Parametric Study of Drone-based Gas Pollution Monitoring System Integrating Internet of Things Technology

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ABSTRACT

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| **Gas pollution is predominant in the area of Niger Delta, Nigeria due to large volume of oil and gas exploration and their related activities. The environment is often affected by flared gases, which are harmful to humans, aquatic life in the ocean, animals and the natural environment. This study presents a novel approach for monitoring air pollution with drone and Internet of Things (IoT) technology. The design utilizes electrochemical sensors for detection of hazardous gases and ESP8266 module for real time data transmission and cloud-based data presentation. The system facilitates sustainable environmental studies by providing access to areas that are hard or unsafe to reach, anytime. The research locations were Okoromboko and Okoroutip communities in the Eastern Obolo Local Government Area of Akwa Ibom State, Nigeria. The results show affordable method for measurement of air quality in real time, especially in the challenging areas that are affected by oil and gas exploration, production and refining processes, such as Niger Delta region of Nigeria. The study demonstrates feasibility of harnessing drone and IOT for real-time environmental monitoring aimed at equipping researchers and policy makers with data to protect human lives, public health and sustainable development. While minor limitations were observed, such as restricted flight duration and short range of Wi-Fi connectivity, these challenges can be addressed in future study through advancement in battery technology, consideration of long-range communication protocols and application of machine learning technology.** |

***Keywords****: Drone, gas sensor, IoT monitoring, pollution detection, wireless communication.*

1. INTRODUCTION

Air pollution, due to its detrimental impacts on the environment, economy, and human health, has emerged as a significant global challenge [1][2]. The World Health Organisation (WHO) defines air pollution as a process when any chemical, physical or biological substance modifies the basic characteristics of the atmosphere and contaminates its interior or exterior surroundings [3][4]. Reduced air pollution is a critical component of promoting long-term development. One of the worldwide and localised challenges is air pollution, mostly caused by energy generation and use [5]. Air pollutants, therefore, can be classified into biological and air toxic pollutants, where carbon monoxide, carbon dioxide, ozone, nitrogen dioxide and sulfur dioxide are involved in this process [6][7]. Gas pollution is predominant in the area of Niger Delta, Nigeria due to large volume of oil and gas exploration and their related activities. The environment is often affected by flared gases, which are harmful to humans, aquatic life in the ocean, animals and the natural environment. The effect of this gas exploration on the ecosystem often led to the extinction of aquatic life and hampered economic growth. Waste dumps, gas flaring, and food processing units are sources of ammonia, hydrogen sulfide, carbon monoxide, sulfur dioxide, nitrogen dioxide, volatile organic compounds, and particulates released into the atmosphere [8]. Gas flaring and its activities are discussed in the studies [9][10], and the attendant impacts are well documented. Natural environment and air pollution are of great concern to life and activities of people, plants and animals. Accordingly, [11][12][13] studies revealed that the immediate surroundings in which oil exploration facilities operate can be toxic. The toxic nature of this area shows that air, water, land, flora and fauna, human beings, natural resources and the inter-relationship that exists between them are grossly polluted. Our environment determines the well-being and existence, but man’s activities (air pollution) destroy the natural air quality of the environment (ecosystem), directly or indirectly. Air pollution occurs when there is contamination of air quality, that is, when air contains gases, fumes, dust or odour in harmful quantities which can cause damage to the ecosystem [14]. Air pollutants such as carbon monoxide (CO), carbon dioxide (CO2), sulphur, ozone, nitrogen oxides, chlorofluorocarbons and unburned hydrocarbons, volatile organic compounds and other heavy metals are not only toxic but can also cause air pollution. The above highlights and its activities within the Niger Delta region of Nigeria necessitates air pollution study. Gas emissions emanating from welding torches, cutting of metals, welding operations, periodic painting of oil and gas facilities, also contribute to air pollution. Thus, air pollution monitoring is a critical aspect for managing and preserving our natural resources within the Niger Delta region. Traditional methods of gas pollution data collection, such as ground-based surveys and satellite imaging [15][16][17], have limitations in terms of accessibility, resolution and cost. Recent advancements in technology have introduced unmanned aerial vehicles (UAV), commonly known as drones, as a viable and innovative solution to these challenges [18]. Drones offer several advantages, including the ability to cover large areas quickly, provide high-resolution data and access remote or hazardous areas [19][20]. Equipped with various sensors, drones can collect a wide range of data types, including multispectral and hyperspectral imaging, thermal sensing and light detection and ranging. The integration of drones with IoT technology enables real-time wireless communication, data collection, transmission [21][22][23] and analysis; facilitating immediate decision-making and timely interventions in gas pollution management.

