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Urban Air Quality Monitoring Using Non- Flying Drone

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Introduction

Air pollution in urban areas is a critical issue with significant adverse effects on public health and environmental sustainability. Rapid urbanization and industrialization have exacerbated pollution levels in cities worldwide. Monitoring air quality is essential to understand pollution patterns and implement effective mitigation strategies.

Conventional air quality monitoring systems rely on fixed stations equipped with high-precision instruments to measure pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO), and ozone (O3). While these systems provide accurate data, their static nature limits spatial coverage and fails to capture localized variations in pollution levels. Emerging technologies offer opportunities to enhance air quality monitoring through mobile platforms that can collect data dynamically across different locations.

This project explores a novel approach by employing a non-flying drone model equipped with environmental sensors to monitor urban air quality at street levels. The system combines advanced microcontroller technology with wireless communication to enable real-time data acquisition and visualization. By integrating multiple sensors capable of measuring particulate matter concentration, temperature, humidity, atmospheric pressure, and air quality index, the proposed system provides a comprehensive assessment of urban air quality. The use of a non- flying drone model addresses challenges associated with aerial drones, such as regulatory restrictions and high operational costs. Instead, the ground-based platform offers a cost- effective alternative while maintaining mobility to cover different areas within urban environments. This proof-of-concept project aims to demonstrate the feasibility of such systems in enhancing our understanding of urban pollution dynamics and supporting informed decision-making for sustainable urban development.

Drones, also known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS), have revolutionized various industries and applications. These flying robots can be remotely controlled or operate autonomously using pre-programmed flight plans and onboard sensors. Initially associated with military use, drones have expanded into civilian and commercial sectors, offering versatile solutions for tasks ranging from aerial photography to environmental monitoring. The global drone market is projected to exceed $101 billion by 2032, driven by technological innovation, lower costs, and clearer regulations.

Air pollution in urban areas has become a pressing environmental and public health concern. As cities expand and industrialize, the concentration of pollutants such as particulate matter (PM2.5 and PM10), nitrogen oxides (NOx), and ozone (O3) increases, leading to adverse health effects on urban populations. WHO data show that almost all of the global population (99%) breathe air that exceeds WHO guideline limits and contains high levels of pollutants, with low- and middle-income countries suffering from the highest exposures. The combined effects of ambient air pollution and household air pollution are associated with 7 million premature deaths annually.

Rotary wing drones, a specific category of UAVs, offer unique capabilities that make them particularly suitable for various applications, including urban air quality monitoring. Unlike fixed-wing drones, rotary-wing models can hover in place, maneuver in tight spaces, and perform vertical takeoffs and landings. These characteristics allow for precise positioning and extended observation periods, which are crucial for collecting detailed data in complex environments. Rotary wing drones have a wide variety of applications thanks to their Vertical Take-Off and Landing, hover, and low-speed capabilities.

Different types of air quality sensors exist for use in ambient air monitors according to the substance(s) to be measured, where electrochemical (for measurement of chemical substances concentration such as CO and O3) and light-scattering sensors (for measurement of particulate matter concentration using laser or infrared light) act as examples

To be able to manage air quality, ambient air is monitored. The concentration of air pollutants such as PM2.5 and/or PM10 is sensed by sensors that are either static (such as sensors placed on ground-fixed monitoring stations) or mobile (such as those placed on terrestrial or aerial vehicles, among others).

Some limitations that static air quality sensors include are the need for additional sensors to monitor air quality in large areas, limited spatial resolution, and a wrong spatial distribution which may affect information accuracy.

Literature Review

2.1. Review on Drone-Assisted Air-Quality Monitoring Systems

Authors: Piyush Kokate, Anirban Middey, Shashikant Sadistap, Gaurav Sarode, and Anvesha Narayan

Published in: Drones and Autonomous Vehicles (2023), 1, 10005

Drones equipped with low-cost sensors (LCS) offer a mobile, cost-effective, and real-time alternative to traditional stationary air-quality monitoring systems. The review highlights:

- **Pollutants Monitored:** CO_2, CO, NO_2, O_3, SO_2, VOCs, PM.
- **Drones Used:** Multi-rotor (dominant) C fixed wing.
- **Sensor Placement:** Best on top to reduce turbulence effects.
- **Challenges:** Battery life, regulatory restrictions, meteorological interference.
- **Future Trends:** AI-driven drones, improved sensor accuracy, extended battery life.

