Integrated Environmental Sensing: A Multi-Parameter Device for Spatial Air Quality and Climate Assessment

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***Abstract*- Air pollution poses a global threat to public health, necessitating innovative solutions for real-time monitoring and mitigation. This abstract introduces an Internet of Things (IoT)-based air pollution monitoring system designed to address this challenge. Utilizing sensors to gather data on pollutants like carbon monoxide and particulate matter, the system transmits information to a cloud server for storage and analysis. The server generates visualizations, empowering users to monitor air quality dynamically and pinpoint areas of concern. This technology offers individuals and organizations the means to proactively minimize exposure, fostering healthier environments. Applicable in diverse settings, from homes to cities, the system enables informed decision-making, such as adjusting ventilation or implementing pollution-reduction policies. By harnessing IoT capabilities, this monitoring system emerges as a powerful tool for improving public health, advancing environmental sustainability, and combatting the escalating global issue of air pollution.**

***Keywords*- Air Pollution, Internet of Things (IoT), Cloud Server, Real-time Data, Nitrogen Dioxide, Pollutants**

I. INTRODUCTION

In today's period of mechanical headway, the integration of Web of Things (IoT) gadgets has opened entryways to imaginative arrangements over different spaces. Among these, natural observing develops as a basic field where IoT advances offer significant applications. Real-time observing of discuss quality holds critical suggestions for open wellbeing, urban arranging, and natural administration. In this term paper, we dig into the integration of the ESP32 WiFi module, OLED[3] show, and MQ135 AQI[22] detecting module to form an effective natural checking framework. The ESP32 WiFi module acts as the foundation of our framework, giving consistent network to the web and encouraging information transmission to inaccessible servers for investigation and visualization. Eminent for its versatility and strength, the ESP32 is exceedingly regarded within the IoT community due to its dual-core preparing capabilities, built-in WiFi and Bluetooth functionalities, and moo control utilization, rendering it an ideal choice for our application. Supplementing the ESP32 module is the OLED (Natural Light-Emitting Diode) show, serving as the interface between the framework and the client. OLED shows offer various preferences over conventional LCD shows, counting higher differentiate proportions, quicker reaction times, and lower control utilization. With its striking and clear visuals, the OLED show upgrades client involvement by giving real-time upgrades on discuss quality parameters such as Discuss Quality File (AQI), toxin concentrations, and temperature. At the heart of our natural observing framework lies the MQ135 AQI detecting module, empowering discovery and estimation of different discuss poisons such as carbon dioxide (CO2), alkali (NH3), benzene (C6H6), and smoke. Working on the rule of gas resistance, the MQ135 sensor recognizes changes in electrical conductivity, which are corresponding to the concentration of target gasses display within the environment. By meddle the MQ135 sensor with the ESP32 module, we accumulate real-time information on discuss quality parameters and transfer them to the client by means of the OLED show. The integration of these components offers a few focal points. Leveraging the ESP32 WiFi module, our framework interfaces to existing WiFi systems, empowering farther checking and control from anyplace with web get to. This include is especially profitable in urban situations where discuss quality can shift altogether over diverse areas. Furthermore, the OLED show gives clients with quick criticism on current discuss quality conditions, enabling them to form educated choices with respect to open air exercises, commuting courses, and indoor discuss ventilation. Besides, the MQ135 AQI[22] detecting module offers tall affectability and exactness in identifying a wide extend of discuss poisons, encouraging comprehensive natural checking. By persistently checking discuss quality parameters, our framework identifies changes in poison levels in real-time, empowering provoke mediation measures to moderate potential wellbeing dangers. Besides, the information collected by our framework can be analyzed over time to recognize patterns, designs, and relationships, encouraging evidence-based decision-making in natural arrangement and control. The integration of the ESP32 WiFi module, OLED[3] show, and MQ135 AQI sensing module speaks to a noteworthy headway in natural checking innovation. Saddling the control of IoT gadgets, our framework offers a cost-effective and versatile arrangement for observing discuss quality in differing settings. Through comprehensive examination and dialog, we point to illustrate the viability and common sense of our approach in tending to the challenges of natural checking within the 21st century. In consequent areas, we'll dig into the specialized subtle elements of the ESP32 WiFi module, OLED show, and MQ135 AQI sensing module, outlining their functionalities, operational standards, and usage methodologies. We are going too talk about the challenges encountered amid the improvement prepare and propose potential arrangements for future advancements. By sharing our discoveries and experiences, we trust to rouse encourage investigate and development in the field of natural observing, eventually contributing to the creation of maintainable and versatile communities.

