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Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection

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Abstract

The "Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection" thesis presents a comprehensive study on the development and implementation of an autonomous unmaned aerial system equipped with gas and smoke sensors for industrial safety and environmental monitoring. The project aims to address the limitations of traditional fixed sensors in providing comprehensive coverage of industrial facilities, particularly in detecting hazardous gas and smoke releases. The study encompasses a detailed exploration of the system's design, integration of hardware and software components, and the utilization of IoT principles for real-time monitoring using blynk platform and transmit the gas sensing data for the results. The manuscript provides insights into the transformative journey of developing an innovative Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection, highlighting the project's objectives, methodologies, and the seamless coordination between hardware components and data communication protocols.

1. INTRODUCTION

Industrial facilities face significant safety risks from hazardous gas and smoke releases. Traditional fixed sensors, while useful, often fail to provide complete coverage, leading to potential safety blind spots. This study introduces unmanned aerial vehicle (drone) equipped with advanced sensors as a solution [1]. Hazardous gas and smoke in industrial environments, resulting from processes like chemical reactions or equipment malfunctions, pose a severe risk to worker safety and environmental health. Despite their utility, fixed sensors have limitations in detecting these hazards across entire factory floors [2].

Research proposes using drones to overcome the limitations of fixed sensors. These drones can efficiently navigate and monitor the entire factory floor, providing real-time data and covering areas inaccessible to fixed sensors. The project's core goal is to enhance industrial safety through the development of an Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection (IFMS-DHGSD). This system aims to provide comprehensive monitoring, using sensors such as the MQ-2 for accurate hazard detection, and integrating with platforms like Blynk for data analysis [3]-[5].

2. PREVIOUS RESEARCH FOR DRONE WITH HAZARDOUS GAS AND SMOKE DETECTION

The "Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection" thesis addresses the critical need for enhanced safety measures in industrial environments. Traditional fixed sensors often fall short in providing comprehensive coverage, leading to potential safety risks. To overcome these challenges, the project focuses on the development of an innovative autonomous drone system equipped with gas and smoke sensors. The manuscript outlines the project's background, problem statement, objectives, and the scope and limitations, providing a comprehensive overview of the research's significance and potential impact on industrial safety practices.

The use of drones in industrial safety, highlighting their flexibility and advanced technology for hazardous gas detection. Key advancements in sensor and image processing technology are noted, such as those seen in the Autonomous Valet Parking Drone [6]. The real-time capabilities of these drones, similar to IoT-based systems [7], are emphasized for their rapid response and data transmission. This research, including a comparative study , showcases the evolving role of drones in enhancing industrial safety practices, particularly in the context of the Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection project.

2.1 Comparing Approaches to Drone-Based Hazardous Gas and Smoke Detection

The ever-present threat of hazardous gases and smoke necessitates efficient detection systems. In the realm of drone-based solutions, researchers have explored various approaches, each with its own strengths and limitations. The system utilizing readily available sensors like MQ-2 and KY-026 for real-time monitoring of indoor spaces [8]. This method offers the advantages of early warning through LED and voice alerts but relies on internet connectivity and incurs setup and maintenance costs. In contrast, The TinyML technology, leverage the enabling autonomous and secure devices for localized data processing [9]. This approach boasts low cost, low power consumption, and enhanced security, but faces limitations in algorithm complexity and model training for specific gases like ammonia. Next, the present of a swarm of UAVs equipped with gas sensors for industrial air pollution monitoring [10]. While this method excels in accessing hard-to-reach areas and minimizing human risk, it is hampered by sensor accuracy limitations compared to professional equipment, potential privacy concerns in urban environments, and vulnerability to communication attacks.

Several proposed methods exist for gas detection, each with its own advantages and disadvantages. The utilizing drone-based gas detection systems for real-time monitoring, offering cost-effectiveness and wireless data transmission but requiring height control equipment and sensor calibration [11]. Then, the integrating wireless sensor networks with UAVs for remote data collection and 3D mapping, achieving cost-effectiveness but facing complex subsystem integration [12]. Next, others article proposes a gas monitoring and power cut-off system for underground mines, providing a faster response and safety features but requiring a power supply and manual reset [13]. An IoT-based low-cost gas detection system, emphasizing affordability and user-friendliness but limited by range and prototype limitations [14]. Finally, the developing of a UAV-mounted multisensor platform for versatile gas monitoring, enabling multi-gas measurement but introducing payload weight and connectivity challenges [15].