Key Takeaway:

Drones significantly enhance environmental monitoring but require further advancements in sensor precision, AI integration, and operational regulations for optimal efficiency.

2.2. Unmanned Aerial Vehicles for Air Pollution Monitoring: A Survey

Authors: Naser Hossein Motlagh, Pranvera Kortoçi, Xiang Su, Lauri Lovén, Hans Kristian Hoel, Sindre Bjerkestrand Haugsvær, Varun Srivastava, Casper Fabian Gulbrandsen, Petteri Nurmi, and Sasu Tarkoma

Published in: IEEE Internet of Things Journal, 2023

Key Takeaways:

UAVs + Sensors: Real-time, cost-effective air pollution monitoring (CO, CO_2, SO_2, O_3, PM).
Challenges: Power limits, sensor accuracy, regulatory hurdles.
Solutions: AI-based calibration, 5G, edge computing, multi-UAV coordination.
Future: Smarter drones with autonomous navigation + enhanced data analytics.

Conclusion: UAVs revolutionize air-quality tracking but need better energy efficiency, AI integration, and regulatory frameworks.

2.3. Review on Drone-Assisted Air-Quality Monitoring Systems

Authors: Piyush Kokate, Anirban Middey, Shashikant Sadistap, Gaurav Sarode, Anvesha Narayan

Published in: Drones and Autonomous Vehicles, November 2023

Drones equipped with low-cost sensors (LCS) provide a mobile, cost-effective, and real- time alternative to stationary air-quality monitoring stations. Multi-rotor drones dominate due to their stability and adaptability, while fixed-wing drones offer longer flight times.

Key challenges include sensor accuracy, battery limitations, and regulatory restrictions. Proper sensor placement (above the drone) reduces turbulence effects. Future trends focus on AI-driven automation, improved sensor calibration, and IoT integration to enhance monitoring accuracy and efficiency.

2.4. Air Quality Monitoring Using Drones (UAV)

Authors: R. Alberto Bernabeo, Gianmarco D'Alessandro, Alessandro Ceruti, Laura Tositti, Nhan Nguyen, and Thanh Phuoc Ho

Published in: IOP Conference Series: Earth and Environmental Science, 2024

Key Takeaways:

UAVs + Smart Sensors: Efficient real-time air pollution monitoring (CO_2, CH_4, NOx, PM). **Application in Vietnam:** Focus on urban areas, landfills, and airports to track greenhouse gas (GHG) emissions.
Challenges: Sensor accuracy, propeller interference, power limitations, and regulatory issues.
Innovations: UAV-based 3D atmospheric mapping, remote aerosol sampling, and chemical speciation.
Future Scope: Policy development, integration with smart cities, and enhanced environmental monitoring strategies.

Conclusion: UAVs provide a cost-effective, flexible solution for air quality assessment, but advancements in sensor technology, flight stability, and regulatory frameworks are essential for widespread adoption.

Methodology

The project methodology for the urban air quality monitoring system using a non-flying drone model encompasses several key phases. Initially, a comprehensive literature review was conducted to identify existing gaps in urban air quality monitoring and to inform the design of the proposed system. This review highlighted the limitations of stationary monitoring stations and aerial drones, emphasizing the need for a mobile ground-based solution. The system design phase focused on integrating multiple environmental sensors with a microcontroller-based architecture. An Arduino Mega was selected as the primary controller due to its processing capabilities and compatibility with various sensors. The sensor suite includes particulate matter sensors, a BMP280 for atmospheric pressure and altitude measurements, a DHT22 for temperature and humidity readings, and an MQ135 for air quality assessment. To enable

wireless data transmission, an ESP32 module was incorporated for real-time logging to the ThingSpeak IoT platform.