Gas pollution poses a severe threat to environmental sustainability and public health, causing respiratory diseases, cardiovascular problems and premature deaths. Traditional gas pollution monitoring systems rely on stationary sensors, which are limited by their fixed locations, high installation costs and inability to provide real-time, dynamic data in hard-to-reach or rapidly changing environments. To address these challenges, this design aims at developing a drone-based gas pollution monitoring system integrated with IoT technology to provide real-time, mobile and high-resolution air quality data. This system enhances gas pollution assessment, improves environmental management, and supports decision-making for mitigating gas pollution's impacts on health and ecosystems. The specific objectives of the study include developing a drone-based system capable of capturing gas pollution data, integrating various sensors to monitor environmental conditions and detect air pollutants (harmful gases) and developing a communication system for real-time data collection and dissemination.

2. RESEARCH material and methodOLOGY

**2.1 Research Design and Location**

The design focused on equipping drones with lightweight, high-precision sensors capable of measuring key air pollutants, including particulate matter, carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide. The system leveraged wireless communication technologies to transmit data to a central server or cloud platform for advanced analysis and visualisation. By combining drone mobility with IoT capabilities, the project aims at delivering a scalable, cost-effective, and flexible solution for air quality monitoring, addressing the growing demand for dynamic pollution assessment and enabling informed environmental management and policymaking decisions. Despite the potential benefits, the work acknowledges certain limitations, including the operational range and flight duration constraints due to battery capacity. In addition, adverse weather conditions affecting drone stability and sensor accuracy, potential interruptions or delays in wireless communication and the initial investment and maintenance costs are addressed. The research locations were Okoromboko and Okoroutip communities in the Eastern Obolo Local Government Area of Akwa Ibom State, Nigeria.

* 1. **Gas Pollution Monitoring Methods and Technologies**

Gas pollution monitoring is a systematic process that involves collecting, analysing and interpreting data from the natural environment to understand gas pollution conditions, track changes over time, and assess the impact of human activities alongside natural phenomena on ecosystems. Effective gas pollution monitoring is crucial for informed decision-making, policy development and sustainable resource management. Gas pollution monitoring serves several purposes, including assessing gas pollution conditions, detecting changes and trends, ensuring compliance with regulations, assessing and managing risks and promoting public awareness and education [24]. Various methods are employed to achieve these objectives, including remote sensing using satellites, drones, and aerial photography to provide large-scale and high-resolution data on land use, vegetation coverage, water bodies, and atmospheric conditions. In situ monitoring involves direct measurement of gas pollution parameters at specific locations using sensors and instruments. Biological monitoring assesses the health and diversity of biological communities to infer ecosystem health. Technologies that facilitate effective gas pollution monitoring include geographic information systems (GIS) for integrating and analysing spatial and temporal data, drones and UAVs equipped with sensors for high-resolution data collection, IoT devices and networks for real-time monitoring [25][26]. Machine learning and big data analytics for identifying patterns and predicting trends [27]. These methods and technologies collectively contribute to a comprehensive understanding of gas pollution conditions, enabling effective management and conservation of natural resources.

