PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 7 No. 1 (2026) 357-365
https://publisher.uthm.edu.my/periodicals/index.php/peat

AIRVIS 3D: Real Time Indoor Air Quality Dashboard for and Gas Leak Detection

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DOI: https://doi.org/10.30880/peat.2026.07.01.041

Article Info

Received: 12 January 2026
Accepted: 20 February 2026
Available online: 25 May 2026

Keywords

Air Indoor Quality, M5Stack, Dashboard, 3D spatial,Firebase,Real-Time Monitoring,Volatile Organic Compounds,Cloud, User-Friendly

Abstract

This project presents AIRVIS 3D: Real-Time Indoor Air Quality Dashboard for Gas Leak Detection, focusing on the design and implementation of an interactive dashboard for real-time monitoring of indoor air conditions. The system integrates IoT sensors with an ESP32-based M5Stack microcontroller to detect harmful gases such as carbon monoxide, methane, and volatile organic compounds (VOCs). Sensor data is transmitted wirelessly to Firebase, which serves as the cloud platform for data storage and synchronization. The core component of this system is a user-friendly dashboard that visualizes gas concentration in a 3D spatial layout, enabling users to understand gas distribution across different indoor zones and heights. The dashboard includes alert indicators, live charts, and responsive design for desktop and mobile use. It allows for real-time updates, early warnings, and improved decision-making in managing indoor air quality. This project highlights the importance of intuitive dashboard interfaces in enhancing environmental monitoring, user engagement, and safety response in residential, commercial, and industrial spaces.

1. Introduction

Indoor air quality (IAQ) has emerged as a major public health problem as the globe grows more industrialized and urbanized [1]. A variety of pollutants, including carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter (PM), and hazardous gases like carbon monoxide (CO), methane (CH4), and propane (C3H8) often accumulate at higher concentrations indoors than in outdoor environments [2]. These gases may cause short-term and long-term hazardous gases that are released incidents of severe risks including poisoning, explosions, or fires [2] such as cardiovascular and lung diseases. Since hazardous gases like CO are colorless and odorless, these gases are hard to detect without specialized sensors, making early detection systems essential for minimizing harm [3].

Most air monitoring systems continue to use primitive sensors, which only offer two measurements, limiting their effectiveness in complex environment. gas spread along various axes since gases spread three dimensionally because of airflow, impediments, and temperature differences, it is imperative to locate gas spread along various axes. The limitations of conventional 2D sensing were highlighted by incidents such as the Putra Height tragedy in 2025, underlining the need for accurate monitoring tools. 3D localization enables the system to locate precisely the source of gas, direction of spread, and concentration gradients, providing a significant improvement over traditional method [4]. Previous studies have explored various methods of gas detection. For instance, Deepika et al. focused on fire detection in smart homes [5], while El Barkani utilized machine learning for gas leakage identification [6]. Similarly, Takei developed a 3D gas localization using drones [7], and Janarthanan emphasized real-time monitoring [8]. However, most of these systems lack the interactive dashboard capabilities proposed in this study.

To address these challenges, this study aims to develop "AirVis 3D", a user-friendly dashboard for real-time air quality monitoring and gas leak alerts. By utilizing Internet of Things (IoT) technology, the system integrates M5Stack sensor data with cloud computing to utilize air quality data in 3D space to detect and localize sources of leakage. This system allows industrial operators to pay close attention to gas levels and receive warnings immediately via mobile and desktop platforms. Consequently, this approach supports proactive airflow control and ensures the safety of indoor environments by preventing accidents in high-risk areas.

2. Methodology

2.1 System Architecture

Figure 1 illustrates the overall system architecture of the AirVis 3D. The process begins with the 3D IAQ sensor nodes arranged across X, Y, and Z axes to capture volumetric air quality data. This telemetry is transmitted wirelessly via Wi-Fi to the Firebase cloud platform, which acts as a real-time bridge for data synchronization. Finally, the processed data is retrieved and displayed on a cross-platform dashboard, allowing users to monitor environmental metrics via both desktop and mobile devices seamlessly