The non-flying drone model was constructed using a quadcopter frame, equipped with 1000rpm DC motors and propellers for simulated mobility. An L298 motor driver was implemented to control motor speed, allowing for adjustable movement patterns. Power management was carefully considered to ensure optimal performance of all components.

Software development involved programming the Arduino Mega using the Arduino IDE and relevant libraries for sensor integration and data processing. The ESP32 was configured to establish Wi-Fi connectivity and manage data transmission to ThingSpeak. Custom algorithms were developed to process and format sensor data for efficient storage and visualization.

The testing phase included calibration of individual sensors, followed by integration testing of the complete system. Field trials were conducted in various urban locations to assess the system's performance in real-world conditions. Data collected during these trials was analyzed to validate the system's accuracy and reliability in capturing localized air quality variations.

Throughout the project, iterative improvements were made based on test results and feedback. The final phase focused on optimizing data visualization on ThingSpeak, creating user-friendly interfaces for stakeholders to access and interpret air quality data effectively. This methodology demonstrates a systematic approach to developing a novel, mobile air quality monitoring solution for urban environments.

System Design

The urban air quality monitoring system employs a non-flying drone model as a mobile platform for data collection. At the core of the system is an Arduino Mega microcontroller, chosen for its processing capabilities and compatibility with various sensors. The sensor suite includes particulate matter sensors for detecting PM2.5 and PM10, a BMP280 for measuring atmospheric pressure and altitude, a DHT22 for temperature and humidity readings, and an MQ135 for air quality assessment. To enable wireless data transmission, an ESP32 module is integrated for real-time logging to the ThingSpeak IoT platform.

The non-flying drone model is constructed using a quadcopter frame, equipped with 1000rpm DC motors and propellers to simulate mobility. An L298 motor driver is implemented to control motor speed, allowing for adjustable movement patterns. This design enables the system to navigate urban environments at street level, capturing localized variations in air quality that stationary monitors might miss. Power management is carefully considered to ensure optimal performance of all components, with a dedicated power supply unit providing the necessary energy for extended operation.

The system's design prioritizes modularity and scalability, allowing for easy integration of additional sensors or upgrades to existing components. This flexibility ensures that the monitoring platform can adapt to evolving air quality measurement needs and technological

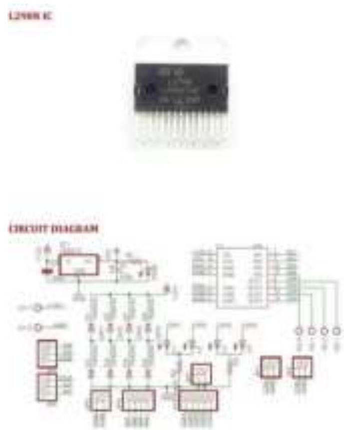
advancements. The combination of a mobile ground-based platform with advanced sensor technology and wireless connectivity represents a novel approach to urban air quality monitoring, addressing the limitations of both stationary systems and aerial drones.

Hardware Requirements

Arduino Mega, Quadcopter Frame, ESP32, Lcd Display, Particulate Matter Sensor, BMP280 Sensor, DHT22 Sensor, MQ135 Gas Sensor, 1000rpm DC Motors, Propellers, L298 Motor Driver, Power Supply Unit

Software Requirements

Arduino IDE, ThingSpeak API, Embedded C/C++ Programming Libraries, Data Visualization Tools (ThingSpeak Dashboard)