2.2 Hardware and Software Details

A comprehensive overview of technologies and components relevant to the domains of drone technology and the Internet of Things (IoT) [16]. An educational kit featuring a programmable quadcopter equipped with a COEX Pix flight controller and a Raspberry Pi 4 as an onboard computer is described [16]. This kit is designed to offer an immersive learning experience, emphasizing hands-on exploration in the field of drone technology. It also includes a camera module for computer vision applications and various sensors and peripherals. The role of radio remote controls in manual flight control and emergency interventions is highlighted [16]. These controls ensure that human operators can override autonomous behaviors when necessary. The significance of manual flight modes is outlined, as they determine radio controller stick assignments and other flight characteristics. The development of autonomous drone technology is elaborated upon, underscoring its versatility in executing pre-programmed flight plans, navigating through obstacles, and making real-time decisions based on sensor data [17].

The applications of autonomous drones across fields such as aerial mapping, surveillance, and agriculture are emphasized. The use of ArUco markers as visual landmarks for drone navigation is introduced [16]. These markers are strategically placed on the ground or objects and are captured by the drone's camera. Computer vision algorithms then analyze them to determine the drone's position and orientation. In the context of electricity generation, transmission, and distribution monitoring, the applications of the Internet of Things (IoT) are discussed [18]. IoT systems enable real-time monitoring and optimization of distribution components, contributing to reduced operating costs and decreased dependence on fossil fuels.

The capabilities of the Raspberry Pi 4 single-board computer are highlighted, including its quad-core Cortex-A72 processor, ample memory options, and various connectivity features [19]. These features make it a versatile platform for diverse computing projects. The ESP8266 single-board microcontroller is introduced [20], characterized by its compact design and integrated Wi-Fi module. It is particularly well-suited for IoT applications and offers efficient performance with low-power consumption. Lastly, the MQ-2 gas sensor module's sensitivity to a range of gases, including methane, butane, propane, alcohol, and smoke, is discussed [21]. This sensor operates on the principle of a tin dioxide (SnO2) semiconductor, making it suitable for detecting gas leaks, fire hazards, and smoke in industrial floor monitoring systems and drone-based applications. Table 1 shows the software used in this development project.

Table 1 *List of Hardware*

No.	Component	Description
1.	Drone base COEX Clover	is Open-source UAV for learning drone technology and robotics. Supports programming languages and ROS, ideal for education, research and hobbyists.
2.	Raspberry Pi 4	Affordable single-board computer for education and hobbies. Powerful processor, various RAM options, runs Raspberry Pi OS, connects with USB, HDMI, and GPIO pins. Versatile for programming, home automation, and media centers.
3.	ESP8266	Low-cost Wi-Fi microchip for IoT projects. Compact size, full TCP/IP stack, microcontroller capability. Popular for Wi-Fi applications in hobby and education.
4.	The MQ-2 sensors	Detects LPG, propane, methane, hydrogen, and smoke. High sensitivity, fast response, low power consumption. Ideal for safety applications like gas leak detection.

3. MATERIALS AND METHODS

3.1 IFMS-DHGSD System flowchart

The operational flow of the Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection (IFMS-DHGSD) is outlined in Fig. 1, Fig. 2, and Fig. 3. The drone's autonomous mobility and hazardous gas detection are depicted in Fig. 1 and Fig. 2, where all sensors initialize upon startup, entering real-time monitoring mode. The gas and smoke sensors, highlighted in Fig. 3, play a crucial role in detecting harmful substances along the drone's path.