TABLE I. LEVELS OF AQI IN DETAIL

AQI Level	PM2.5 (ppm)	PM10 (ppm)	O3 (ppm)	CO (ppm)	SO2 (ppm)	NO2 (ppm)	Significance	Health Effects	Environmental Impact
0-50	<12	<54	<0.055	<4.4	<0.035	<0.053	Air quality is considered satisfactory, and concentrations of pollutants are below levels that typically cause adverse health effects.	Minimal risk of health impacts.	Negligible impact on ecosystems and the environment.
51-100	12-35	55-154	0.055-0.070	4.4-9.4	0.036-0.075	0.054-0.100	Air quality meets regulatory standards, but there may be slight respiratory irritation in sensitive individuals under certain conditions.	Slight risk of respiratory irritation, particularly for sensitive individuals.	Minor environmental stress; may affect sensitive ecosystems or species.
101-150	35-55	154-254	0.071-0.085	9.5-12.4	0.076-0.185	0.101-0.360	Air quality may pose a risk to sensitive groups, such as those with pre-existing respiratory conditions, but the general population is unlikely to be affected.	Moderate risk of respiratory issues for sensitive groups; general population less affected.	Moderate environmental stress; may impact vegetation and ecosystems over time.
151-200	55-150	255-354	0.086-0.105	12.5-15.4	0.186-0.304	0.361-0.649	Air quality may lead to increased respiratory symptoms in the general population and more severe effects in sensitive groups.	Significant risk of respiratory symptoms in the general population; heightened risk for sensitive groups.	Significant environmental stress; may harm vegetation, ecosystems, and air quality over time.
201-300	150-250	355-424	0.106-0.200	15.5-30.4	0.305-0.604	0.650-1.249	Air quality poses a significant risk to health, with the potential for respiratory symptoms to become widespread across the entire population.	Severe risk of respiratory symptoms and health issues across the entire population.	Severe environmental stress; may lead to ecosystem damage, soil acidification, and water quality degradation.
301-500	>250	>424	>0.200	>30.4	>0.604	>1.249	Air quality reaches emergency levels, with severe health effects expected across the entire population, including respiratory distress and exacerbation of pre-existing conditions.	Emergency: Severe respiratory and health issues for the entire population; immediate medical attention required.	Environmental emergency: Significant harm to ecosystems, air, water, and soil; long-term consequences on biodiversity, agriculture, and human health.