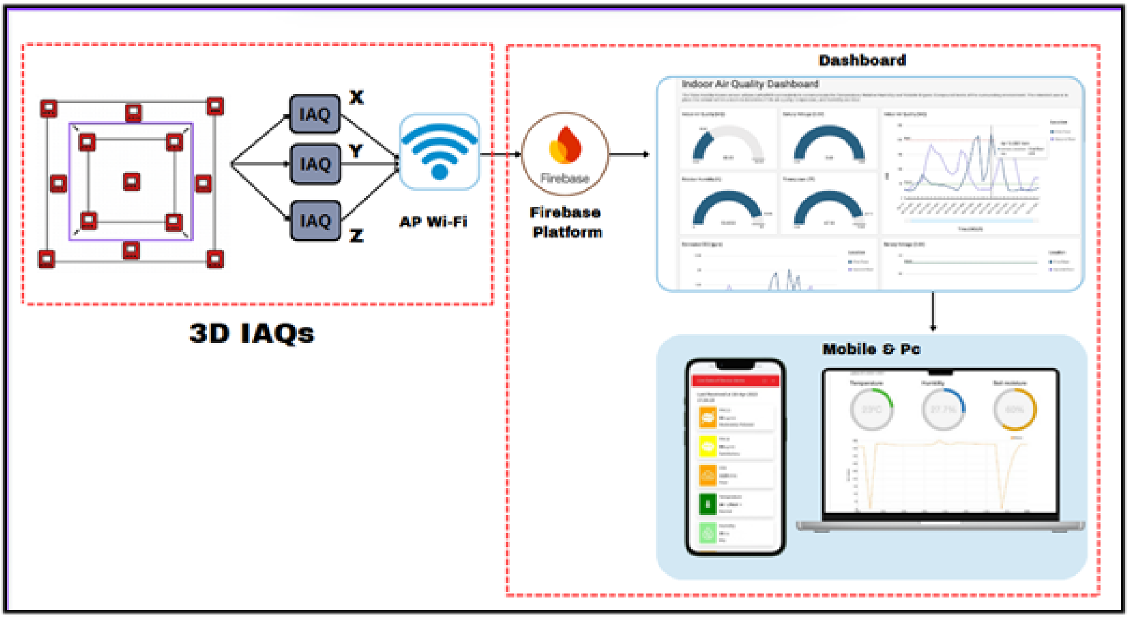

Fig.1 *System Architecture 3D IAQs*

1.2 System IoT Flowchart

The IoT monitoring system operational logic is illustrated in Fig.2 This is done by starting the M5Stack microcontroller and instantiating the environmental sensors, and connecting it to the Firebase cloud via Wi-Fi. The system is constantly accessing sensor data and comparing it to safety limits; unsafe data will result in instant visual warning on the dashboard, whereas safe data would be recorded to Google sheets to analyze the history. This loop of continuous detection ensures that there is always safety of the environment till the system is switched off manually.