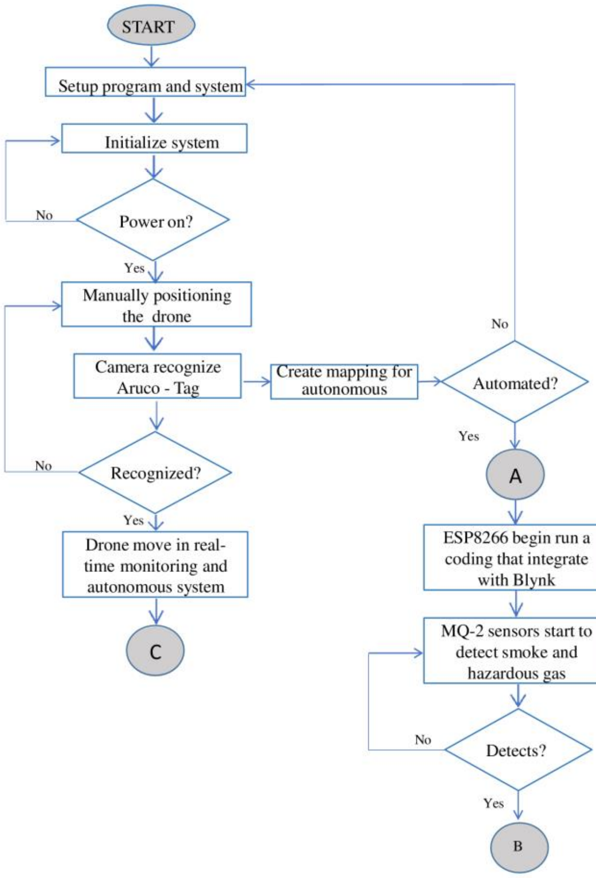

Fig. 1 First part of the IFMS-DHGSD System flowchart

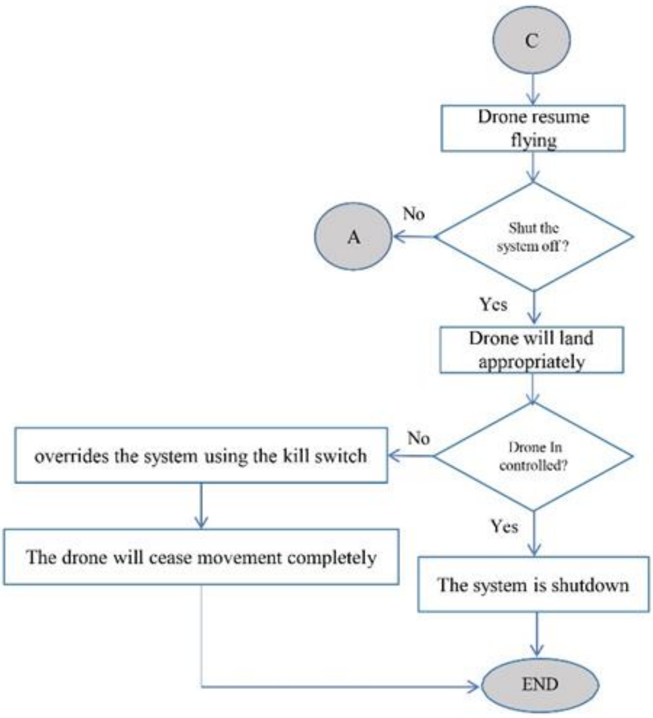

Fig. 2 First part of the IFMS-DHGSD System flowchart

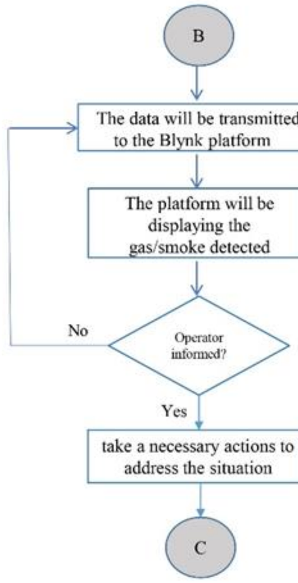

Fig. 3 Third part of the IFMS-DHGSD System flowchart

3.2 IFMS-DHGSD Block Diagram

The simplified project block diagram for the Industrial Floor Monitoring System Drone with Hazardous Gas and Smoke Detection (IFMS-DHGSD) has illustrated in Fig. 4 is. The primary control unit integrates a Raspberry Pi and PIXRACER PCU for autonomous drone functionality and manual control, powered by a LiPo 4S battery. The main input sensor, the MQ-2, specializes in detecting hazardous gases and smoke, ensuring industrial safety. An external ESP8266 microcontroller enhances capabilities, interfacing with the MQ-2 sensor. This setup provides crucial data for monitoring the factory floor, with seamless communication and control facilitated by the Raspberry Pi connecting to both the flight controller and ESP8266. The system further interfaces with the Blynk platform for real-time data monitoring and analysis, offering stakeholders immediate insights for decision-making.

