International Research Journal of Multidisciplinary Scope (IRJMS), 2025; 6(1):1362-1372

Original Article | ISSN (O): 2582-631X DOI: 10.47857/irjms.2025.v06i01.02831

Integrated IoT System for Real-Time Air Quality Assessment in Diverse Environments

Sahil S Salvi*, Harish U Tiwari, Sudarshan S Bobade

Department of Civil Engineering, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, Maharashtra, India.

*Corresponding Author's Email: sahil.salvi@pccoer.in

Abstract

In response to escalating concerns over air pollution and its adverse health impacts, we present a comprehensive real-time Air Quality Monitoring System utilizing the Internet of Things (IoT). By deploying a network of cost-effective sensors, this system can measure various pollutants such as CO_2, CO, smoke, and LPG, transmitting data for analysis to aid both authorities and the public in making informed decisions. The core of the system is the ESP32 microcontroller, which integrates sensors like DHT11, MQ135, MQ7, and MQ2 to gather environmental data. Real-time monitoring is facilitated by displaying data on an LCD screen and storing it on the cloud-based ThingSpeak platform for further analysis and visualization. The system's architecture is designed to be both efficient and accessible, utilizing Arduino IDE for code development and ThingSpeak for data handling. The hardware components include the ESP32 microcontroller, various gas sensors, an LCD display, and other essential electronics. The software setup involves configuring the Arduino IDE and ThingSpeak platform for seamless data transmission and visualization. In this research work, we deployed this system in multiple environments, including parking lot, chemical testing lab, and cloud kitchen, to monitor temperature, humidity, and pollutant levels. The results indicated significant variations in air quality across different settings, with the cloud kitchen showing the highest levels of pollutants due to the presence of various chemicals and equipment. Our analysis underscores the importance of continuous air quality monitoring and the system's potential to enhance indoor air quality management proactively.

Keywords: Air Quality Monitoring, Environmental Data Analysis, ESP32, IoT, ThingSpeak.

Introduction

Air pollution, particularly from vehicle emissions, poses significant health and environmental challenges. Addressing this issue requires the implementation of effective monitoring systems. A real-time Air Quality Monitoring System powered by the Internet of Things (IoT) is essential for this purpose (1). By strategically placing IoT sensors, various pollutants can be measured and the data transmitted for analysis. This enables authorities and the public to make informed decisions regarding air quality management (2). Compared to traditional monitoring stations, IoT-based systems are cost-effective, allowing for the establishment of a denser network of monitoring sites, thus improving data accuracy (3). Moreover, these systems can send alerts when pollution levels exceed predefined thresholds, facilitating prompt mitigation measures (4). Indoor air quality is another critical aspect affecting health. Pollutants such as smoke, LPG, and CO_2 can be detrimental, necessitating proper ventilation, maintenance, and monitoring (5). Modern devices like indoor air quality monitors and air purifiers provide real-time data, enabling proactive control to ensure a safe indoor environment (6). IoT-based air pollution monitoring systems, utilizing various sensors and Arduino microcontrollers, aim to detect indoor pollutants and offer real-time air quality monitoring (7). Data is transmitted through mobile applications or web interfaces, allowing access to remote servers and platforms such as ThingSpeak (8). These technologies enhance environmental awareness and promote proactive measures to reduce air pollution, contributing to healthier living environments.

The proposed air pollution detection system utilizes a block structure with the ESP32 microcontroller at its core. The system includes various sensors like the DHT11 for humidity and temperature, MQ7 for carbon monoxide, MQ2 for detecting smoke and LPG, and MQ135 for measuring gases such as carbon dioxide. Real-time data is displayed on an LCD panel and stored on the cloud-based ThingSpeak Platform for visualization

(Received 14th October 2024; Accepted 28th January 2025; Published 31st January 2025)