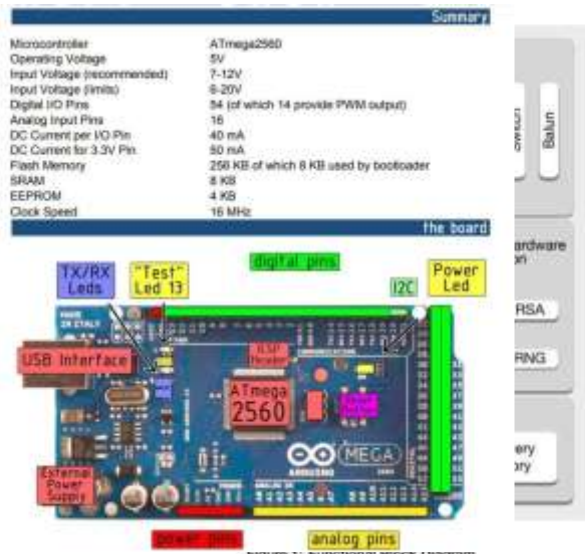


Figure 1: Functional Block Diagram

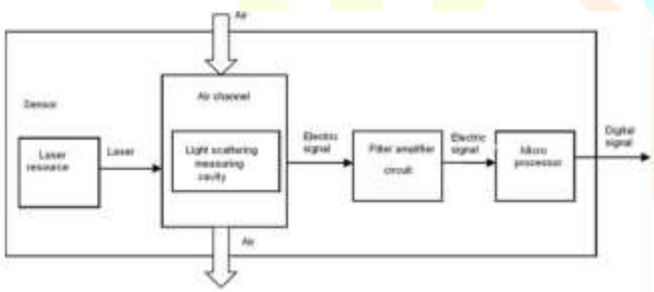


Figure 1 Functional block diagram of sensor

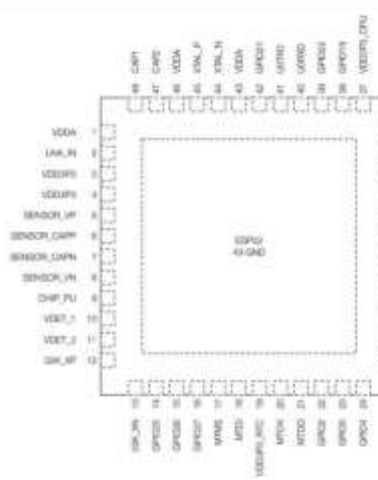


Figure 2: ESP32 Pin Layout (QFN 6*6, Top View)

Model			MQ135
Sensor Type			Semiconductor
Standard Encapsulation			Bakelite, Metal cap
Target Gas			ammonia gas, sulfide, benzene series steam
Detection range			10~1000ppm(ammonia gas, toluene, hydrogen, smoke)
Standard Circuit Conditions	Loop Voltage	V_c	≤24V DC
	Heater Voltage	V_H	5.0V±0.1V AC or DC
	Load Resistance	R_L	Adjustable
Sensor character under standard test conditions	Heater Resistance	R_H	29Ω±3Ω (room tem.)
	Heater consumption	P_H	≤950mW
	Sensitivity	S	Rs(in air)/Rs(in 400ppm H_2)≥5
	Output Voltage	Vs	2.0V~4.0V (in 400ppm H_2)
	Concentration Slope	α	≤0.6(R_{400ppm}/R_{50ppm} H_2)
Standard test conditions	Tem. Humidity		20℃±2℃; 55%±5%RH
	Standard test circuit		Vc:5.0V±0.1V; V_H: 5.0V±0.1V
	Preheat time		Over 48 hours

