria, as summarized in Table 2:

Component	Avail	Compatible	Accuracy	Doc & Lib
ESP32 T-Beam	Yes	Yes	n/a	[1]
Piezo Buzzer	Yes	Yes	n/a	[2]
BMP280 Sensor	Yes	Yes	±0.5 °C from 0-60 °C	[3]
CO2 Sensor Module	Yes	Yes	eCO2: 400-8192ppm; TVOC: 0-1187ppb	[4]
Dust Sensor Module	Yes	Yes	0.5V/0.1mg/m^3	[5]
Methane Gas Sensor Dual Gas MEMS Gas Sensor	Due to shipping issues, the items are not available. In this prototype, we use simulated data to test our buzzer and web analysis.			

Table 2: Key Selection Criteria of Project Electronic Hardware Components

2.1.2. Details of the Selected Sensors

a. ESP32 T-Beam

The ESP32 T-Beam, listed in the UWA stock list, is an excellent choice for projects requiring durable, long-range communication capabilities. One of its standout features is the integrated LoRa and Wi-Fi module. This module facilitates long-range, low-power wireless communication, distinguishing itself from traditional wireless methods by offering much longer communication distances. Such a feature becomes particularly advantageous in environments like mines, where standard communication methods, such as Wi-Fi or cellular, often face disruptions or complete blockages due to the depth or isolation of certain areas. Moreover, the T-Beam is designed to be power-efficient, operating with minimal energy consumption.

b. CO2 Sensor Module

Housed within UWA's equipment inventory, the CO2 Sensor Module stands out for its ability to detect eCO2 (equivalent carbon dioxide). The eCO2 measurement, as implied, provides an estimate of CO2 levels in the environment based on the volatile organic compounds detected, rather than offering direct CO2 measurements. Although it doesn't deliver a direct CO2 concentration, it offers invaluable insights into air quality, especially when direct measurements are not available. Meanwhile, the detection of MOX levels is essential, as it relates to the sensor's capability to identify a broad range of volatile organic compounds (TVOCs). This dual functionality, combined with its ultra-low power consumption and precision NTC thermistor, makes the module a crucial tool for monitoring air quality in various settings, including mining environments.

c. BMP280 - Atmospheric Sensor

The BMP280, available in the UWA stock list, is an adept atmospheric sensor capable of measuring both temperature and humidity. Within the distinct and frequently demanding environment of mining, these two parameters hold significant importance. Monitoring these atmospheric variables is vital, as variations in temperature or humidity can impact the health and safety of mine workers directly. For example, temperature shifts can present thermal risks to workers, while changes in humidity can influence equipment corrosion or exacerbate respiratory conditions. Given these pivotal concerns, the BMP280 stands as an essential tool, ensuring that the atmospheric conditions within the mine consistently adhere to safe and optimal standards.

d. Dust Sensor Module

Listed in the UWA's stock, the Duinotech Dust Sensor Module specializes in detecting particulate matter. In mining environments, airborne dust and particulates are a significant concern due to potential respiratory health risks and equipment degradation. This sensor plays a vital role in ensuring the air quality remains within safe limits for both workers and machinery.

e. Dual Gas Sensor - (CO and CH_4) **Unavailable due to shipping issue**

The Dual Gas Sensor is adept at detecting both carbon monoxide and methane. Given the significance of these gases, especially in mining environments, this sensor offers dual functionality that could be particularly efficient. Its capability to detect both gases might render the standalone methane sensor, thereby optimizing both costs and sensor integration.

f. Nitrogen Dioxide (NO_2) Sensor **Unavailable due to shipping issue**

The Nitrogen Dioxide Sensor plays a crucial role in monitoring NO_2 emissions. Given that NO_2 is a typical byproduct of machinery combustion, especially in industrial settings, it's vital to detect and manage its levels. This sensor ensures a safer environment by keeping track of such emissions, thereby mitigating health risks associated with prolonged exposure.

g. Piezo Buzzer - 5V Breadboard Friendly

Available in the UWA stock list, the Piezo Buzzer is a breadboard-friendly alert system. Given its compatibility and accessibility, it's particularly useful in scenarios where immediate notifications are crucial. In a mining or industrial environment, if any sensor detects parameters surpassing safe thresholds, this buzzer can swiftly alert workers, ensuring prompt response and enhanced safety measures.

2.1.3 Hardware Implementation and Configuration

The hardware was assembled according to the schematic shown in Figure 2. The initial steps involved connecting and validating the functionality of the sensors, with specific focus on the ESP32 T-Beam and the gas sensor.