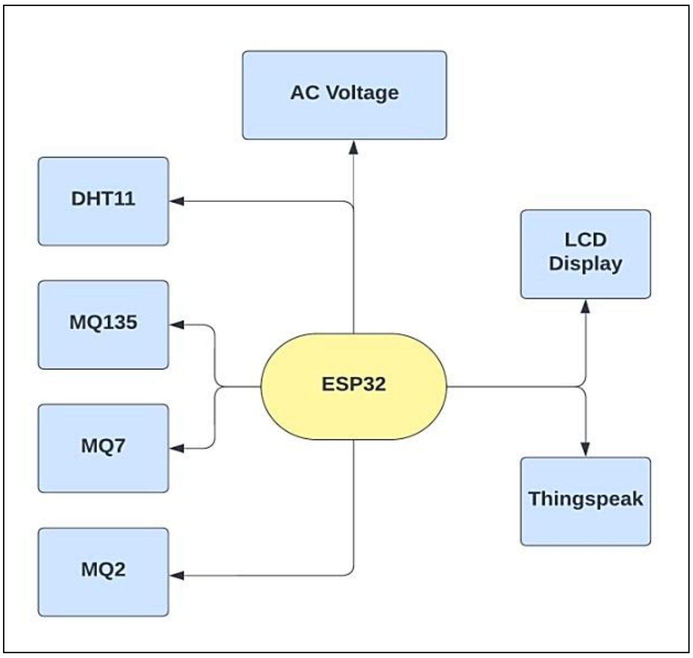

Figure 1: Block Structure

and further analysis. The hardware components required include the ESP32 microcontroller, DHT11 sensor, MQ135 sensor, MQ7 sensor, MQ2 sensor, LCD display, jumper wires, breadboard, and a 9V battery (Figure 1). The software setup involves the Arduino IDE for code development and the ThingSpeak platform for data handling (9). The ESP32 gathers environmental data via the sensors, and the integration with ThingSpeak enables easy data transfer for analysis. The prototype includes all sensor components integrated into a functional system, with data transmission to cloud platforms for processing, storing, and visualizing (10). In this research work, proposed technology is used to monitor temperature, humidity, and pollution levels in a variety of settings, including a parking lot, chemical testing facility, and cloud kitchen. The results revealed considerable differences in air quality between settings, with the cloud kitchen exhibiting the highest levels of pollutants due to the presence of numerous chemicals and equipment and results highlight the relevance of continuous air quality monitoring and the system's ability to improve indoor air quality management proactively. The proposed IoT-based air quality monitoring system offers a cost-effective, real-time, and scalable alternative to traditional high-precision government-grade stations. By integrating MQ135, MQ7, and MQ2 sensors with an ESP32 microcontroller, it effectively detects CO, LPG, and smoke, though periodic calibration is needed. Its main advantage is real-time monitoring via an LCD display and remote access through ThingSpeak, unlike conventional systems that offer delayed readings. Compact and affordable, it's ideal for small-scale use, whereas commercial systems are expensive and complex.

Methodology

The indoor air quality monitoring devices which are available to be used for home is desktop type monitoring gadgets (11). The methodology for developing and implementing an IoT-based real-time Air Quality Monitoring System involves several critical steps, from hardware selection to data analysis (12). This section outlines the systematic approach undertaken in the project, ensuring clarity and reproducibility.

System Architecture

The proposed air quality monitoring system comprises several key components, each playing a crucial role in ensuring accurate and reliable data collection and transmission. At the heart of the system is the ESP32 microcontroller, which serves as the central processing unit (13). This versatile microcontroller interfaces with various sensors and is responsible for transmitting data to the cloud (14). The sensors used include the DHT11 for humidity and temperature measurements, the MQ7 for detecting carbon monoxide, the MQ135 for measuring carbon dioxide and other gases, and the MQ2 for detecting smoke and liquefied petroleum gas (LPG). Additionally, an LCD display is integrated into the system to provide real-time data visualization for immediate monitoring (15). The ThingSpeak platform is utilized for storing, visualizing, and analyzing the sensor data, offering a comprehensive overview of air quality metrics. Environmental protection is one of the most important challenges for the people (16). The long-term performance of the system relies on regular maintenance, particularly for sensor calibration and managing degradation due to environmental factors. To ensure consistent performance, the system will feature easy sensor replacement, self-calibration algorithms, and scheduled monitoring to optimize longevity.