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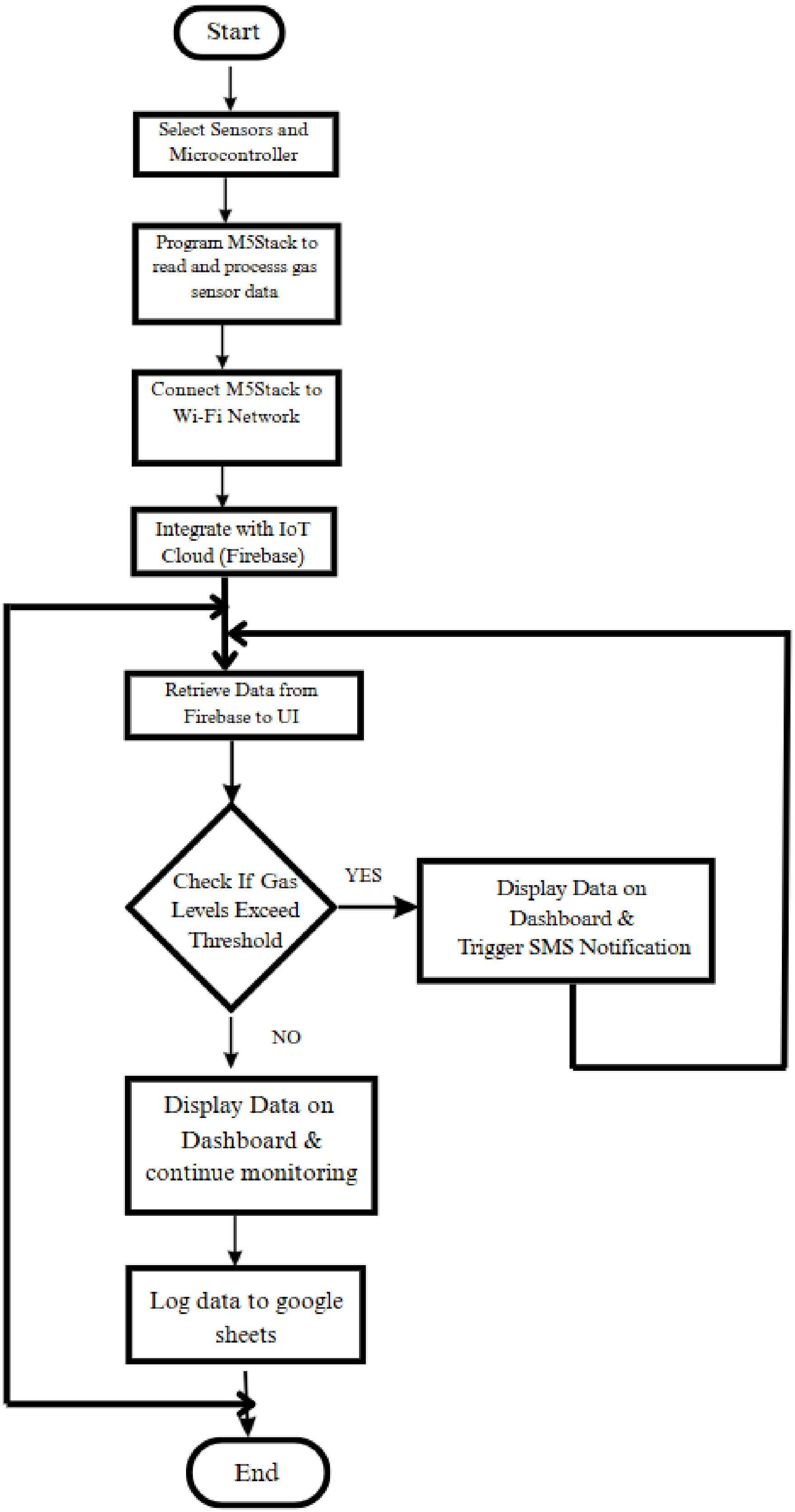

Fig. 2 *System IoT Flowchart*

1.3 Hardware and Firmware Implementation

The hardware infrastructure is developed based on M5Stack microcontroller, which was chosen due to its in-built Wi-Fi and an onboard display useful in debugging. This central unit connects to a multi-node array of environmental sensors that measure the parameters of TVOC, eCO2, CO and NH3 which are placed in strategic locations to facilitate the 3D spatial localization. These sensor modules transmit data that is tagged with a particular spatial location to the Firebase Realtime Database instead of just one reading. This arrangement will enable the system to produce a volumetric 3D map on the dashboard so users can also locate particular areas of contamination in a room as opposed to using an average. The implementation of these components is visualized in Figure 3. Figure 3(a) shows the configured M5Stack units displaying real-time gas readings on their onboard screens, confirming successful sensor integration. Meanwhile, Figure 3(b) illustrates the firmware logic developed using the UI Flow interface, which is responsible for processing the sensor data and transmitting it wirelessly to the Firebase cloud for storage.