For the ESP32 T-Beam, the default pins SCL (Pin 22) and SDA (Pin 21) were used for communication. The following code snippet was utilized for sensor setup and usage:

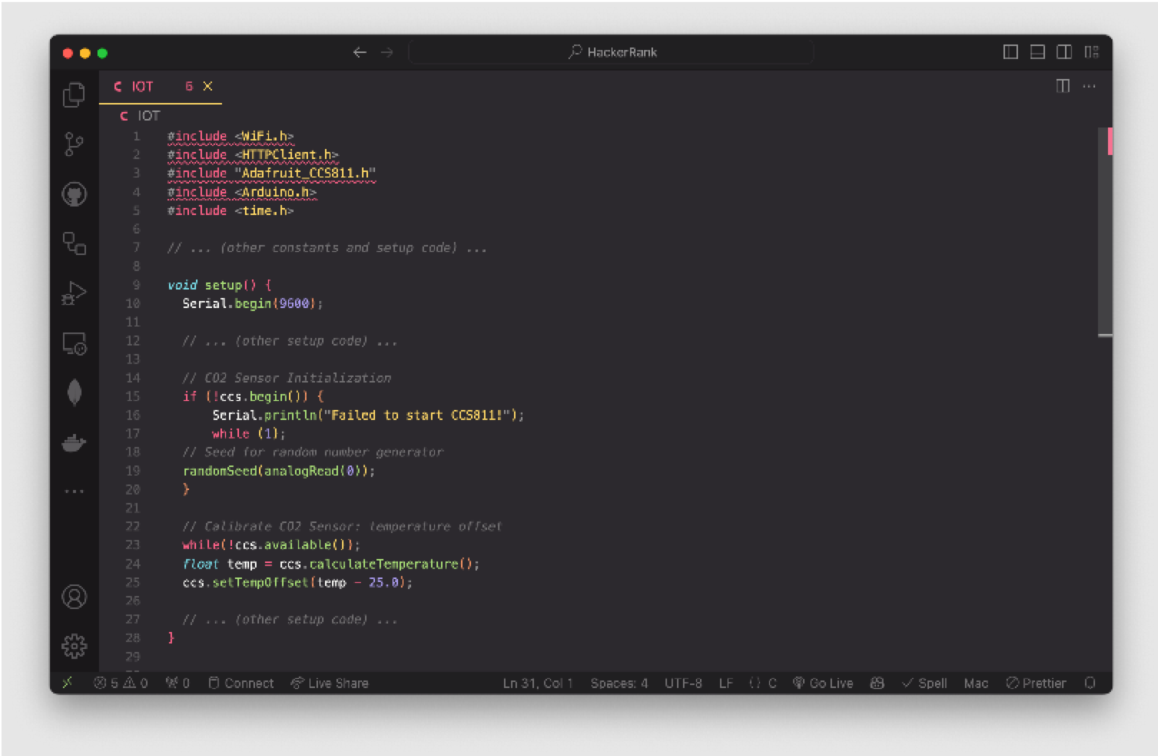


Figure 2: Code Snippet Utilized for Sensor Setup And Usage

The ESP32 T-Beam setup was straightforward, thanks to readily available documentation, ensuring a smooth verification process.

For the gas sensor (CO2 sensor), the Adafruit CCS811 library was used to facilitate communication. The sensor was calibrated for temperature offset to ensure accurate readings. The gas sensor data, including eCO2 and TVOC levels, were obtained and monitored as part of the hardware configuration.

The remaining detailed aspects of the setup, including the Dust Sensor and the BME280 Sensor, were integrated into the software part of the project for comprehensive monitoring and data transmission.

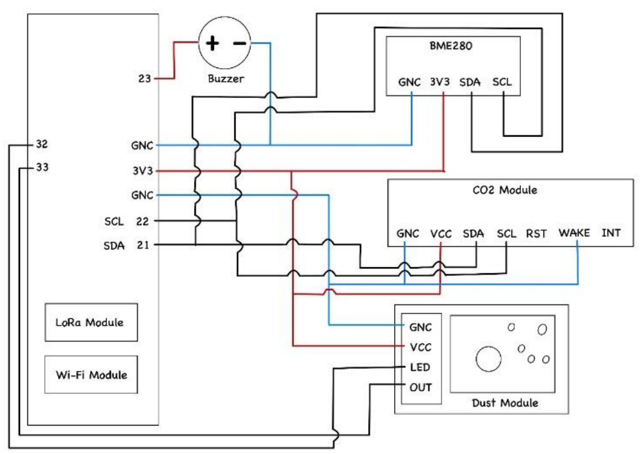
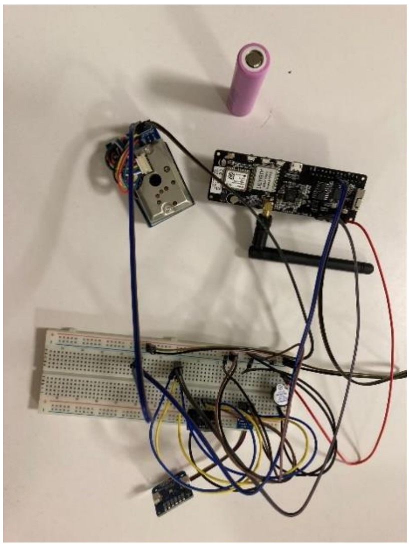