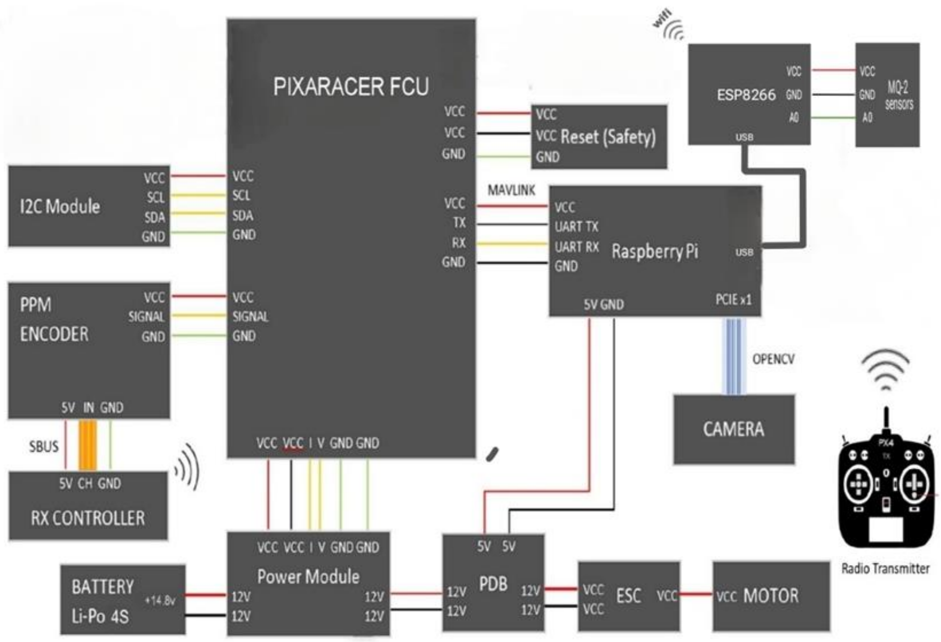

Fig. 4 IFMS-DHGSD System Block Diagram

3.3 Hardware Development

3.3.1 Casing Design and 3D Printing

A custom 3D-printed casing was designed using Autodesk Inventor software to house the system's key components: MQ-2 sensors, cooling fans for gas absorption, and the esp8266 microcontroller. The box-shaped design features optimized space and easy attachment to a drone (see Fig. 5 for the 3D design and 3D-printed casing). The design was then transformed into a physical reality using an Ender V3 3D printer. The layer-by-layer printing process ensured precise reproduction of the intricate details, resulting in a highly durable and accurate casing. The lid features strategically placed openings for optimal airflow and fan placement, while dedicated compartments provide secure housing for the sensors and microcontroller.