* 1. **Traditional Gas Pollution Monitoring Method and Drone-based Monitoring System**

Traditional gas pollution monitoring methods have long been used to gather data concerning various gas pollution parameters, including air and water quality, soil health, and biodiversity. However, these methods present several significant challenges and limitations in today’s rapidly changing gas pollution landscape. Traditional methods are often resource-intensive and costly, requiring substantial financial investments, human labour, and specialised equipment. They also lack the ability to cover large areas efficiently, with stationary sensors providing data from fixed points that may not represent wider gas pollution conditions. Additionally, traditional methods provide data at limited spatial resolution, leading to gaps in data and an incomplete understanding of gas pollution conditions. Furthermore, ground-based surveys and manual data collection are prone to human error, which can affect the accuracy and reliability of the data.

In contrast, drone-based monitoring systems offer several advantages. Drones equipped with advanced autonomous navigation systems can navigate complex environments without human intervention [28]. They can also capture high-resolution imagery and remote sensing data using multispectral, hyperspectral, and LiDAR sensors [29]. The integration of artificial intelligence and machine learning algorithms enables drones to analyse data in real-time and make informed decisions autonomously. Advanced communication technologies, such as 5G networks and satellite communication systems [30][31][32], enable seamless data transmission between drones and ground stations. The advantages of using drones in gas pollution monitoring include flexibility and mobility, cost-effectiveness, rapid deployment, and high-resolution data acquisition. However, drone-based monitoring systems also face several challenges, including regulatory compliance, limited flight endurance, data processing and analysis, and potential environmental impacts [33]. Summarily, traditional gas pollution monitoring methods have significant limitations, and drone-based monitoring systems offer a promising solution. By leveraging advanced technologies, drones can provide high-resolution data, real-time monitoring, and cost-effective solutions for gas pollution monitoring. However, addressing the challenges and limitations of drone-based monitoring systems is crucial for their successful implementation.

* 1. **Drone System Components**

The drone system consists of hardware and software components. The hardware components include DC motors, electronic speed controller, sensors, communication system and frame structure.

**2.4.1 Frame Structure**

The frame design for the drone system is a crucial component of a quadcopter, providing structural support and withstanding significant tensile and compressive forces [34]. As the foundation for all other components, the frame's design determines the configuration and alignment of the motors, as well as the spacing between them, playing a vital role in the drone's overall stability and performance. Frame development for the drone system is presented in Figure 1.

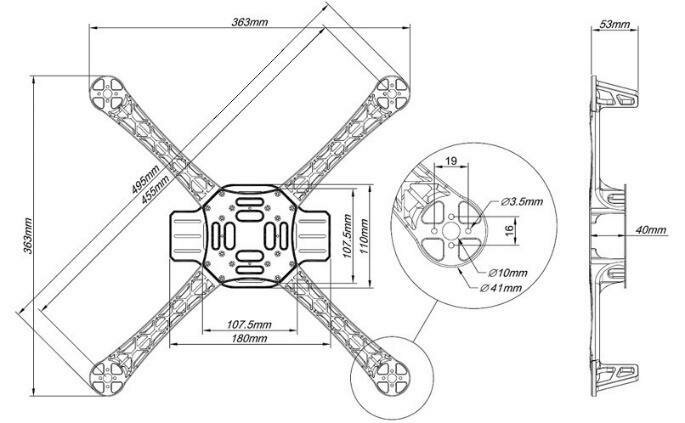


Figure 1: Frame design for drone system.

**2.4.2 Brushless DC Motor**

A brushless DC (BLDC) motor is a synchronous motor that utilises an electronic controller to switch DC currents to the motor windings, generating magnetic fields that rotate in space and cause the rotor to follow [35][36]. BLDC motors are renowned for their high efficiency, excellent controllability and power-saving advantages, making them an ideal choice for various applications. The BLDC motor operates through electronic commutation, eliminating the need for brushes. It consists of a rotor with permanent magnets and a stator with windings. The stator windings are energised in a specific sequence by an electronic controller, creating a rotating magnetic field that interacts with the rotor magnets and causes the rotor to spin. The controller synchronises the energising sequence using feedback from sensors or non-sensor techniques, ensuring smooth and efficient operation. Due to their efficiency and reliability, BLDC motors were selected for this project.