Figure 3: Layout Diagrams of IoT Hardware



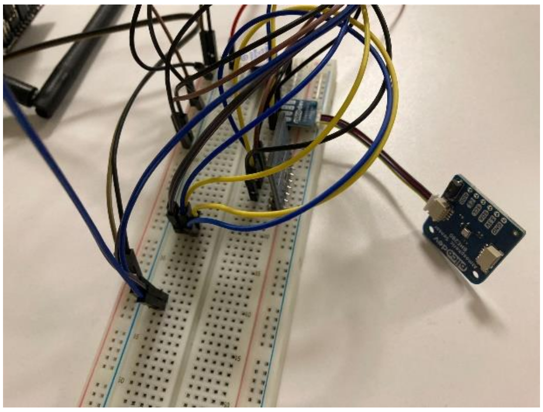


Figure 4 & 5: Photographs of EPS32 and Sensors

To address air quality concerns within mining environments, our system integrates a meticulously curated array of sensors. This selection includes the CO2 Sensor Module, which detects eCO2 and MOX levels; the BMP280 Atmospheric Sensor for temperature and humidity readings; and the Duinotech Dust Sensor Module that specializes in capturing particulate matter presence. Although the Dual Gas Sensor (for carbon monoxide and methane detection) and the Nitrogen Dioxide Sensor (to monitor NO_2 emissions) are currently unavailable due to shipping issues, we'll use simulated data to represent their readings. This approach allows us to test and demonstrate the system's alert functionalities. The Piezo Buzzer, which is breadboard-friendly and available in the UWA stock list, is integrated to play a pivotal role in providing immediate hazard alerts based on these simulated readings. Each sensor and module were selected based on its unique pollutant or condition detection capabilities. To uphold the system's precision, we intend to adhere to a rigorous calibration routine and timely battery replacements. The system's evolution will be determined by continual feedback and thorough evaluation of performance metrics.

For efficient data transmission, we employ the ESP32 T-Beam microcontroller, renowned for its built-in Wi-Fi module, ensuring reliable communication even in remote mining locations. Data from multiple sensors is aggregated and transmitted to Firebase, our cloud-based centralized database, for storage, subsequent analysis, and review. Additionally, a buzzer has been integrated to facilitate rapid alert notifications as part of our threshold-based alert system.

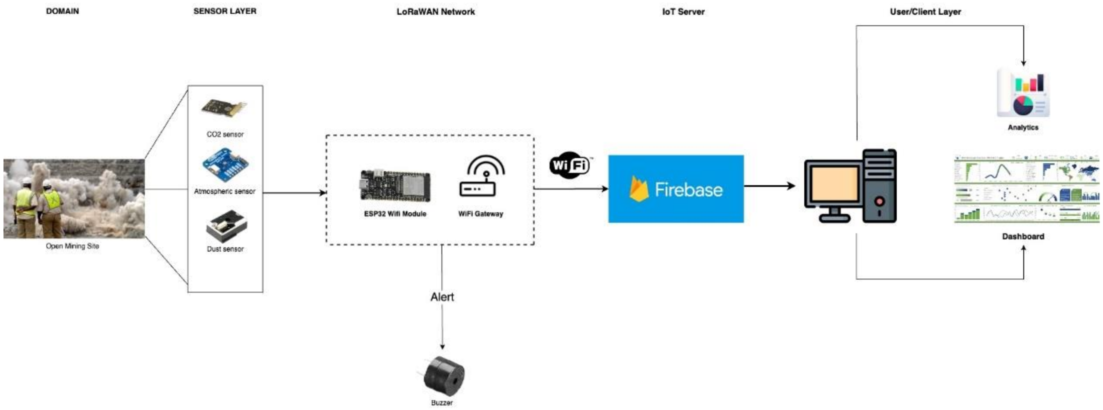


Figure 3: Block Diagram of Implementation

2.2. Software Implementation

2.2.1. Software Architecture

After completing the hardware deployment and configuration, our project was developed to run in a client-server model. Regarding the client side, the ESP32 T-Beam devices collect data from the multiple sensors and transmit it over the WIFI. On the sever side with a long-term view towards convenient data storage and review, a centralized database or cloud-based platform receives, stores, and processes the data from the multiple ESP32 T-Beam devices.

2.2.2 ESP32 T-Beam Connectivity and Wi-Fi Configuration

The ESP32 T-Beam microcontroller serves as a crucial component in the system, responsible for sensor data collection and transmission. The following sections outline the connectivity and Wi-Fi configuration for this device.

To enable remote communication and data transmission, the ESP32 T-Beam is configured to connect to a Wi-Fi network using the following parameters:

SSID (Service Set Identifier): The name of the Wi-Fi network to connect to, which is specified in the code.

Password: The Wi-Fi network password, configured in the code.