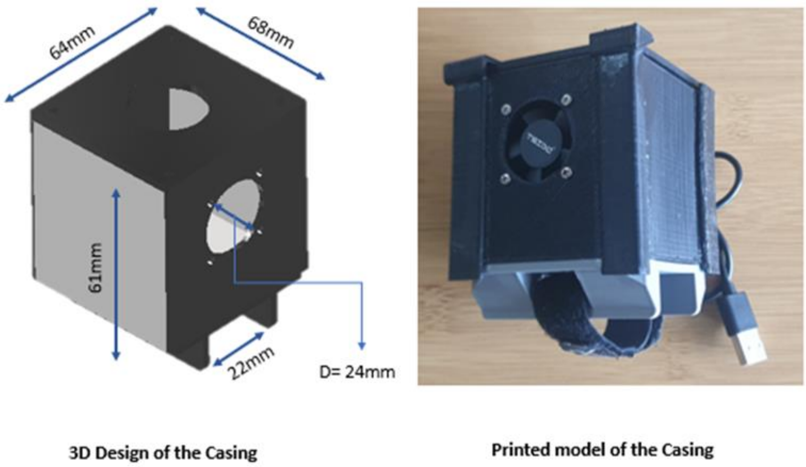

Fig. 5 3D design and the printed model with component

3.3.2 Controller Interfacing and Circuit Testing

The system's hardware circuit involves an ESP8266 microcontroller, an MQ-2 gas sensor, and a ventilation fan. The ESP8266 is programmed to connect to Wi-Fi and the Blynk platform, enabling real-time gas level monitoring and fan control through the Blynk app. The sensor's analog output is connected to pin A0, while the fan is connected to pin D2 (see Fig. 6 for circuit testing setup). Testing involves powering up the circuit and monitoring sensor readings in the Blynk app. Fan control is tested through a designated button. A simulated gas leakage scenario, conducted with safety precautions, verifies sensor threshold activation, fan triggering, and logging of the event on Blynk. This testing ensures seamless integration of components for effective gas detection and responsive control.

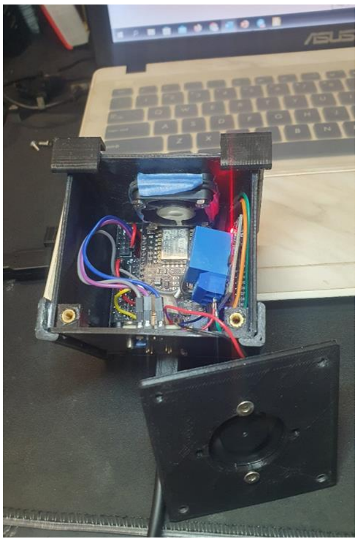

Fig. 6 Hardware circuit testing

3.3.3 Sensor Testing and Calibration

The system's core component is the MQ-2 gas sensor, connected to the ESP8266 microcontroller via VCC, GND, and A0 pins. This configuration allows the ESP8266 to read analog values, which reflect the presence of hazardous gases in the environment. Testing involved uploading code to the ESP8266 and monitoring readings in the Arduino Serial Monitor. Variations in these readings, confirmed through controlled tests with simulated gas sources (conducted with safety precautions), established the sensor's responsiveness. A gas detection threshold, triggering actions like fan activation, was defined based on readings in a clean environment. Integration with the Blynk app provided real-time sensor data through a gauge widget, ensuring accessible monitoring and confirming the system's effectiveness.

3.3.4 Integrating with the Autonomous Drone

The Coex Clover drone, detailed in Table 2, serves as the aerial platform for our gas sensing system. Equipped with features like a PX4 flight stack, Raspberry Pi computer, and comprehensive sensor suite, it provides a robust base for autonomous operations. We meticulously integrated the gas sensing system, ensuring stability and minimal flight impact. The MQ-2 sensor and ESP8266 microcontroller were securely attached to the drone's top using sturdy tape, maintaining a lightweight configuration for optimal aerodynamics (Fig. 7). A USB cable seamlessly connected the ESP8266 to the Raspberry Pi, enabling synchronized power-up and smooth communication. Troubleshooting was crucial. We tested every component, scrutinized Pi-ESP8266-Blynk interactions, and identified potential bottlenecks. Configurations and settings were adjusted to optimize performance, ensuring effective data transmission and reliable gas detection. Python and block-based coding unlocked the drone's autonomous capabilities. We calibrated the system using ArUco markers, fine-tuning parameters and refining program logic for precise navigation based on the mapped environment. This seamless integration of the gas sensing system with the autonomous drone fosters a powerful synergy between safety monitoring and drone autonomy.