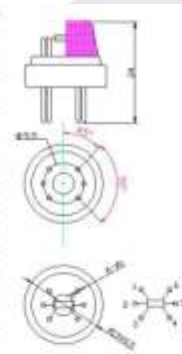
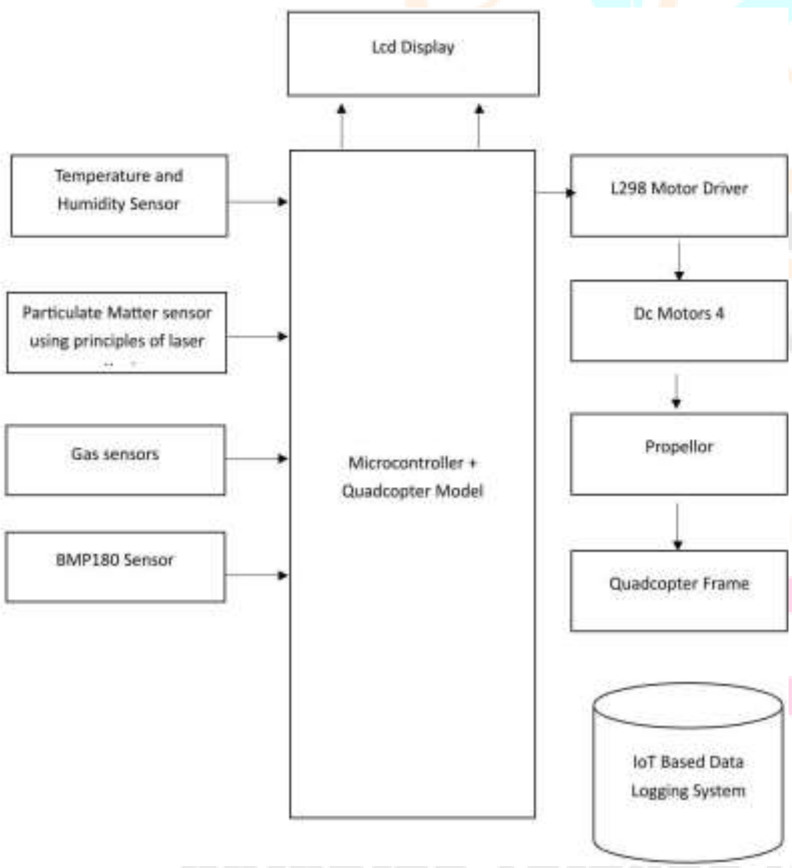