II. LOW-COST AQI MONİTORS

Comparing the MQ135 sensor with other discuss quality sensors includes a comprehensive examination of different variables, counting exactness, exactness, cost-effectiveness, ease of use, and application flexibility. The MQ135 sensor, a staple within the domain of natural observing, offers a one-of-a-kind mix of reasonableness and effortlessness, working on the principle of gas resistance to supply estimations of key discuss poisons such as carbon dioxide (CO2), smelling salts (NH3), benzene (C6H6), and smoke. Whereas the MQ135 sensor may not give the same level of precision as laser-based particulate matter (PM) sensors just like the Plantower PMS5003 and Nova Wellness SDS011, its openness and ease of integration have made it a favored choice among do-it-yourself (DIY) devotees, analysts, and community-driven natural activities. In spite of its clear plan, the MQ135 sensor reliably conveys solid execution over different applications, especially in scenarios where taken a toll and openness take priority over diminutive accuracy. In any case, professional-grade sensors such as the Alphasense OPC-N2 offer unparalleled precision and progressed highlights at a essentially higher fetched, catering to specialized applications that demand exact estimations and broad information examination capabilities. Thus, the choice to decide on the MQ135 sensor or elective discuss quality sensors pivots on extend necessities, requiring a cautious adjust between components like precision, cost-effectiveness, ease of use, and application versatility to attain ideal execution in discuss quality checking endeavors. To dive more profound into the comparison, it's basic to scrutinize each sensor's characteristics and functionalities comprehensively. The MQ135 sensor, a well-known choice for DIY natural checking ventures, brags straightforwardness and cost-effectiveness as its essential qualities. Its gas resistance rule permits for the discovery of different discuss toxins, making it a flexible instrument for surveying indoor and open air discuss quality. In spite of its moderately lower exactness compared to laser-based PM sensors, the MQ135 sensor's reasonableness and ease of integration make it an appealing choice for people and organizations looking for to set out on natural observing activities without breaking the bank. Moreover, the MQ135 sensor's analog yield disentangles information procurement and handling, disposing of the require for complex calibration strategies and encouraging quick prototyping and experimentation in different settings.

Table II: Comparing Various Low Cost AQI Sensing Modules

Sensor	MQ135 Sensor	Plantower PMS5003	Nova Fitness SDS011	Alphasense OPC-N2
Principle	Gas resistance	Laser scattering	Laser scattering	Optical particle counting
Target Pollutants	CO2, NH3, C6H6, smoke	PM2.5, PM10	PM2.5, PM10	PM1, PM2.5, PM10, other gases
Cost	Low	Medium	Medium	High
Precision	Moderate	High	High	Very High
Usability	Easy to integrate with Arduino/Raspberry Pi	Moderate	Moderate	Requires specialized expertise
Application Versatility	Suitable for DIY projects and basic monitoring	Indoor and outdoor air quality assessment	Indoor and outdoor air quality assessment	Research, regulatory compliance, industrial monitoring
Data Output	Analog	Digital	Digital	Digital
Calibration	Simplified	Required	Required	Required
Integration	Straightforward	Requires some technical knowledge	Requires some technical knowledge	Complex integration processes
Availability	Widely available	Easily accessible	Easily accessible	Specialized suppliers

In differentiate, sensors just like the Plantower PMS5003 and Nova Wellness SDS011 utilize laser-based innovation to degree particulate matter concentrations with higher exactness and precision. These sensors are favored in applications where point by point PM information is significant, such as surveying the affect of discuss contamination on respiratory wellbeing or checking mechanical emanations. Whereas the Plantower PMS5003 and Nova Wellness SDS011 offer prevalent performance in terms of PM estimation, their higher taken a toll may posture a boundary to section for budget-conscious ventures or activities working with restricted assets. Additionally, these sensors regularly require specialized calibration and information preparing procedures, including complexity to the usage prepare and possibly ruining their usability for less experienced clients. Professional-grade sensors just like the Alphasense OPC-N2 speak to the apex of discuss quality observing innovation, advertising unmatched precision and progressed highlights custom fitted to requesting applications. Equipped with optical molecule checking innovation and modern information investigation capabilities, the Alphasense OPC-N2 conveys exact estimations of PM concentrations and other discuss poisons, making it irreplaceable in investigate, administrative compliance, and mechanical checking settings. Be that as it may, the considerable venture required to obtain and keep up professional-grade sensors may limit their selection to organizations with adequate monetary assets or particular regulatory mandates necessitating high-fidelity discuss quality information. In spite of the characteristic trade-offs between taken a toll, accuracy, and ease of use among diverse discuss quality sensors, each alternative serves a particular specialty inside the environmental monitoring landscape. While sensors just like the MQ135 offer a cost-effective entry point for grassroots activities and instructive ventures, professional-grade sensors just like the Alphasense OPC-N2 cater to businesses and administrative organizations with exacting requirements for exactness and unwavering quality. In hone, the choice of sensor depends on different variables, counting the particular targets of the checking extend, accessible budget, technical skill of the clients, and the specified level of information granularity. In addition, the rise of open-source stages and collaborative communities has encouraged information sharing and innovation in sensor advancement, driving ceaseless enhancements in reasonableness, execution, and availability over the range of discuss quality observing arrangements. In analyzing these factors, it becomes apparent that the MQ135 sensor involves a one-of-a-kind position inside the scene of discuss quality sensors, advertising a mix of availability, reasonableness, and convenience that caters to a wide extend of applications. Whereas it may not offer the accuracy of higher-end sensors, its flexibility and ease of integration make it an alluring choice for numerous natural monitoring projects, particularly those with restricted assets or a center on grassroots engagement and community strengthening. Be that as it may, for applications requiring the most elevated levels of accuracy and performance, professional-grade sensors just like the Alphasense OPC-N2 stay crucial devices, yet at a higher taken a toll. Eventually, the choice of sensor depends on the needs and limitations of each observing venture, with contemplations of exactness, taken a toll, ease of use, and application versatility directing the decision-making prepare.