**2.4.3 Electronic Speed Controller (ESC)**

An Electronic Speed Controller (ESC) is a crucial drone component that regulates motor speed by translating flight controller signals into precise electrical pulses [37]. It ensures smooth acceleration, deceleration, and consistent motor operation, managing power delivery from the battery to the motors for efficient propulsion and stable flight. The ESC works by receiving control signals and adjusting power delivery to the motor. It converts DC power [38] from the battery into variable AC voltage for brushless motors, controlling speed by altering the duty cycle. Advanced ESCs feature thermal protection, feedback, active braking, and heat management for enhanced performance. Multiple ESCs are used in quadcopters, one for each motor, to ensure synchronised operation and responsiveness.

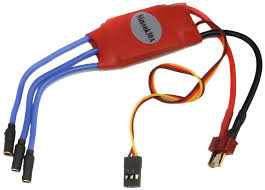


Figure 2: Electronic speed controller.

**2.4.4 GPS Module**

A GPS module is a vital drone component that provides precise location and navigation data, enabling autonomous flight and waypoint navigation [39]. It communicates with satellites to determine the drone's real-time position, altitude, and speed, integrating with the flight controller for path planning and geofencing. The GPS module works by receiving signals from multiple satellites, calculating distances using time delays, and triangulating its precise position using at least four satellites. Advanced GPS modules feature enhanced signal processing and compatibility with multiple satellite systems, improving positioning precision and operational efficiency. This enables accurate and reliable performance in applications like mapping, surveying, and delivery.

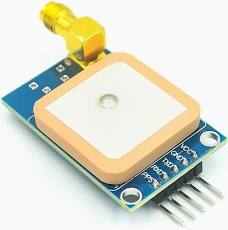


Figure 3:. GPS module.

**2.4.5 RC Controller and Radio Module**

The RC controller and radio module facilitate drone operation, providing a communication link between the pilot and the drone. The RC controller sends commands for movement, altitude adjustment, and other functions through joysticks and switches, which are transmitted via the radio module to the drone's onboard receiver. The radio module ensures a stable and responsive connection, even over long distances, allowing for precise control. Modern systems feature multiple channels, telemetry feedback, and secure communication protocols, enhancing reliability and user control. This setup provides real-time control for drones and other remote devices, enabling precise and responsive operation.

**2.4.6 Wireless Communication Module**

The ESP8266 module is a low-cost, Wi-Fi-enabled microcontroller that enables seamless wireless communication [40] between drones and external devices, such as smartphones or cloud platforms. It facilitates real-time data transmission, remote monitoring, and control, making it ideal for IoT applications in drones. With its low power consumption, built-in TCP/IP stack, and compatibility with various sensors, the ESP8266 enhances drone connectivity and enables advanced functionalities like real-time telemetry and automation. Its versatility and affordability make it a popular choice for drone applications.



Figure 4: ESP8266 communication module.

**2.4.7 Gas Sensors**

MQ-7 and MQ-135 gas sensors are versatile and cost-effective devices that detect various gases, including methane, carbon monoxide, ammonia and hydrogen, by measuring changes in conductivity when exposed to target gases. They are widely used in drones for air quality monitoring and environmental assessment, providing real-time data on pollutant concentrations. MQ sensors are ideal for drone integration due to their lightweight design, high sensitivity, and compatibility with microcontrollers. Applications include industrial emission tracking, hazardous gas detection, and agricultural monitoring, making them suitable for environmental and safety applications.



Figure 5: Gas sensor.