Hardware Setup

The hardware setup of the air quality monitoring system integrates several critical components to ensure comprehensive environmental data collection and real-time monitoring. At the core of the system is the ESP32 microcontroller, selected for its robust dual-core processing capabilities, integrated Wi-Fi, and Bluetooth functionalities, making it highly suitable for Internet of Things (IoT) applications (17). This microcontroller acts as the central unit that interfaces with various sensors and transmits data to the cloud.

The system employs the DHT11 sensor for measuring temperature and humidity with high accuracy, providing essential environmental data that can influence air quality. To detect a broad range of gases, the MQ135 sensor is used, capable of sensing carbon dioxide (CO2), ammonia, benzene, and other gases. This sensor enhances the system's ability to monitor multiple air pollutants simultaneously (18).

For specific detection of carbon monoxide (CO), a critical air pollutant, the MQ7 sensor is incorporated into the setup. This sensor's ability to accurately measure CO levels is vital for assessing air quality, particularly in urban and industrial areas (19). Additionally, the MQ2 sensor is included to detect smoke and liquefied petroleum gas (LPG), further extending the monitoring capabilities of the system to cover various combustion-related pollutants.

An LCD display is integrated into the hardware setup to provide real-time data visualization. This feature enables immediate access to the collected data, allowing for prompt monitoring and response. The components are connected and prototyped using jumper wires and a breadboard, which facilitate easy assembly and modification of the system during the development phase. The entire system is powered by a 9V battery, ensuring mobility and ease of deployment in different environments. This power source supports the system's operation without the need for a constant external power supply, making it adaptable for field use and remote monitoring applications. The proposed IoT-based air quality monitoring system is energy-efficient, utilizing the low-power ESP32 microcontroller and intermittent sensor operation to reduce energy consumption, making it suitable for long-term deployment, even in remote or off-grid locations. While challenges like sensor calibration and data transmission stability exist, they can be addressed with adaptive sampling rates and energy-saving techniques, offering a scalable and cost-effective solution for sustainable air quality monitoring.

Software Setup

The software setup of the air quality monitoring system is designed to ensure seamless integration, data processing, and real-time monitoring. Central to this setup is the Arduino Integrated Development Environment (IDE), which is used to write and upload code to the ESP32 microcontroller. The Arduino IDE supports C++ programming and provides a comprehensive suite of libraries and examples that facilitate development. This environment allows for the efficient implementation of sensor interfacing, data acquisition, and communication protocols necessary for the system's operation.

In conjunction with the Arduino IDE, the ThingSpeak platform is employed for data storage, visualization, and analysis. ThingSpeak, an open-source Internet of Things (IoT) platform developed by MathWorks, provides robust tools for handling the sensor data transmitted by the ESP32. It allows for the creation of channels where data from various sensors can be securely stored and visualized in real-time. Additionally, ThingSpeak offers built-in MATLAB analytics, enabling advanced data analysis and visualization capabilities that are crucial for interpreting air quality metrics and trends. The integration of these software tools ensures that the air quality monitoring system can efficiently collect, transmit, and analyze environmental data. The Arduino IDE's versatility and ease of use streamline the development process, while ThingSpeak's powerful data handling and analytical features provide a comprehensive platform for monitoring and assessing air quality in real-time. This combination of software tools is essential for developing a reliable and effective air quality monitoring system.