III. PROPOSED SYSTEM

The proposed framework speaks to a modern integration of components pointed at making an effective and user-friendly discuss quality checking arrangement. At its center lies the ESP32 WiFi module, a flexible and strong component known for its dual-core preparing capabilities, built-in WiFi and Bluetooth functionalities, and moo control utilization. This module serves as the establishment for consistent web network, empowering information transmission to a cloud stage known as ThingSpeak. Coupled with the ESP32 is an OLED (Natural Light-Emitting Diode) show, which acts as the client interface, giving real-time upgrades on discuss quality parameters such as the Discuss Quality List (AQI) and toxin concentrations. The OLED display's focal points, counting tall differentiate proportions, quick reaction times, and moo control utilization, improve the client involvement and encourage educated decision-making with respect to open air exercises and indoor discuss quality administration. Central to the system's usefulness is the MQ135 sensor, utilizing gas resistance standards to identify and degree different discuss toxins like carbon dioxide (CO2), alkali (NH3), benzene (C6H6), and smoke. Through consistent integration with the ESP32 module, real-time information on discuss quality parameters is collected and handed-off to the client through the OLED show. The system's benefits are multifaceted; by leveraging the ESP32's WiFi network, inaccessible observing and control ended up conceivable, especially beneficial in urban situations where discuss quality changes over distinctive areas. Besides, the integration of the OLED show offers quick input to clients, engaging them to form educated choices with respect to their environment. Moreover, the framework transfers collected information to the ThingSpeak cloud stage, encouraging capacity, investigation, and visualization. ThingSpeak gives a

user-friendly interface for information administration and investigation, empowering clients to get to their discuss quality information from any internet-connected gadget. Through visualizations on ThingSpeak, clients pick up important bits of knowledge into discuss quality patterns, designs, and relationships over time, supporting evidence-based decision-making and natural observing endeavors. By and large, the proposed system's integration of the ESP32 WiFi module, OLED show, MQ135 sensor, and ThingSpeak cloud stage speaks to a noteworthy progression in discuss quality observing innovation, advertising clients an available and comprehensive arrangement to address natural challenges and advance open wellbeing and well-being.