**2.4.8 Software and IOT Cloud System**

Ardupilot mission planner is an open-source ground control software for planning, monitoring, and analysing drone missions. It enables users to create detailed flight paths, configure drone settings, and view real-time telemetry data. Advanced features like autonomous flight, data logging, and fail-safe mechanisms enhance mission reliability, making it a valuable technique for both hobbyists and professionals in aerial mapping, agricultural surveying, and environmental monitoring. Arduino is an open-source microcontroller. It was employed in this study for the development and control of the drone system. Its simplicity and flexibility allow users to program and integrate sensors, motors, and communication modules. Arduino's extensive library support and compatibility with components like GPS modules and ESC make it ideal for prototyping and developing customised drone solutions.

**2.5 Methodology**

The system block diagram illustrates the interconnected subsystems enabling its operation and functionality. Key components include flight controller (manages stability and navigation), power system (battery, ESCs, and voltage regulators), sensors (gyroscopes, accelerometers and GPS), propulsion system (motors and propellers) and communication module for real-time data transmission. These components work together to ensure efficient propulsion, stable flight and reliable communication, as depicted in Figure 6.

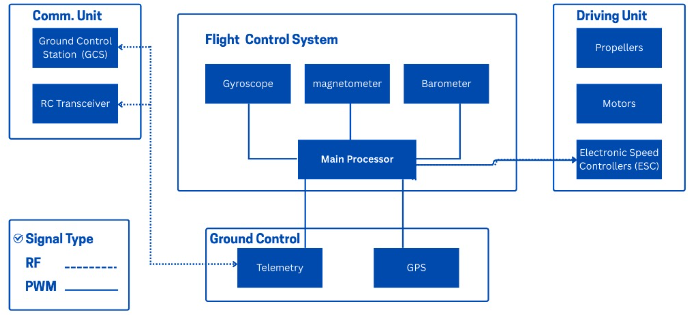


Figure 6: Block diagram of drone system

The system consists of gas sensors for detection, a microcontroller (ESP8288, processes and calibrates data), power supply (LiPo battery and voltage regulators), communication module (ESP8266 Wi-Fi), transmits data to cloud platform and visualisation interface (dashboard) and mobile app, displays real-time pollutant data. These components work together to detect pollutants, process data, and enable remote monitoring and decision-making. The block diagram of the gas sensor and communication system is presented in Figure 7.

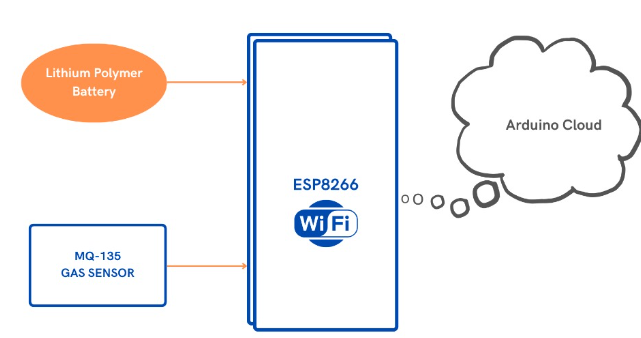


Figure 7: Block diagram of gas sensor and communication system.

The system integrates hardware and software components to function and detect, measure, and transmit air quality data in real-time. Key components include microcontroller (ESP8266), gas sensors (MQ-series), GPS module (tracks location), Wi-Fi module (wireless communication), power supply (7.4V Li-ion battery) and cloud platform (stores and visualises data). The system is programmed using Arduino IDE, and sensor readings are transmitted to the cloud in JSON format. Data is displayed on a dashboard, showing pollutant levels and locations on a map. Sensor calibration was done using reference environments and equations to calculate pollutant concentrations. The microcontroller programming, data transmission and visualisation use Arduino IDE to read sensor data, append GPS coordinates, transmit data via ESP8266 module to the cloud in JSON format using HTTP POST requests, and visualise on a dashboard. Figure 8, shows the gas monitoring sensor integration process.