Table 2 *COEX Clover specification*

No.	Features	Specification
1.	Flight Controller	COEX Pix with PX4 flight stack
2.	Onboard Computer	Raspberry Pi 4
3.	Camera Module	Included for computer vision applications
4.	Sensors and Peripherals	Various sensors and peripherals included
5.	Educational Focus	Comprehensive educational kit for drone learning
6.	Raspberry Pi Image	Pre-configured image with necessary software
7.	Autonomous Capabilities	Supports programming of autonomous flights

Table 2 *continue*

No.	Features	Specification
8.	Radio Remote Control	Included for manual control and emergencies
9.	Telemetry and Command	Advanced autonomous systems may use radio communication for telemetry and commands

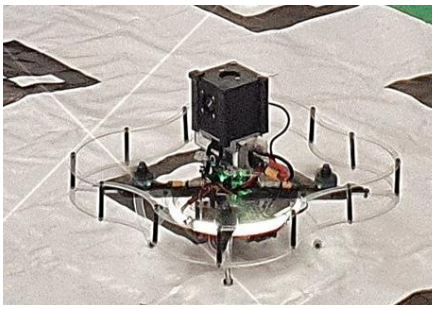

Fig. 7 Integrating hazardous gas sensing with COEX Clover

4. RESULTS AND DISCUSSION

Our integration of the hazardous gas detection system with the Coex Clover drone opens exciting possibilities for enhanced industrial safety and proactive risk management. This section delves into the key observations, data analysis, and insights gleaned from our comprehensive testing and evaluation.

4.1 Seamless Integration and Robust Hardware:

The COEX educational kit proved to be an ideal platform for seamless integration, thanks to its powerful COEX Pix flight controller and Raspberry Pi onboard computer. The strategically placed MQ-2 gas sensor, powered by an ESP8266 microcontroller, effectively detects hazardous gases in diverse scenarios (Fig. 8). We constructed a custom 3D-printed housing (Table 3: 170g) that not only protects sensitive components but also incorporates cooling fans for efficient gas absorption and simplifies attachment to the drone.

Table 3 *COEX Clover specification*

Components	Number of quantity	Mass of one quantity (gram)	Total mass (gram)
Hazardous gas sensing systems with casing	1	170g	170g
Frame	1	282g	282g
Motor	4	38g	152g
Battery	1	200g	200g
ESC	4	23g	92g
Flight controller	1	38g	38g
Raspberry Pi	1	46g	46g
Propeller	4	15g	60g
Total mass			1040g

Fig. 8 Actual Hardware of IFMS-DHGSD

4.2 Real-time Data Monitoring and Control:

Blynk emerged as a critical link in providing real-time data monitoring and control. The combined power of the ESP8266 and MQ-2 sensor delivered accurate gas concentration readings, while Blynk's user-friendly interface offered stakeholders immediate e insights and actionable data visualization. Autonomous capabilities, leveraging ArUco markers for navigation, empowered the drone to execute complex tasks in dynamic environments with precision (Fig. 9).

Fig. 9 Autonomous flight for the drone operation testing

4.3 Rigorous Testing and Optimization:

We meticulously tested and optimized every aspect of the system to ensure reliability and efficacy. From securing the gas sensor to addressing connectivity issues between the ESP8266 and Raspberry Pi, each step was scrutinized to iron out potential challenges. The successful deployment of the autonomous capabilities using Python in diverse operational scenarios underscores the system's resilience and adaptability. Fig. 10 showcases the actual hardware of the gas sensing box, highlighting the meticulous integration of components.

Fig. 10 Actual hardware of Hazardous gas sensing box

4.4 Blynk: Empowering Proactive Safety Management:

The Blynk app plays a crucial role in proactive safety management. Its user-friendly interface features a prominent gas concentration gauge for immediate insights and a dedicated button for manual control of the fan [Fig. 11 (a)]. Users can access real-time gas data from anywhere via mobile and web dashboards [Fig. 11 (b), (c)], enabling them to monitor environments remotely and respond swiftly to potential hazards.