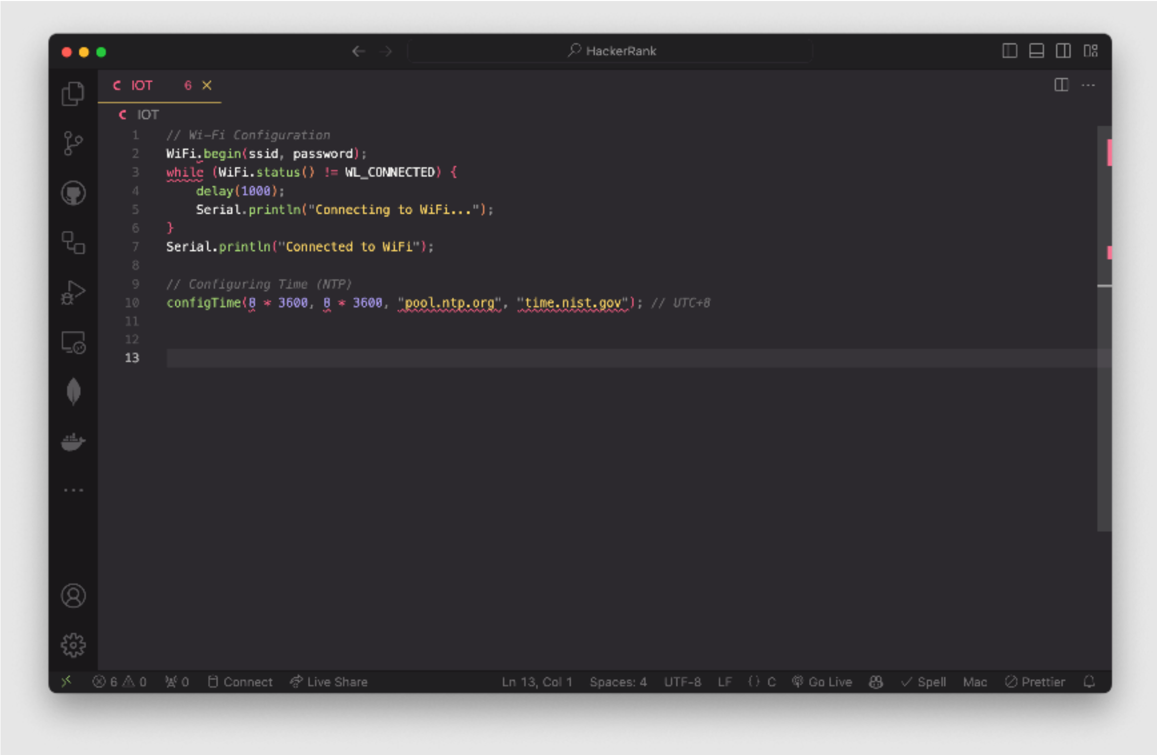


Figure 4: Code Snippet of Wi-Fi Configuration

The ESP32 T-Beam establishes a connection to the specified Wi-Fi network using these credentials. Once connected, it can transmit data to remote destinations, such as a Firebase Realtime database.

As depicted in Figure 8, the Wi-Fi configuration is tailored to ensure that the microcontroller connects seamlessly to the designated network, facilitating the real-time relay of sensor data. Upon establishing this connection, the ESP32 T-Beam is enabled to relay data to various remote repositories, including a Firebase Realtime database, as outlined in Figure 5.

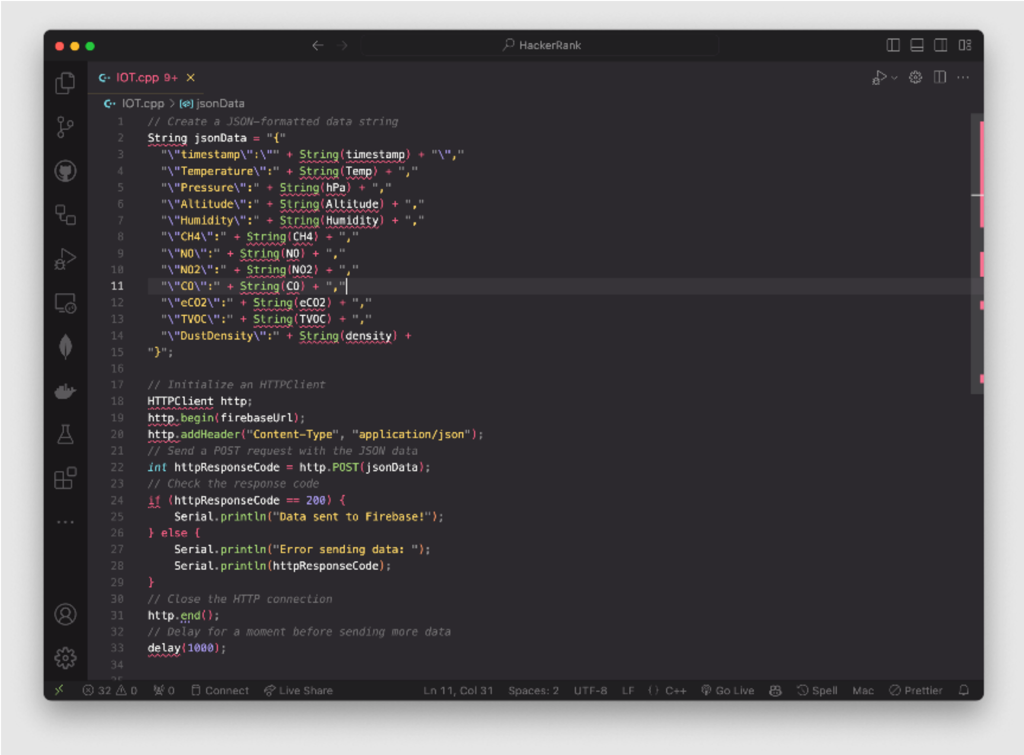


Figure 5: Code snippet of JSON Data Conversion and Initialization of HTTPClient

Data collected from various sensors, including temperature, pressure, humidity, gas concentration, and dust density, are aggregated by the ESP32 T-Beam. The device utilizes HTTPClient and HTTP POST requests to send this data to a Firebase-based centralized database. The data transmission process involves converting sensor readings into a JSON format and sending it to the Firebase server using the URL https://cits5506-default-rtdb.firebaseio.com/sensorData.json.