Data Acquisition and Processing

The data acquisition and processing component of the air quality monitoring system is pivotal to its functionality. The ESP32 microcontroller is meticulously programmed to interface with various sensors, ensuring accurate data collection and real-time display on an LCD screen (Figure 2). The DHT11 sensor reads temperature and humidity levels, providing essential environmental data. The MQ7 sensor is specifically designed to detect carbon monoxide (CO) levels, which is crucial for monitoring air pollution. The MQ135 sensor measures concentrations of carbon dioxide (CO_2) and other gases such as ammonia and benzene, offering a comprehensive assessment of air quality. The MQ2 sensor is used to detect smoke and liquefied petroleum gas (LPG), thus extending the range of pollutants monitored by the system. The ESP32 microcontroller utilizes its built-in Wi-Fi capabilities to transmit the collected sensor data to the ThingSpeak server. This data transmission process involves several key steps: Registration involves creating an account on the ThingSpeak platform and setting up a new channel to receive and store the sensor data. An API key is obtained from ThingSpeak to ensure secure and authenticated data transmission. Finally, the API key is integrated into the Arduino code, enabling the ESP32 to send data to the ThingSpeak server. This systematic approach to data acquisition and processing ensures that the air quality monitoring system operates efficiently and reliably. The use of ThingSpeak for data storage and analysis allows for real-time visualization and advanced analytics, making it possible to monitor air quality trends and make informed decisions based on accurate environmental data. The transmission and storage of environmental data on cloud platforms raise security and privacy concerns, which are addressed through encryption protocols and secure authentication. Future improvements will enhance security with end-to-end encryption and explore IoT-specific cloud services to ensure data integrity and confidentiality.

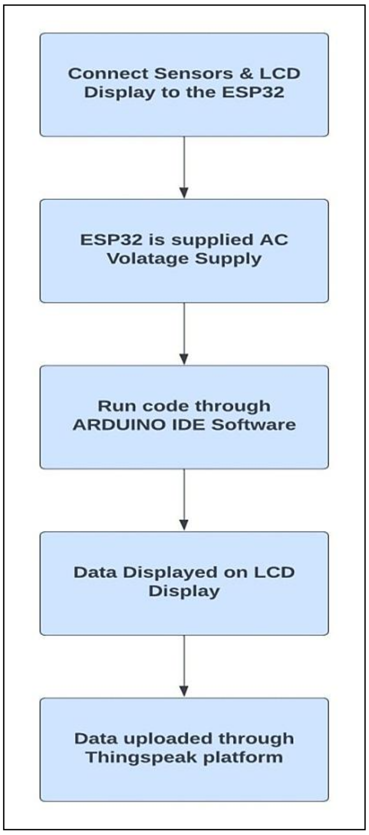

Figure 2: Connections and Data Processing

Prototype Development

The development of a functional prototype involves the careful assembly and integration of the ESP32 microcontroller, sensors, LCD display, and other essential components on a breadboard (Figure 3). The ESP32 acts as the central hub, interfacing with all the sensors and ensuring that the data is accurately displayed on the LCD screen. This setup allows for efficient real-time monitoring of air quality parameters.

In terms of connectivity, the prototype is configured to connect seamlessly to local Wi-Fi networks. This connectivity enables the system to transmit collected sensor data to cloud platforms such as ThingSpeak. The data transmitted to ThingSpeak is then processed, stored, and visualized, providing a comprehensive view of the environmental conditions. This setup not only facilitates real-time data monitoring but also supports advanced data analytics and trend analysis, thereby enhancing the overall functionality and utility of the air quality monitoring system.

Data Visualization and Analysis

The ThingSpeak platform offers a user-friendly interface for visualizing sensor data through various graphs and charts. This visualization capability is crucial for interpreting the collected data and making informed decisions. The key parameters displayed on the ThingSpeak platform include temperature, humidity, the Air Quality Index (AQI), carbon monoxide (CO) levels, and LPG and smoke levels. Temperature is continuously monitored and displayed to track changes over time, providing insights into environmental conditions. Humidity levels are tracked to ensure comfort and maintain optimal air quality, which is essential for both health and safety. The AQI is an aggregated score derived from the data collected by all sensors. It provides an overall indication of air quality, helping users quickly assess environmental conditions. CO levels are monitored for safety purposes, as elevated levels can be hazardous to health. LPG and smoke levels are critical for detecting potential fire hazards and gas leaks, thereby enhancing safety and emergency preparedness. By leveraging the visualization tools provided by ThingSpeak, users can easily interpret and analyze the data collected by the air quality monitoring system. This capability enables real-time monitoring and long-term trend analysis, facilitating effective air quality management and decision-making.