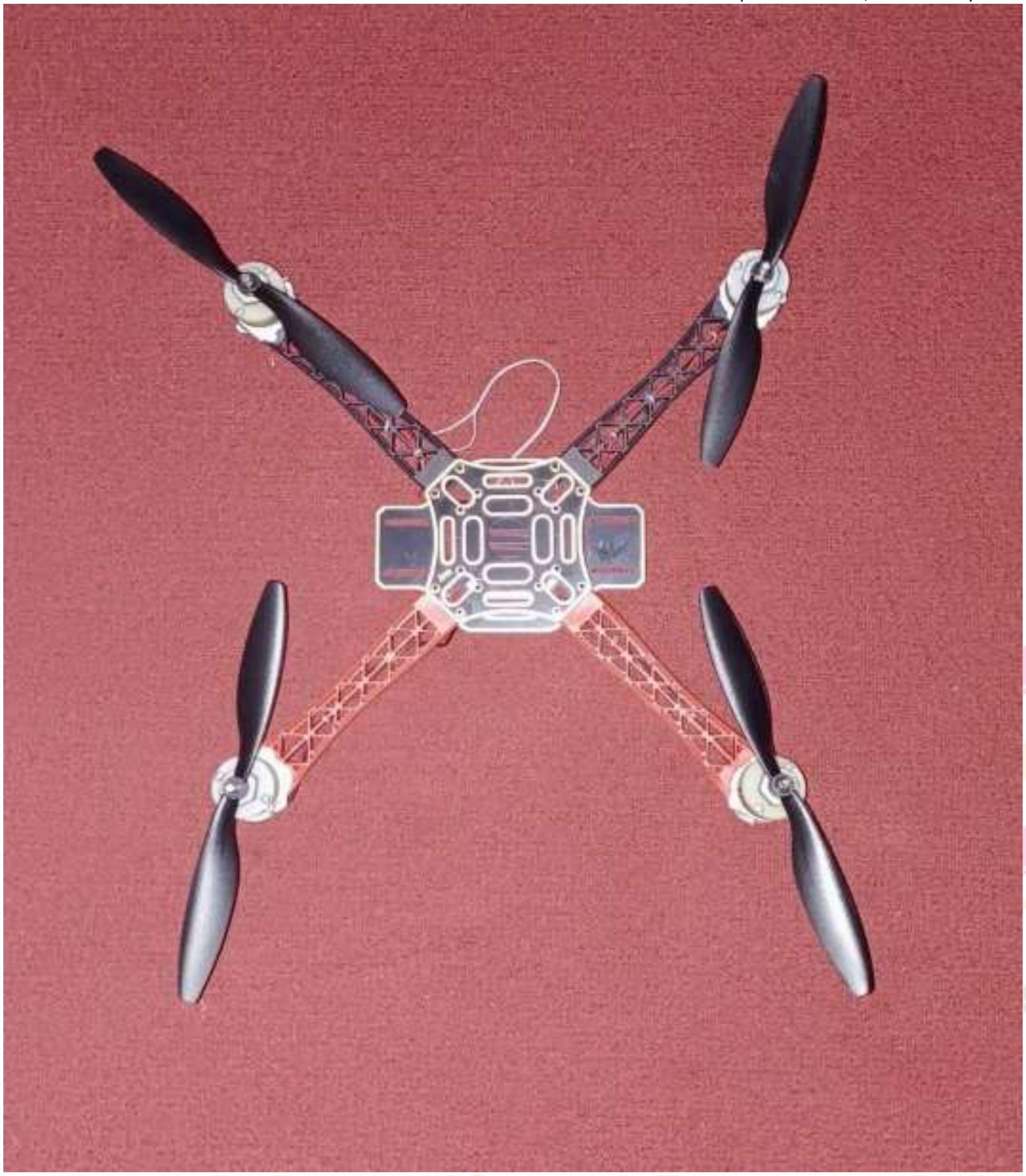
Fig1.Sensor Structure
Unit: mm

Main characteristics

- Zero false alarm rate
- Real-time response
- Correct data
- Minimum distinguishable particle diameter :0.3 micrometer
- High anti-interference performance because of the patent structure of six sides shielding
- Optional direction of air inlet and outlet in order to adapt the different design
- Very Slim

Block Diagram:



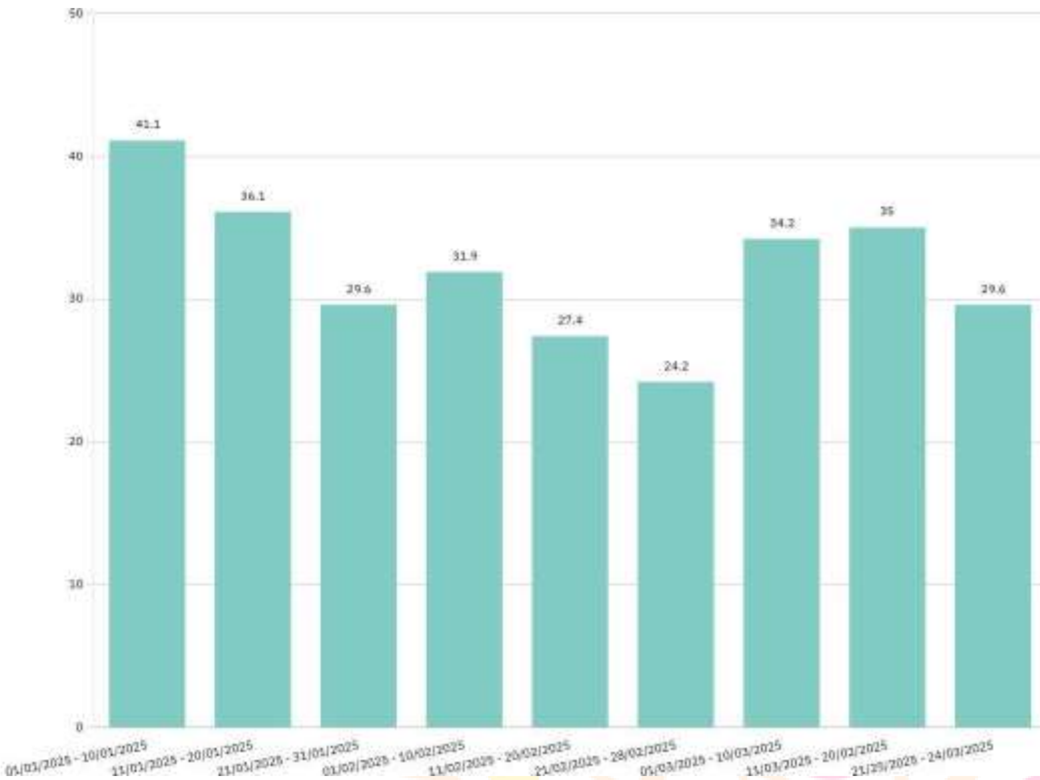


Result and Discussion

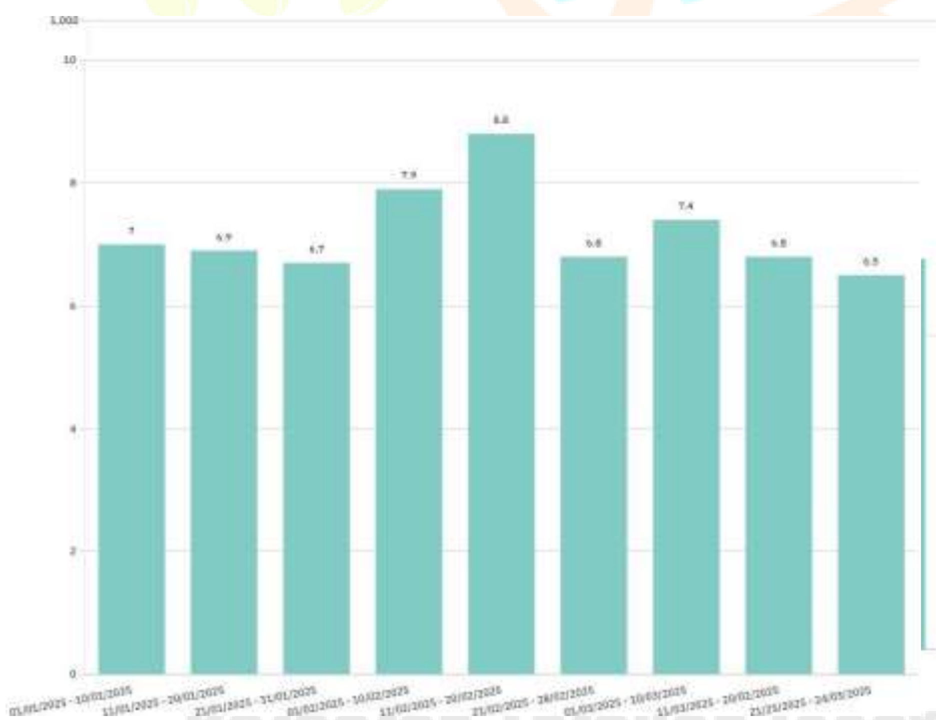
The initial results from connecting the Arduino Mega to an LCD display have demonstrated successful visualization of basic sensor readings such as temperature and humidity levels. The integration of the gas sensor has provided preliminary insights into local air quality conditions by detecting harmful gases. These findings indicate that the system is capable of functioning as intended, providing essential information about environmental parameters relevant to urban air quality.

As further testing is conducted with additional sensors, it is anticipated that more comprehensive data will be collected, allowing for a detailed analysis of pollution levels across different urban areas. The ability to visualize this data in real-time on platforms like ThingSpeak will enable stakeholders to make informed decisions regarding public health interventions and environmental policies.

In conclusion, these initial results underscore the project's potential impact on enhancing urban air quality monitoring capabilities through innovative technology integration.

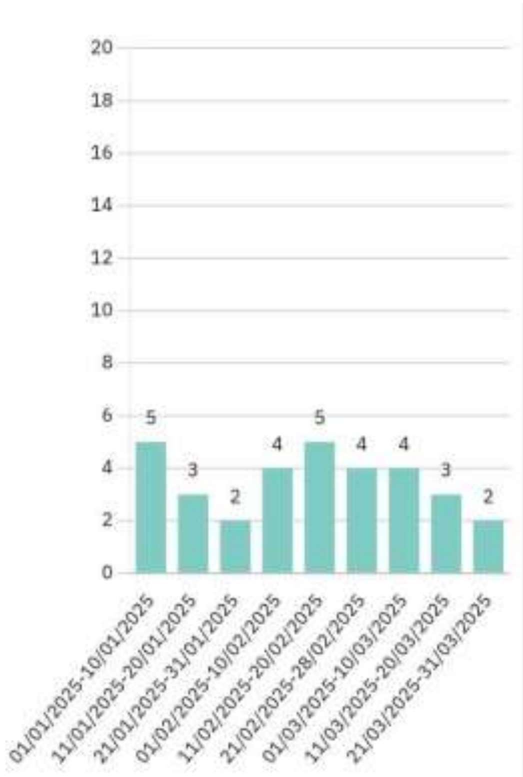


Particulate Matter 2.5 during the period 01/01/2025 to 24/03/2025 measured in micrograms per cubic meter.