This configuration allows the ESP32 T-Beam to provide real-time air quality information to the centralized database for storage, analysis, and further review.

2.2.3 ESP32 T-Beam Buzzer Alert

The integrated monitoring system, anchored by the ESP32 T-Beam microcontroller, exemplifies the forefront of safety technology in mining environments. One of its standout features is the sophisticated buzzer alert system tailored for timely hazard detection and notification. This alert system operates based on meticulously defined thresholds:

- Dust Levels: Elevated PM2.5 and PM10 concentrations in the atmosphere have established health implications. The California Ambient Air Quality Standards recommend a 24-hour average of 50 μg/m3 for PM10. Our system employs these 50 μg/m3 thresholds, triggering alerts when breached, to protect against respiratory health risks and potential equipment degradation due to increased dust presence. [18]

- CO2 Levels: Research spanning various environments, including schools and office spaces, has produced a spectrum of findings concerning CO2 concentrations. Specifically, in office settings, concentrations ranging between 400-800 ppm did not show a significant correlation with respiratory issues. On the other hand, several studies conducted in educational institutions have drawn links between elevated CO2 concentrations (>2100 ppm) and respiratory symptoms, particularly instances of coughing.

Given the confined and potentially poorly ventilated nature of mining environments, it is prudent to adopt stringent air quality benchmarks. Consequently, our project has set an eCO2 threshold at 800 ppm. Surpassing this level can be interpreted as a heightened presence of VOCs, suggesting compromised air quality. This has important implications, potentially affecting both the health of mining personnel and the efficiency of equipment within the mine. [19]

- TVOC Levels: An extensive study conducted in industrial facilities reported a median TVOC concentration of 845 μg/m3 and recommended a target of 300 μg/m3 for typical industrial indoor air. While this research primarily pertained to indoor industrial settings, the nature of mining environments, often characterized by confined spaces and limited ventilation, makes them comparable to such indoor scenarios. Given these similarities and in the interest of ensuring the utmost safety, our system has adopted the conservative threshold of 300 μg/m3 for TVOCs. Alerts are activated when TVOC concentrations approach or surpass this established benchmark, signaling potential risks and assisting in maintaining optimal air quality within the mine. [20]

Should any sensor detect values surpassing these thresholds, the 'playMelody' function is activated, producing a distinct alert melody.

Considering the diverse conditions of various mining scenarios, these thresholds offer adjustability, ensuring system applicability across different mining contexts.

Lastly, the 'stimulate_sensors()' function simulates sensor readings, facilitating system testing and comprehension. A randomized selection mechanism sets the system's mode - "safe" or "danger." The "safe" mode yields simulated readings within safety margins, while "danger" mode shows elevated readings, activating the auditory alert. An embedded code block ensures orderly program termination for non-standard modes.