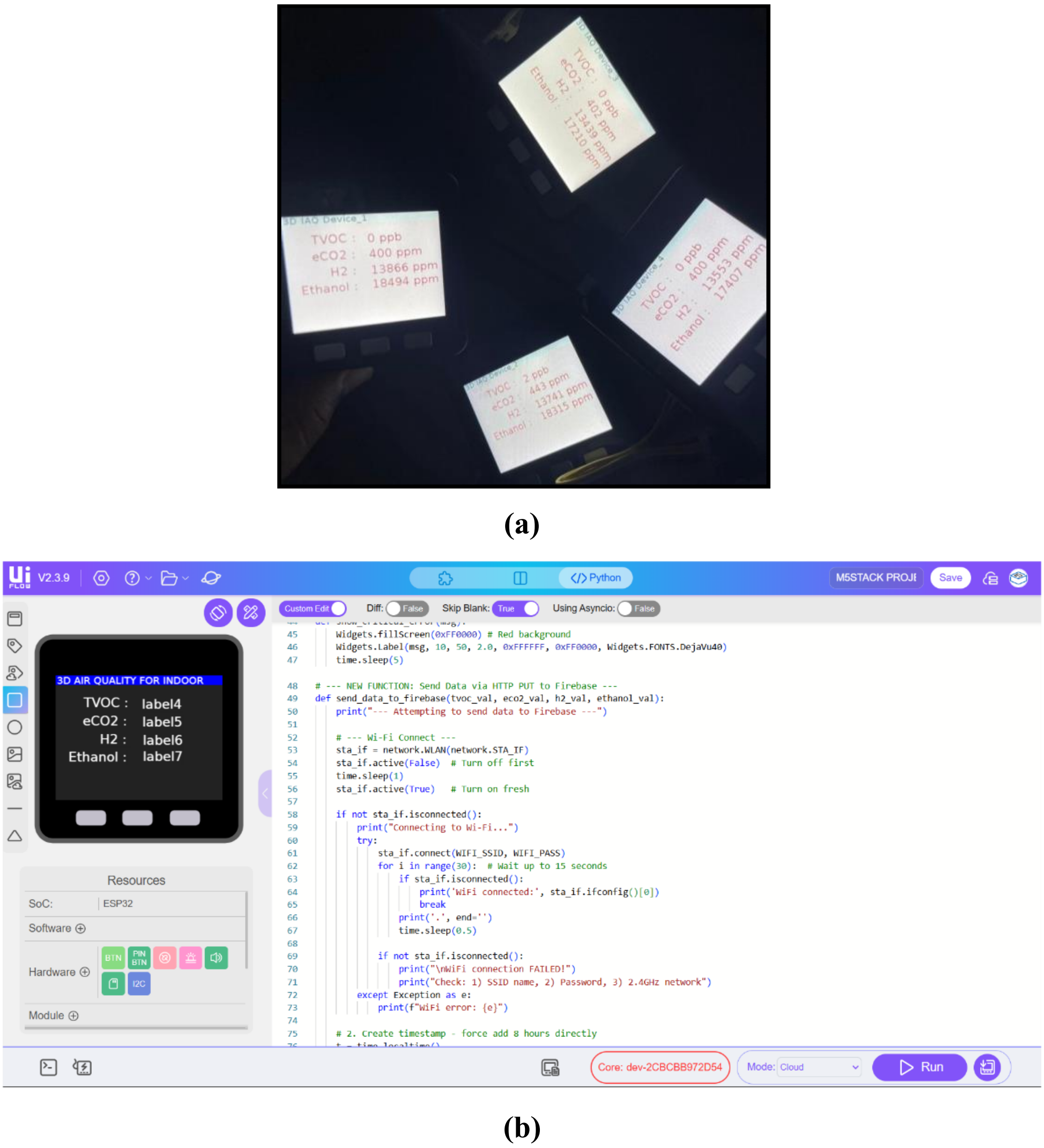

Fig. 3 *(a) Configured M5Stack Core display; (b) UI Flow logic to send sensor data to Firebase*

1.4 Dashboard Development

The development of the interface prioritized low latency and accessibility by utilizing a serverless architecture to minimize maintenance overhead. To achieve a backend integration, the system utilizes Google Firebase as a Backend-as-a-Service (BaaS) with sensor telemetry being saved in a JSON tree data format so that it can be synchronized in real time across all the connected devices without manually refresh individual web pages. The dashboard was built on the frontend with standard HTML5, CSS3 and JavaScript and applied the principles of the Responsive Web Design (RWD) model so that the most important visualization items such as the "Spatial Mini-Map" can be automatically resized to fit a mobile-screen or desktop-screen display. More so, AI-assisted tools were added to the development lifecycle to speed up the development, Claude was used to optimize Python connectivity logic on the M5Stack, and Google AI Studio helped to develop the CSS layout in a few hours, to ensure a modern and high-contrast user experience. The resulting interface, utilizing these AI-assisted design principles, is shown in Figure 4. It demonstrates the high-contrast control system layout where real-time telemetry from multiple devices is aggregated alongside the 3D spatial mini-map, ensuring a streamlined user experience for monitoring complex environmental data

Fig. 4 *Dashboard development with AI-assisted tools.*

The dashboard layout was designed based on effective visualization patterns suggested by Bach et al. [10] to ensure user clarity. Furthermore, the integration of AI for dynamic dashboard optimization follows the approach discussed by Ramdani et al. [9]and aligns with the data visualization strategies proposed by Pappas and Whitman [11] to ensure user clarity. The interface also adheres to principles of performance dashboards to maximize productive monitoring [12].