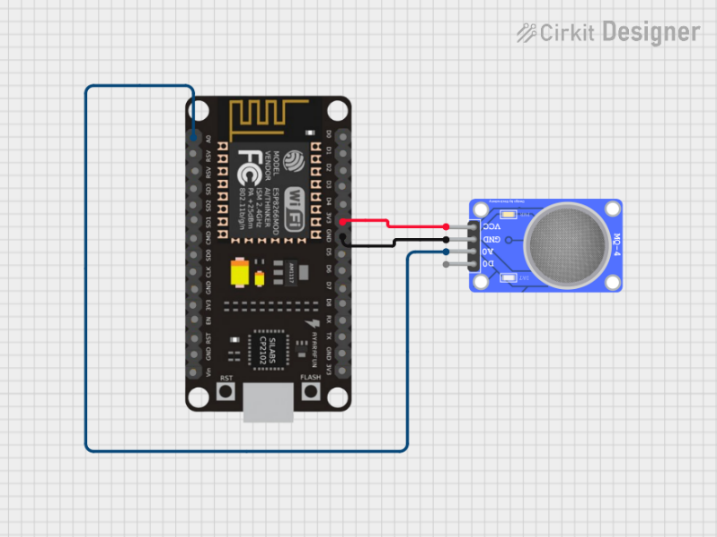


Figure 8: Gas monitoring sensor system.

From the above presentation, in this study, the sensor resistance (Rs) is calculated.

Rs (Ω) = [(Vs / Vout) – 1] × RL (1)

Where: Vs = supply voltage, Vout = sensor output voltage, and RL = load resistance.

The Drone rotational dynamics representation is given by [41];

Where R = matrix transformation, Sᶿ = Sin (θ); Sɸ = Sin (ɸ); and S ψ = Sin (ψ). Cᶿ = Cos (θ); Sɸ = Cos (ɸ); and S ψ = Cos (ψ). Applying the force and moment balance laws, the quadcopter motion equation [42];

(4)

Where *K1* = drag coefficient (Assuming zero since drag is negligible at low speed).

3. results and discussion

This section discusses the procedure involved in the data-capturing process. The sensors were calibrated to ensure accurate readings by exposing sensors to known gas concentrations and adjusting sensitivity. In this case, the process guaranteed reliable data collection during flight operation by the drone. Initial test flights assessed the drone's stability, communication module performance, and data transmission capabilities while performing a pollution monitoring operation. Data collected during test flights was compared with traditional air quality monitoring stations to evaluate accuracy. Discrepancies were addressed through fine-tuning and software adjustments, ensuring reliable data processing and transmission. The gas pollution trend is revealed in Table 1. The mobility of the system is presented in Table 2, and the system power consumption analysis is presented in Table 3.Results for the air quality monitoring system are tabulated in Table 1. The MQ-135 and MQ-7 sensors were calibrated and tested for air quality monitoring, achieving MQ-7: 97.14% accuracy for CO detection in urban settings, and MQ-135: 98% accuracy for overall air quality in both industrial and rural areas, respectively. Table 1 presents gas sensor readings.

Table 1. Sensor readings compared with reference values

|  |  |  |  |
| --- | --- | --- | --- |
| Test Location | Urban Area | Industrial Area | Rural Area |
| Pollutant | CO | CO | CO |
| Reference Value (PPM) | 10.50 | 30.00 | 15.00 |
| Sensor Reading (PPM) | 10.20 | 29.50 | 14.80 |
| Accuracy | 97.14 | 98.33 | 98.67 |

**3.1 Mobility and Coverage**

The drone’s ability to cover diverse terrains was tested by measuring pollutant levels over a 2km radius in an industrial area. The results in Table 2 demonstrate the system’s capability to sustain a communication link and provide data over a wide range, with minimal signal loss during flight operation. In this scenario, achievable results from the three investigated areas are presented. Given the fact that air pollution in industrial zones is always of higher impact compared to the residential and rural areas. From Table 2, also, the rural area result also shows moderately higher air pollution data. This is obvious as the studied communities are faced with air pollution challenges from the oil and gas production companies in this location. The residential arrears results are least affected by this finding.