2.2.3 Firebase

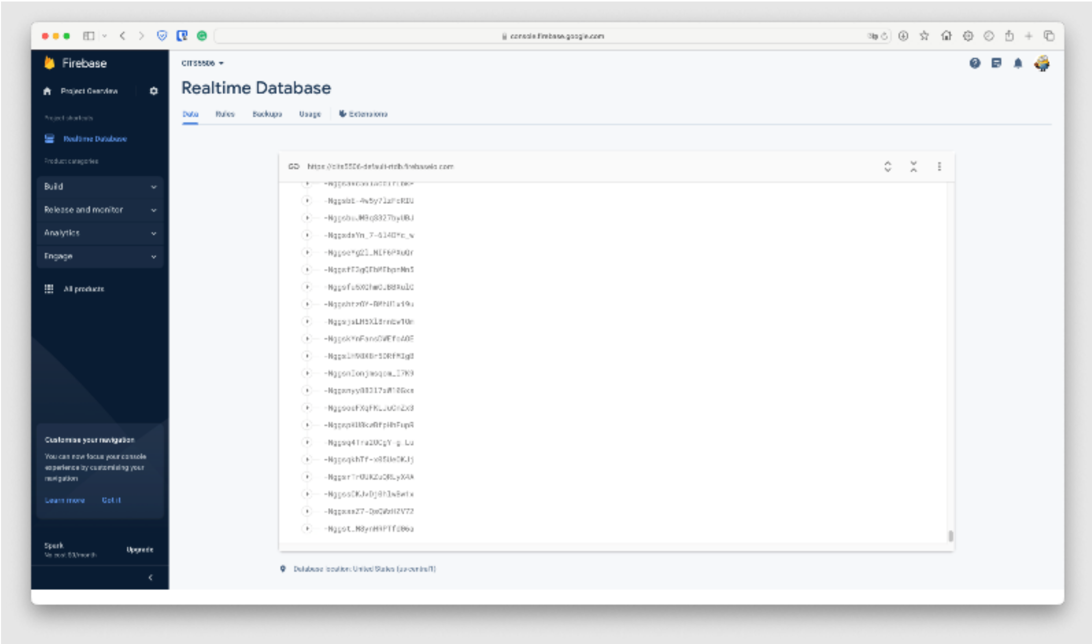


Figure 6: Firebase's Realtime Database Collecting Data from Sensors

Upon conducting research, we found that Firebase aligns well with our project requirements. Firebase offers a range of cloud services covering data analytics, cloud storage, and web hosting. Among these, we chose the Realtime Database for its suitability. This database system employs real-time processing to handle workloads with continuously changing states, aligning perfectly with our expectations. This feature allows our devices to connect to the Realtime Database, with multiple sensors regularly pushing the collected data into it. As another component of our system, the web will also connect to the same service and update in real-time when changes occur in the database, facilitating the subsequent implementation of real-time visual displays on the web. Firebase's functionality greatly streamlines the connection between our hardware and software, leading us to select Firebase's Realtime Database as our data storage and analysis solution.

2.2.4 Flask App & Data Analysis

In the architectural phase of our web application, Flask emerged as our framework of choice and basic HTML & CSS for front-end. We gravitated towards Flask because of its amalgamation of simplicity, flexibility, rapid development capabilities, and potential for extensibility. With Flask as our foundation, we've crafted two core features for our web interface: a dynamic display of streaming data captured from air quality sensors and a dedicated analytics page for a deep dive into this data.

Given the nature of mining operations, this tool is especially tailored for management or officers stationed in offices close to the mining area, rather than the miners themselves. This setup ensures that those in decision-making capacities are armed with real-time data to make informed judgments regarding onsite conditions. Additionally, the data stored in Firebase not only serves immediate operational purposes but also holds legal significance. It can be leveraged in potential lawsuits or to ensure compliance with employee safety regulations and standards.

Firstly, our initial step involved setting up a Firebase database on the Firebase Cloud. This process utilized a connection key, ensuring a secure link between Firebase and Flask. By establishing this bridge, we created a connection that formed the foundation for our project.

In the preliminary stages, we used random data. This approach allowed us to confirm that the data was successfully being displayed in the front-end interface. This ensured the seamless flow of information from our backend to the front-end.

Once we were confident in the integrity and functionality of our backend, including its ability to connect with the Firebase database and present data in the front-end, we shifted our focus to the front-end development.

The homepage of our project adeptly presents a table illustrating real-time data pulled from Firebase. The analytics wing of our interface showcases sensor readings, vividly represented through gauges (Figure 7) and comprehensive graphs (Figure 8). This visual ensemble provides an in-depth view of various environmental parameters, encompassing temperature, humidity, and gas concentrations like CO, CO2, CH4, NO, NO2, and TVOC.

Harnessing the power of the Highcharts JavaScript library, our gauges, as seen in Figure 7, classify the detected toxic fumes into three discernible severity tiers: high, medium, and low. Each tier is reinforced with a tailored message to promptly update management or officers about air quality nuances.

The primary ambition behind this visual framework is to distill complex gas concentration data into intuitive, actionable insights. When gas concentrations touch the 'high severity' zone, a critical alert cascades to the management. Medium concentrations evoke a moderate warning, while lower concentrations prompt a subtle advisory. This tiered approach ensures continuous vigilance and equips management and officers with the information they need, especially if conditions trend towards potential hazards.

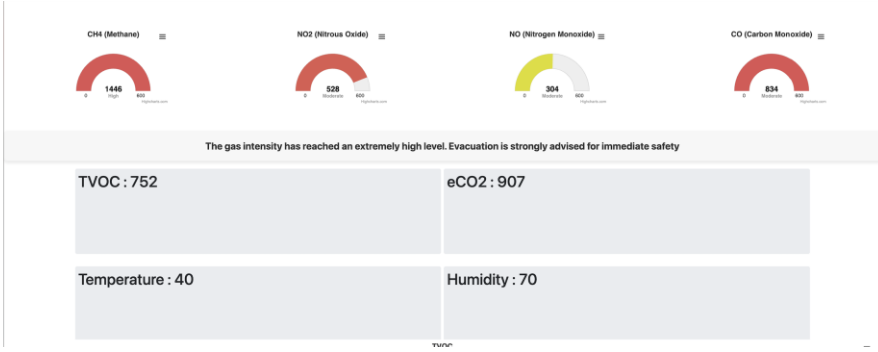


Figure 7: Analytics Webpage Sensor Reading Gauges

As depicted in 8, our system actively gathers data on temperature, TVOC (Total Volatile Organic Compounds), eCO2, and humidity, visualizing these parameters using line charts. This visualization approach facilitates a nuanced analysis of patterns over time. Drawing data directly from the database, the user interface showcased in Figure 6 provides real-time updates every second. Constructed using foundational web technologies - HTML5 and CSS3 - and enhanced with JavaScript for dynamic functionality, this user interface offers both elegance and utility. Moreover, a print function situated at the top right corner of the line charts enables stakeholders or management in offices near the mining area to produce tangible records of the data, beneficial for documentation or review purposes.