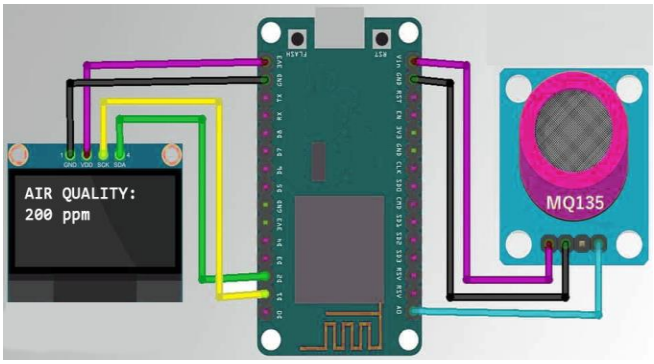

Figure 1. Circuit Diagram of AQI Sensing Device

The ThingSpeak cloud stage plays a urgent part within the proposed discuss quality checking framework by encouraging information capacity and visualization. Through consistent integration with the ESP32 WiFi module, the framework transfers collected information to ThingSpeak, where it undergoes storage and preparing to form live visualizations. The method starts with the ESP32 module collecting real-time discuss quality information from the associated MQ135 sensor. This information, counting poison concentrations and other significant parameters, is at that point designed and transmitted to the ThingSpeak cloud stage through WiFi network. Upon accepting the information, ThingSpeak stores it in assigned channels, which act as virtual holders for organizing and overseeing datasets.

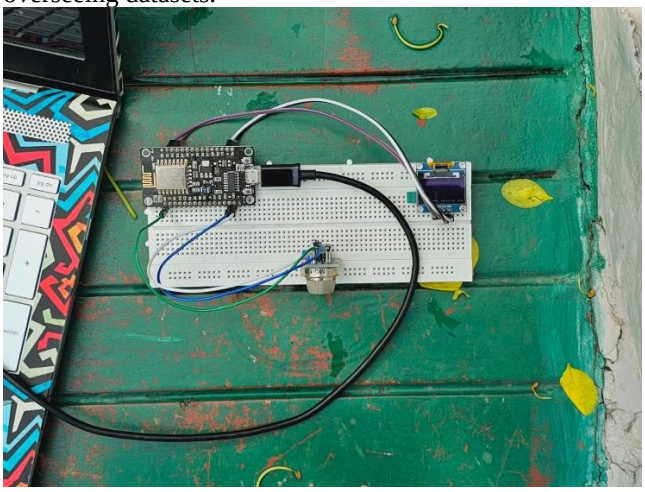

Figure 2. Prototype of Model

ThingSpeak offers a assortment of visualization apparatuses, counting line charts, bar charts, histograms, and heatmaps, permitting clients to customize their shows based on their particular checking needs and inclinations. By visualizing air quality information in real-time, clients can recognize changes, inconsistencies, and potential natural dangers, enabling them to create educated choices and take opportune activities to relieve dangers. Moreover, ThingSpeak gives built-in support for information investigation and robotization through its MATLAB Analytics capabilities.