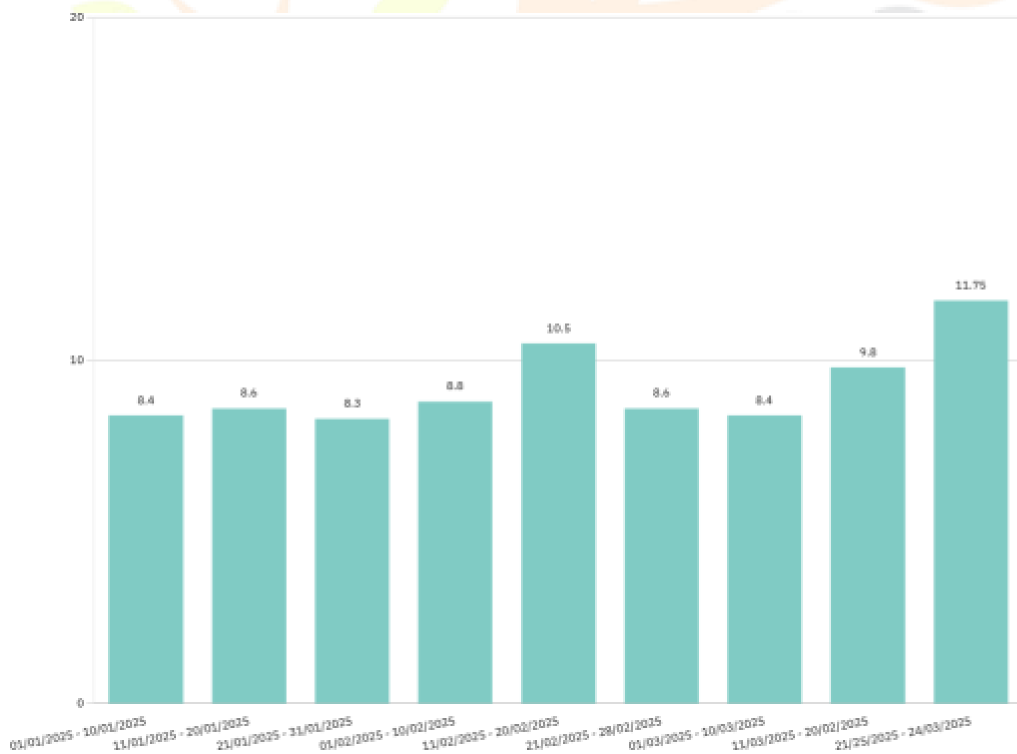


Carbon Monoxide level during the period 01-01-2025 to 24-03-2025 measured in ppb (parts per billion).

Nitrogen Dioxide level during the period 01-01-2025 to 24-03-2025 measured in ppb.



Sulphur Dioxide level during the period 01-01-2025 to 24-03-2025 measured in ppb.



Ozone level during the period 01-01-2025 to 24-03-2025 measured in ppb.

Conclusion

The development of a non-flying drone model for urban air quality monitoring represents a significant advancement in addressing the limitations of traditional stationary systems. By integrating multiple environmental sensors with microcontroller technology and wireless communication capabilities, this project has laid the groundwork for a comprehensive solution that can dynamically assess air quality at street levels.

The successful connection between hardware components has demonstrated feasibility in visualizing critical environmental parameters such as temperature, humidity, and gas concentrations. As further work progresses with additional sensor integration and software development, it is expected that this system will provide valuable insights into localized pollution levels across urban landscapes.

Ultimately, this project aims not only to enhance our understanding of urban air quality dynamics but also to support informed decision-making processes that contribute towards healthier environments for communities.