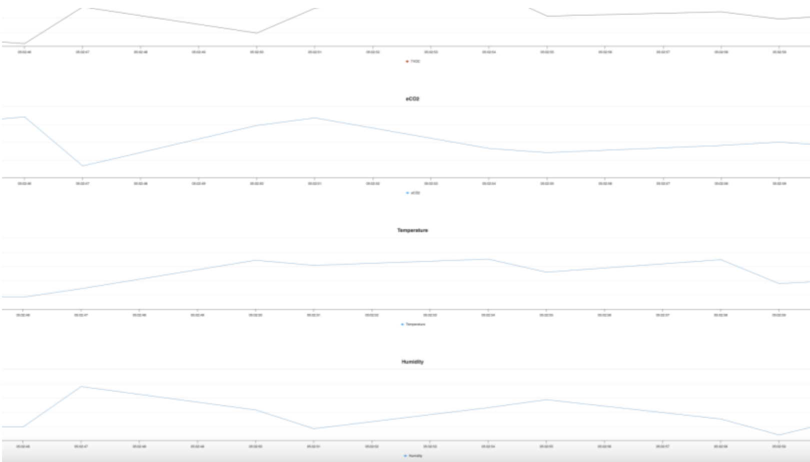


Figure 8: Analytics Webpage Sensor Reading Graphs

3. FURTHER DISCUSSION

3.1. Recommendation And Future Work

a. Security Issues

Since our air quality monitoring system in mining are connected to the Internet, without any appropriate security measures, could be vulnerable to various security issues, including unauthorized access of the system and data tampering or eavesdropping by hackers. In considering future enhancements to the security framework of our smart air quality monitoring system for mining sites, we're evaluating the adoption of advanced and secure communication protocols. One promising approach is the implementation of the MQTT (Message Queuing Telemetry Transport) protocol, fortified with SSL/TLS encryption. This combination is projected to streamline and secure the data transfer between the gas sensors and our cloud storage, potentially Firebase or a similar platform.

To address potential security challenges, especially in terms of Authentication and Authorization, we're looking into leveraging the capabilities of AWS IoT. AWS IoT Lambda offers comprehensive, fine-grained access control through its IAM (Identity and Access Management) roles and policies. By integrating these features, we aim to ensure that only authorized devices and applications associated with mining companies will have permission to publish or subscribe to MQTT topics, further reinforcing our system's security.

These proposed enhancements underscore our commitment to evolving our platform, keeping abreast of technological advancements, and ensuring optimal security in dynamic mining environments.

b. Connectively Coverage

Ensuring robust connectivity is pivotal for the optimal operation of the smart air quality monitoring system in mining sites. Signal interruptions due to physical barriers, atmospheric conditions, or interference from other devices can impede data transfer and system functionality.

One effective solution is the adoption of wireless mesh networks, allowing devices to relay signals amongst themselves and ensuring connectivity even in more remote locations. Multi-modal connectivity, integrating Wi-Fi, LoRaWAN, and cellular networks, can further bolster this system, allowing for adaptable connectivity tailored to various terrains and conditions. The strategic placement of repeater stations can also extend and strengthen signal coverage, ensuring a wider reach.

Looking ahead, the advent of 5G technology presents promising potential. Its capabilities for high-speed data transfer and low latency could significantly enhance system performance in mining contexts. Additionally, integrating edge computing, which processes data locally at the source, can mitigate constant data relay needs, thereby streamlining system operations.

c. Limited Battery Life

The longevity of battery life remains a persistent challenge in smart air quality monitoring systems, especially within mining environments. To counteract this, several strategies can be adopted. A primary approach involves the creation of energy-efficient algorithms. By crafting these algorithms to demand less processing power, the energy consumption of devices can be substantially reduced. Another effective method is the incorporation of duty cycling. This technique permits devices to go into a low-energy sleep state and only become active during critical functions such as data collection or transmission, thereby conserving energy. For operations in opened mine sites, an innovative solution is the use of solar harvesting. By fitting devices with compact solar panels, sunlight can be captured and transformed into supplementary power for the devices, offering a renewable energy source.

Additionally, there will a significant potential in the realm of advanced energy harvesting due to the rapid development of technology. Techniques like vibration energy harvesting, particularly relevant in the vibratory environment of mines, could be explored to recharge devices. Moreover, as the world of technology continues to evolve, it is paramount to keep a vigilant eye on the progress in battery technologies. The emergence of batteries boasting longer lifespans, swift charging capabilities, or greater energy density can be game changers for ensuring uninterrupted monitoring in challenging mine terrains.

d. **Adapting formula for Air Quality Index**

While individual monitoring of harmful gases is crucial, assessing each gas's severity independently might not provide a comprehensive picture of the environmental quality in mining areas. Therefore, we propose the incorporation of the Air Quality Index (AQI) formula in future iterations of our system. This will present a more holistic understanding of air toxicity, enabling the management and on-site officers to be promptly alerted to potential hazards due to escalating toxic concentrations. The AQI interpretation can vary based on regional standards; our focus will be on adapting the AQI specifically for Australia, as detailed in Figure 9 [16] & [17]