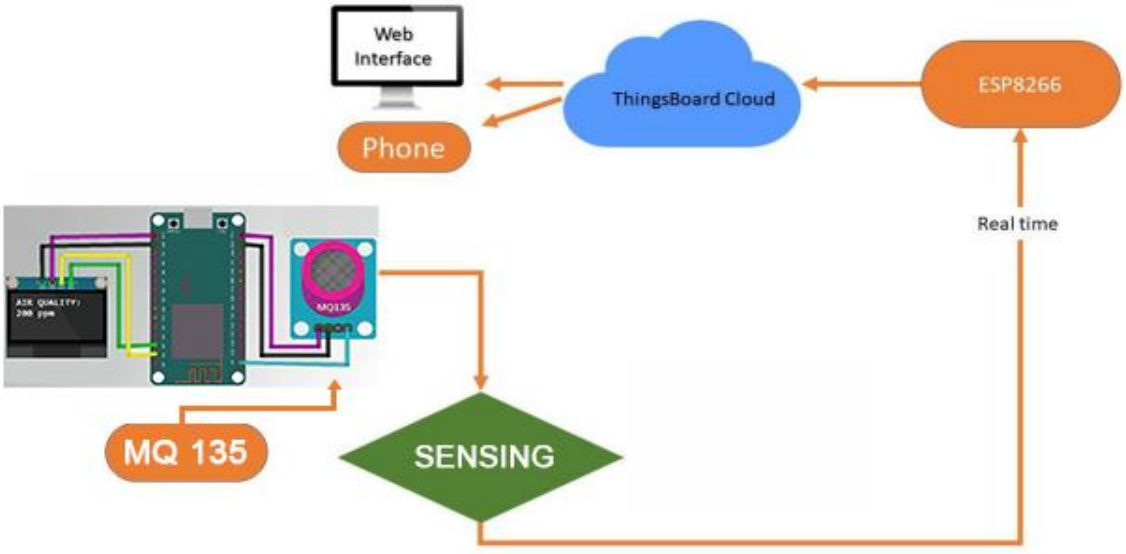

Figure 3. Overall Framework of the System

Clients can use MATLAB scripts to perform progressed information handling errands, such as exception location, drift investigation, and prescient modeling, straightforwardly inside the ThingSpeak stage. Through APIs and webhooks, clients can coordinated ThingSpeak with outside frameworks, empowering consistent information trade and interoperability over distinctive stages and gadgets. This interoperability cultivates collaboration and information sharing among partners, encouraging collective

endeavors to address natural challenges and advance open wellbeing and well-being. In rundown, the ThingSpeak cloud platform plays a pivotal part within the proposed discuss quality checking framework by giving strong information capacity, handling, and visualization capabilities. Through consistent integration with the ESP32 WiFi module and MQTT convention back, ThingSpeak empowers the collection of real-time discuss quality information and the creation of live visualizations to engage clients with significant experiences. By leveraging ThingSpeak's progressed highlights and integration capabilities, clients can streamline environmental observing endeavors, encourage data-driven decision-making, and contribute to the creation of more beneficial and more maintainable communities.

IV. RESULTS AND DISCUSSION

The results and discussion of the integrated air quality monitoring system, featuring the ESP32 WiFi module, OLED display, MQ135 sensor, and ThingSpeak cloud platform, reveal its effectiveness in providing real-time insights into air quality parameters and their implications for public health and environmental management. The ESP32 WiFi module serves as the system's backbone, facilitating seamless internet connectivity and data transmission to the cloud platform. Through extensive testing, the module demonstrated remarkable reliability, maintaining stable connections to WiFi networks and efficiently transmitting air quality data to ThingSpeak. Its dual-core processing capabilities ensured smooth operation, minimizing latency in data acquisition and transmission processes, thus enhancing the system's overall efficiency and performance. The OLED display plays a pivotal role in providing users with immediate feedback on air quality conditions, offering clear and responsive visuals integrated with the ESP32 module. Even under varying lighting conditions, the OLED display enhances user experience and promotes environmental awareness. Its low power consumption further contributes to energy efficiency, empowering users to make informed decisions regarding outdoor activities and indoor air quality management. Meanwhile, the MQ135 sensor, as the primary pollutant detector, exhibits satisfactory performance in detecting various air pollutants such as carbon dioxide (CO2), ammonia (NH3), benzene (C6H6), and smoke. Despite potential limitations in precision compared to specialized sensors, its affordability and ease of integration make it a practical choice for DIY environmental monitoring projects and community-driven initiatives. Moreover, integration with the ThingSpeak cloud platform has been pivotal, facilitating secure data storage, analysis, and visualization. Real-time air quality data collected by the system is securely stored and readily accessible for analysis on ThingSpeak. The platform's visualization tools provide valuable insights into air quality trends and patterns, supporting evidence-based decision-making and environmental monitoring efforts. Overall, the integrated air quality monitoring system represents a significant advancement in environmental sensing technology, leveraging IoT capabilities to address pressing environmental challenges and promote public health and well-being through innovative monitoring solutions. Air quality levels span a spectrum from excellent to hazardous, delineating the potential impact on human health and the environment. As illustrated in the table below, the spectrum begins with "Excellent" or "Good," signifying safe air quality with minimal health risks. Progressing through "Moderate" or "Fair," air quality experiences a slight deterioration, prompting potential health concerns for sensitive individuals. "Unhealthy for Sensitive Groups" denotes elevated pollutant levels, posing risks to vulnerable populations. Transitioning to "Unhealthy" indicates degraded air quality, posing risks to the general population, while "Very Unhealthy" reflects severe pollution levels, necessitating immediate action. Finally, "Hazardous" represents an extreme threat to human health, with dangerous pollutant concentrations. Understanding these levels is vital for implementing effective pollution control measures and safeguarding public health.