3. Result

Routine monitoring and hazard detection AIRVIS 3D dashboard is also to be able to implement fast decisions due to high contrast dark mode interface that reduces eye fatigue. In order to simplify the process of monitoring the routine, the layout is split into three areas of command; the hardware terminals panel in the left-hand corner shows real-time telemetry of all the current nodes, and the network average panel in the upper-right corner gives an immediate overview of the air quality of the room with a semantic cyan color map to indicate the ideal state. When the emergency situation occurs, the system switches to active hazard monitoring involving use of a volumetric hazard visualization through the use of Spatial Mini-Map. This allows visual representation of gas leaks in 3D space, unlike the traditional text-based warnings, when a threshold is exceeded the respective node on the wireframe cube pulses red to draw attention and the relevant hardware card also indicates the metric violated, so that the operators can immediately identify the source and severity of the threat. As demonstrated in Figure 5, the dashboard visualizes a critical event where 'Device 2' triggers a red alert, indicating that gas levels have exceeded the safety threshold in that specific zone.

Fig. 5 *Gas Leak Detection and visual alert*

To enhance management efficiency, the system adopts a Single-Page Application (SPA) architecture with a "Centralized Command Layout," eliminating the need for complex dropdown menus. This layout does not require the use of complicated dropdown lists where the user can see the information of all four cardinal zones (Front, Right, Back, Left) at the same time using the combined hardware list and real-time telemetry plots as demonstrated in Figure 6,

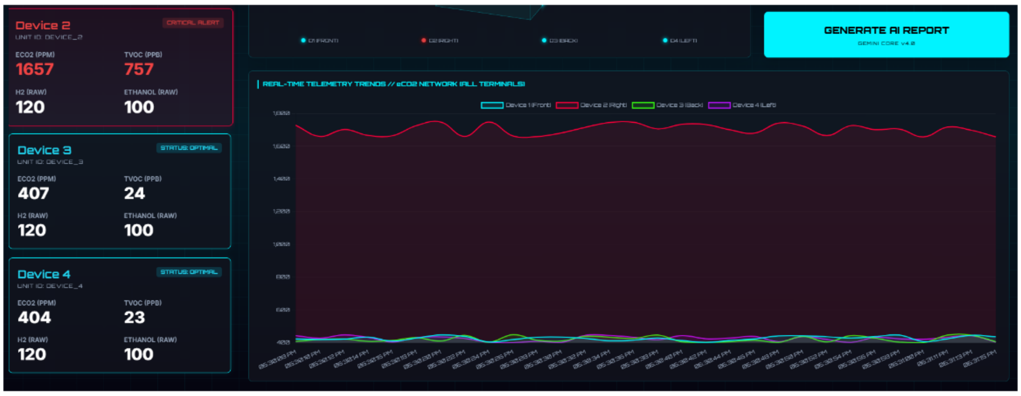

Fig. 6 *Centralized Command Layout for simultaneous multi-zone monitoring*

In order to maintain the credibility of this visualized information, strict data integrity test was conducted by comparing the values in the dashboard and the live backend stream. As verified in Figure 7, the eCO2 readings displayed on the frontend interface perfectly match the real-time data in the Firebase Realtime Database, confirming that the system provides 100% accurate, low-latency environmental updates essential for critical safety management. The system successfully detected gas leaks in real-time. This aligns with findings by Theodore et al. [13], who emphasized the importance of wireless sensor networks in locating leaks efficiently.