AQI Category, Pollutants and Health Breakpoints								
AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5 – 1.0
Moderately polluted (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

$$I_i = \left[\left\{\frac{I_{HI}-I_{LO}}{B_{HI}-B_{LO}}\right\} * C_P - B_{LO}\right] + I_{LO}$$

where

B_{HI}= Breakpoint concentration greater or equal to a given concentration
B_{LO}= Breakpoint concentration smaller or equal to a given concentration
I_{HI} =AQI value corresponding to BHI
I_{LO} = AQI value corresponding to BLO
I_i = Subindex of the pollutant
C_p = Pollutant concentration

Figure 9: Air Quality Index (AQI) formula

e. Improvement of Visuals

Improvement of Visuals: Addressing the current visual constraints, our roadmap includes refining our data visualizations. We intend to incorporate markers on graphs to pinpoint specific instances where pollutant concentrations spiked, signaling hazardous conditions. Additionally, our plans encompass the inclusion of a dedicated page for more granulated data analysis, allowing stakeholders to focus on specific time intervals. Also, instead of using HTML & CSS for the front end we can use powerful frameworks like Angular JS so that all sorts of complex integration in the web development level is possible with less code to write.

f. **Architectural Recommendation:**

In our proposed future architecture, illustrated in Figure 10, we integrate additional sensors such as CO sensors, CH4 sensors, and oxides of nitrogen sensors. These sensors, once connected to the ESP32 T-beam and after following the recommendations in a) and b) and after the secure connection with The Things Network, the management sectors therefore gain access to the visual plots. These visualizations allow them to monitor and analyze the severity levels of harmful gases present in the mining site. This integration provides a comprehensive solution for real-time monitoring and analysis of environmental conditions as the managerial sectors gain actionable insights ensuring a responsive approach to environmental challenge.

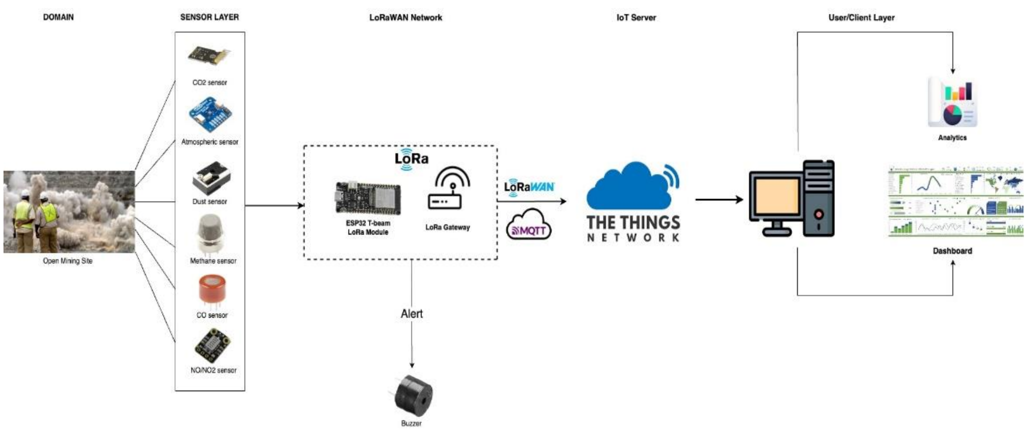


Figure 10: Future Hardware and Software Architecture

4. CONCLUSION

The Smart Air Quality System is a breakthrough for air quality in underground mining. Using the ESP32 T-Beam microcontroller and sensors, it real-time monitors air and instantly alerts miners of hazards with a Piezo Buzzer to monitor and safeguard the health and safety of mining personnel.

For the hardware implementation, we selected gas monitoring metrics tailored to mining hazards. Using the ESP32 T-Beam microcontroller and various sensors, we established a Wi-Fi connection for immediate monitoring and data sharing. If dangers arise, the system promptly sounds a Piezo Buzzer, emphasizing safety.

On the software side, we used Firebase as our central hub for data gathering, storage, and review. This allowed smooth interaction between our hardware and the online interface, providing immediate data displays for better decision-making. Our system prioritizes miner safety, promotes responsible mining, and ensures adherence to environmental guidelines.

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APPENDICES A. GETTING STARTED WITH THE FINAL PRODUCT

`git clone` git@github.com:maxtch/IOTWebDevelopment.git

To set up the local host:

1. Create a Virtual Environment

To create a virtual environment named “myenv”, you would use the following command:

```
python -m venv myenv
```

2. Activate the Virtual Environment

After creating the virtual environment, you need to activate it. The activation command varies depending on your operating system:

- Linux or macOS:

```
source myenv/bin/activate
```

- Windows (Command Prompt):

```
myenv\Scripts\activate
```

- Windows (PowerShell):

```
.\myenv\Scripts\Activate.ps1
```

Once the virtual environment is activated, your command prompt will change to show the name of the activated environment, and any Python packages you install using pip will be installed within this environment, isolated from the global Python installation.

3. Install Dependencies

```
pip install -r requirements.txt
```

4. Run the Application

```
flask run
```