Experimental Setup/Deployment

The air quality monitoring system was strategically deployed across diverse environments to ensure comprehensive data collection and analysis. These environments included parking lots, chemical testing laboratories, and cloud kitchens, chosen for their varying air quality conditions [16]. The system's deployment aimed to capture a wide range of air quality parameters, including temperature, humidity, Air Quality Index (AQI), carbon monoxide (CO) levels, and concentrations of liquefied petroleum gas (LPG) and smoke. Data collection was carried out over an extended period, allowing for the accumulation of a robust dataset necessary for thorough analysis. This systematic approach enabled the monitoring of temporal variations and patterns in air quality across different settings. By deploying the system in these specific environments, the study aimed to address the unique air quality challenges associated with each location, such as vehicle emissions in parking lots, chemical fumes in testing labs, and cooking emissions in cloud kitchens. The gathered data was then transmitted to the ThingSpeak platform for real-time visualization and analysis, leveraging its user-friendly interface for interpreting the sensor readings. This deployment strategy ensured that the collected data was both extensive and reliable, providing a solid foundation for subsequent air quality assessments and decision-making processes. The proposed IoT-based air quality monitoring system is highly scalable, with each unit independently transmitting data to a central platform like ThingSpeak, allowing for easy expansion across larger areas or integration with existing networks. Its wireless communication and ESP32 microcontroller with Wi-Fi and Bluetooth connectivity enable seamless integration with other IoT solutions, supporting real-time monitoring and broad environmental frameworks, making it ideal for smart cities and regulatory compliance.

Data Analysis

The analysis of the collected data involves a systematic comparison with established air quality standards to identify any deviations. This step is crucial for understanding the air quality across different environments and pinpointing areas that require improvement. By comparing real-time sensor data with benchmark values, we can assess the severity of pollution levels and their potential health impacts. Trends in the data are meticulously analyzed to uncover patterns and potential causes of air pollution. This involves examining temporal variations and correlations between different parameters, such as the relationship between increased CO levels and specific activities or times of the day. Identifying these patterns helps in understanding the dynamics of air pollution and the factors contributing to it. The insights gained from this analysis are vital for developing targeted strategies to mitigate air pollution. For instance, identifying peak times of high pollution can inform policies for emission control, and recognizing pollution hotspots can guide the implementation of localized air quality improvement measures. This comprehensive data analysis not only enhances our understanding of air quality but also provides a robust foundation for effective intervention and policy-making aimed at improving environmental health.