Table 2: Mobility and coverage testing

|  |  |  |  |
| --- | --- | --- | --- |
| Test Area | Industrial Zone | Residential Area | Rural Area |
| Distance covered (m) | 2000.00 | 1800.00 | 2500.00 |
| Signal loss (%) | 5.00 | 2.00 | 3.00 |
| Average pollutant level (PPM) | 25.80 | 8.60 | 12.30 |

**3.2 Power Consumption Analysis**

The power consumption of the drone-based system was analysed to determine operational efficiency. The results are presented in Table 3. The drone achieved an average flight time of 1500 seconds per full battery charge.

Table 3: Power Consumption Analysis

|  |  |  |
| --- | --- | --- |
| Component | Power Consumption  (W) | Duration (s) |
| Sensors | 2.5 | 1500 |
| Micro-controller | 1.8 | 1500 |
| Communication | 1.2 | 1500 |
| **Total** | 5.5 | 1500 |

Table 3 also presents significant information concerning the measured parameters and their results during this investigation. Three different measured components: sensor, microcontroller and communication parameters were employed in the study. The power consumption and duration of these components were also measured. It shows that the total power consumption for the test period of 1500 second is 5.5W (wat). This points to the fact that more research should be directed to improve the duration time for similar operations.

**3.3 Discussions**

In this study, from the conceptual design, testing and application of a drone-based gas pollution monitoring system, air pollution activities and their impacts generally could be assessed. The achievable results in this case demonstrate consistent outcomes as air pollution within the Niger Delta region has severe impact to man and its environs (eco-system) concerns, generally. The drone-based gas pollution monitoring system demonstrated exceptional performance in pursuit of this study. The drone has a mobility advantage and is capable of collecting gas pollution data over diverse terrains, covering distances up to 2.5km, which could have been difficult to achieve using the conventional approach of a handheld gas detection system. The sensor measurements' accuracy exceeded 95% reliability due to meticulous calibration of MQ-135 and MQ-7 sensors. The measurements captured by the sensors were effectively transmitted to the cloud with an average transmission time of 1.2 seconds and a success rate above 90% using the ESP8266 wireless communication module. The sensor readings were interfaced for stakeholders to monitor and analyse air quality data, enabling the identification of trends and pollution sources. However, some limitations encountered include minor discrepancies in extreme environmental conditions, restricted flight duration of approximately 1500s seconds per fully charged battery and dependency on Wi-Fi communication system with restricted distance. Plate 1 presents some pictures captured during the system calibration, integration and flight field test.

Plate 1: System Integration and field test.

|  |  |
| --- | --- |
| Plate 1 (a) System integration and calibration | Plate 1(b): System field test |
| Plate 1 (c): Field test and data capturing process | Plate 1 (d): System approach (descending). |

4. Conclusion

This study reviewed and developed a prototype drone-based hazardous gas detection system integrated with IoT technology to provide real-time data transmission. Key achievements include high accuracy in pollutant detection, efficient data transmission, mobility to monitor remote or hard-to-reach areas and geo-tagged air quality data for precise identification of pollution hotspots. Despite limitations such as dependency on Wi-Fi connectivity and restricted flight time, the system demonstrates the potential of harnessing drone and IoT for effective environmental pollution monitoring. Future enhancement includes consideration of long-range communication technology, advanced batteries, renewable energy sources and application of machine learning technology. The study developed effective approach compared to the conventional method for hazardous gases detection to combat gas pollution and protect human life, public health and environment for sustainable development.

Definitions, Acronyms, Abbreviations

CO: Carbon monoxide

CO2: Carbon dioxide

ESP8266: Wi-Fi module for wireless communication

GPS: Global Positioning System

HTTP: Hypertext Transfer Protocol (data transmission format)

IoTs: Internet of Things

JSON: JavaScript Object Notation (data forma

RL: Load resistance

Rs: Sensor resistance

Rxyz: Rotation matrix (for drone dynamics)

Vout: Sensor output voltage

Vs: Supply voltage.

disclaimer (artificail intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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