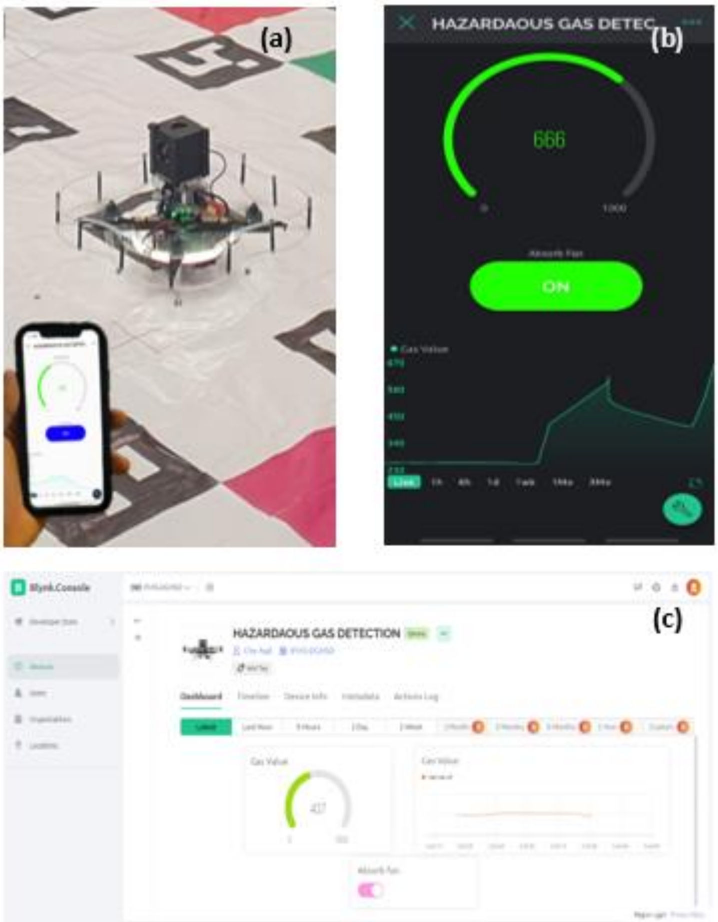

Fig. 11 (a) Blynk application interface on a mobile phone, (b) Blynk mobile dashboard, (c) Blynk web dashboard

4.5 Knowledge Application and Potential Future Directions:

The success of this project opens doors to exciting future directions. One potential avenue is the integration of additional sensors for broader gas detection capabilities, encompassing not just hazardous industrial gases but also environmental pollutants or agricultural monitoring parameters. Additionally, optimization of drone maneuverability and the incorporation of advanced AI algorithms could offer more sophisticated gas plume tracking and real-time threat assessment. In terms of real-world applications, beyond industrial settings, this technology holds immense promise in environmental monitoring, emergency response scenarios, and even search and rescue operations.

Comparisons and Competitive Advantages: Compared to existing gas detection systems, our approach offers several key advantages. The drone-based platform provides aerial mobility and access to areas difficult to reach with traditional ground-based systems. Our system's cost-effectiveness, utilizing open-source software and readily available components, makes it accessible to a wider range of users. Furthermore, the emphasis on real-time data visualization and remote monitoring fosters proactive safety management and rapid response capabilities.

Safety and Ethical Considerations: It is paramount to acknowledge the potential limitations and safety considerations associated with this technology. Environmental factors like wind and humidity can impact sensor accuracy. Autonomous flight capabilities require careful planning and risk mitigation strategies. Data security and privacy concerns must be addressed through robust encryption and responsible data management practices. Ultimately, ethical considerations remain at the forefront, ensuring this technology is used for the benefit of human safety and environmental well-being.

5. Conclusion

Our project successfully integrated a hazardous gas sensing system with an autonomous drone, significantly enhancing industrial safety and environmental monitoring. The COEX Clover platform, equipped with cutting-edge sensors and real-time Blynk control, effectively detects gas leaks, safeguards workspaces, and unlocks novel drone applications in the burgeoning realm of IoT-integrated aerial technology. This project leaps forward in industrial safety and beyond, seamlessly integrating a hazardous gas sensing system with an autonomous drone on the COEX Clover platform. Transcending mere gas detection, it offers a robust tool for proactive risk management, paving the way for a safer, more efficient future. The intricate symphony of hardware and software empowers real-time gas monitoring and remote management through Blynk. The drone's autonomous reach, bolstered by ArUco markers, tackles vast, hazardous spaces, surpassing traditional limitations. Rigorous testing solidifies the system's adaptability and resilience across diverse environments. Moreover, this project illuminates the vast potential of IoT-enabled drones, laying the groundwork for future innovations and diverse applications in this budding field. Beyond gas detection, it paves the way for a safer, more responsive future across countless industries, standing as a testament to collaborative engineering and technological innovation.

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