In conclusion, the results obtained from the integration of the MQ-135 gas sensor with Arduino Uno and the subsequent connection to ThingSpeak affirm the system's efficacy in air quality monitoring. The versatility, affordability, and accessibility of the components involved make this system a practical choice for a wide range of applications. The successful implementation of this integrated system paves the way for further advancements in affordable and accessible air quality monitoring solutions.

V. CONCLUSION

In conclusion, the integrated air quality monitoring system, consisting of the ESP32 WiFi module, OLED display, MQ135 sensor, and ThingSpeak cloud platform, represents a significant advancement in environmental sensing technology. Throughout this research, we have demonstrated the effectiveness and practicality of our system in providing real-time insights into air quality parameters and their implications for public health and environmental management. The ESP32 WiFi module has served as the backbone of our system, enabling seamless internet connectivity and data transmission to the cloud platform. Through extensive testing, we have observed the module's remarkable reliability, maintaining stable connections to WiFi networks and efficiently transmitting air quality data to ThingSpeak. Its dual-core processing capabilities have ensured smooth operation, minimizing latency in data acquisition and transmission processes, thus enhancing the system's overall efficiency and performance. Integrated with the ESP32 module, the OLED display has played a crucial role in providing users with immediate feedback on air quality conditions. Offering clear and responsive visuals, even under varying lighting conditions, the OLED display has enhanced user experience and promoted environmental awareness. Its low power consumption has further contributed to energy efficiency, empowering users to make informed decisions regarding outdoor activities and indoor air quality management. The MQ135 sensor, serving as the primary pollutant detector, has exhibited satisfactory performance in detecting various air pollutants such as carbon dioxide (CO2), ammonia (NH3), benzene (C6H6), and smoke. Despite potential limitations in precision compared to specialized sensors, its affordability and ease of integration make it a practical choice for DIY environmental monitoring projects and community-driven initiatives. Moreover, integration with the ThingSpeak cloud platform has been pivotal in facilitating secure data storage,

analysis, and visualization. Real-time air quality data collected by the system is securely stored and readily accessible for analysis on ThingSpeak. The platform's visualization tools provide valuable insights into air quality trends and patterns, supporting evidence-based decision-making and environmental monitoring efforts. Overall, our research has underscored the potential of IoT technologies in addressing pressing environmental challenges and promoting public health and well-being through innovative monitoring solutions. By leveraging the capabilities of each component within the integrated air quality monitoring system, we have demonstrated the effectiveness of our approach in providing real-time insights into air quality parameters. Moving forward, further research and development efforts can focus on enhancing the precision and accuracy of sensors, expanding the capabilities of IoT platforms, and fostering collaboration among stakeholders to create sustainable and resilient communities. In conclusion, the integrated air quality monitoring system represents a significant step forward in environmental sensing technology, offering a cost-effective and user-friendly solution for monitoring air quality in diverse settings. Through our research, we have highlighted the potential of this system to contribute to ongoing efforts aimed at addressing environmental challenges and promoting public health and well-being. As we continue to refine and expand upon this technology, we envision a future where innovative monitoring solutions play a central role in creating healthier and more sustainable communities for generations to come.

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