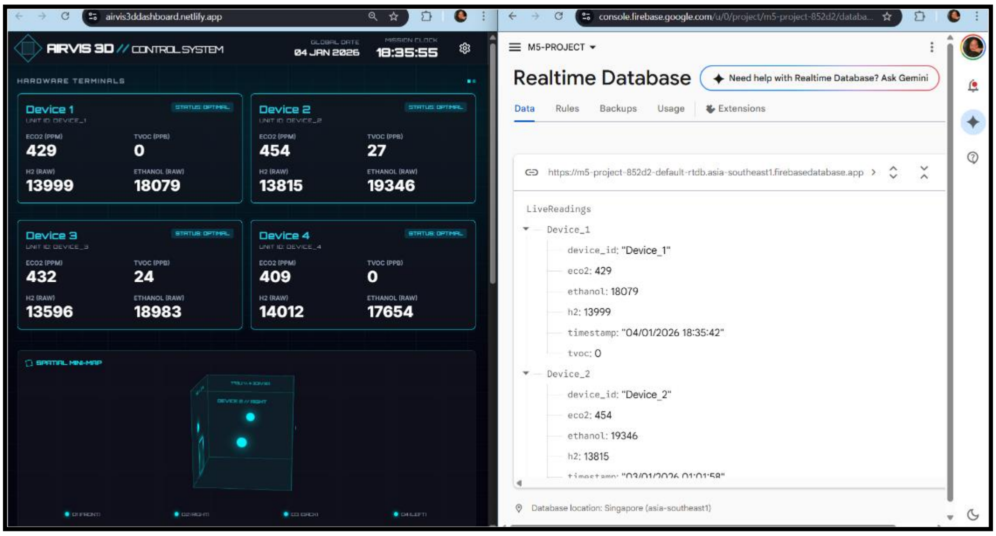

Fig. 7 *Data integrity check: Dashboard vs. Firebase.*

The system's utility extends beyond the control room through Responsive Web Design (RWD), which automatically adapts the interface layout for mobile devices. As shown in Figure 4.5, the dashboard stacks critical data cards vertically for smartphone screens, ensuring safety officers maintain full situational awareness from any location.

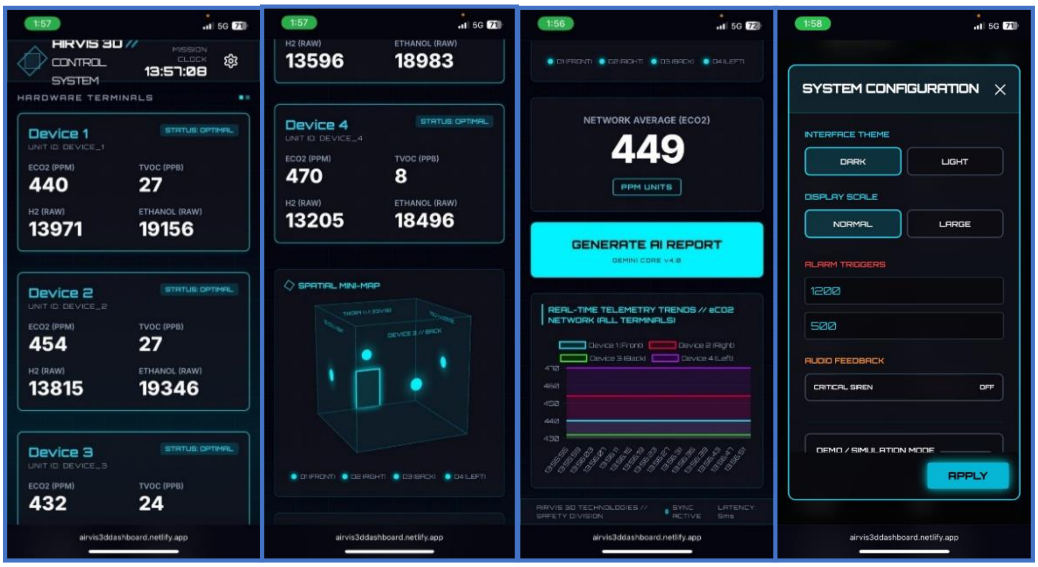

Fig.8 *Mobile Interface for remote monitoring*

The system ensures temporal accuracy via a mission clock to verify connectivity as shown in Figure 9(a) and integrates augmented analytics using the Gemini Core v4.0 AI module. This advanced feature synthesizes complex multi-variable data into concise natural language reports, significantly reducing the time required for operators to interpret trends and actionable safety insights as shown in Figure 9(b).

(a)

(b)

Fig.9 (a) *Date and Time display on dashboard (b) Gemini AI Report Modul*

4. Conclusion

The development of the Smart IAQ Monitoring System successfully addressesthe fundamental constraint of conventional 2D environmental sensing through the provision of a volumetric method of gas leak detection. The system was built upon the M5Stack microcontroller to provide a powerful, low-latency architecture that can synchronize real-time telemetry over multi-zone sensor arrays by connecting it to a serverless Firebase backend. The functional analysis established the effectiveness of the AIRVIS 3D dashboard, which not only allows visualizing the invisible hazards by the responsive virtual mini-map of the spatial map but also improves decisions based on the Gemini Core v4.0 AI reporting module. In sum, this project shows a significant potential of spatial IoT information combined with generative AI analytics to enhance hazard response more quickly and accurately in the indoor settings. The future development will be aimed at the introduction of the machine learning algorithms of predictive maintenance and larger-scale deployment of the sensor network.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for the support.

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