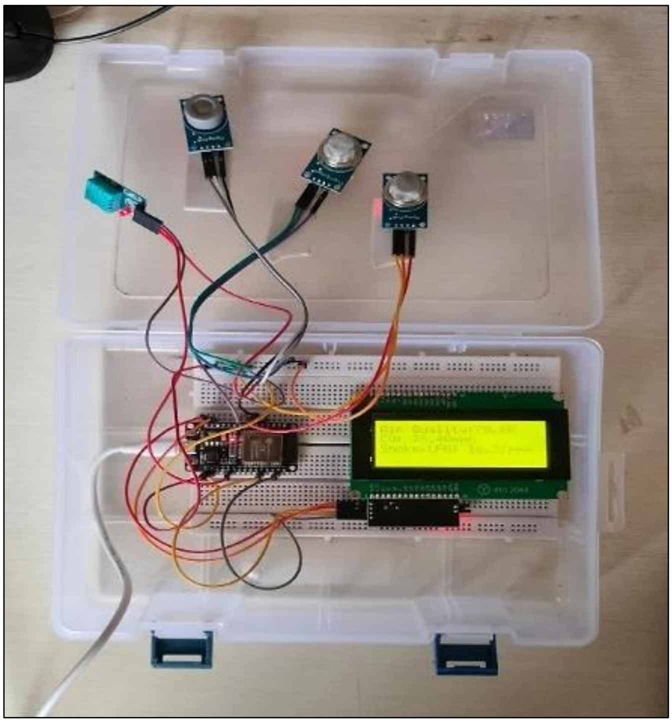

Figure 3: Prototype Developed

Results and Discussion

Temperature

The temperature data collected from various environments, including a parking lot, chemical testing lab, and cloud kitchen, was analyzed and compared with standard temperature values obtained from the National Institute of Health and Indian climate data. The analysis reveals distinct temperature profiles across these environments. In the cloud kitchen, the environment exhibits the highest temperatures. This is primarily due to the presence of numerous heat-generating appliances and activities. The constant use of stoves, ovens, and other kitchen equipment significantly contributes to the elevated temperature levels. In the parking lot, the temperature is notably high, likely due to the combined heat generated by vehicles and machinery, along with the physical activities of people and the exposure to direct sunlight. In the chemical testing lab, the temperature is comparatively moderate. This reflects the effectiveness of climate control measures implemented to ensure accurate experimental conditions and safety when handling various chemicals. The controlled environment is crucial for maintaining the integrity of experiments and the safety of personnel. These variations underscore the importance of temperature regulation in different settings to maintain operational efficiency and adhere to safety standards. Recognizing these temperature differences helps in designing targeted strategies for temperature management, ensuring optimal working conditions and safety in diverse environments.

Humidity

The humidity levels recorded in the parking lot, chemical testing lab, and cloud kitchen were analyzed and compared against standard values provided by the National Institute of Health and Indian climate data. The findings highlight distinct humidity profiles in each environment. In the parking lot, the humidity levels are the highest. This can be attributed to the regular usage of the parking lot for vehicle parking, which generates steam or moisture, and water-based activities that contribute to the increased humidity. In the chemical testing lab, the humidity levels are the lowest. This low humidity is a result of controlled ventilation systems and humidity regulation measures implemented to ensure the integrity of experiments and the safety of personnel handling various chemicals. Such measures are crucial for maintaining a stable and safe environment. In the cloud kitchen, the humidity levels are moderate. This is influenced by the presence of fumes and steam generated by cooking activities. Despite this, the controlled ventilation systems in place help to maintain a balanced humidity level, ensuring both comfort and safety in the kitchen environment. These observations emphasize the importance of humidity control in different settings to ensure operational efficiency and adherence to safety standards. These humidity variations aids in the development of targeted strategies for humidity management, ensuring optimal working conditions in diverse environments.

Air Quality Index (AQI) and Smoke Level

The AQI values for the cloud kitchen, chemical testing lab, and parking lot were measured and compared with standard values. The AQI is a standardized indicator that reflects the overall quality of the air by quantifying the concentration of various pollutants. The results revealed distinct AQI profiles for each environment. In the cloud kitchen, the AQI was the highest, indicating poorer air quality. This is primarily due to the variety of substances released during cooking processes, such as smoke, fumes, and particulate matter, which significantly impact the air quality. In the chemical testing lab, the AQI was moderate. This reflects the effectiveness of controlled air quality measures implemented within the lab, such as ventilation systems and air purifiers, which help to maintain acceptable air quality levels despite the use of various chemicals. In the parking lot, the AQI was the lowest among the three environments, though still below the threshold of 100, indicating acceptable air quality. The relatively lower AQI can be attributed to the open-air environment and the infrequent presence of significant pollution sources.

Smoke levels in the cloud kitchen, chemical testing lab, and parking lot were measured and compared with standard values. The findings highlight the differences in smoke concentration across these environments. In the cloud kitchen, the smoke levels were the highest. This is due to the exposure to a wide range of contaminants and pollution sources, such as cooking fumes and gas emissions, which contribute to elevated smoke levels.In the parking lot, smoke levels were controlled, with infrequent use of LPG and limited sources of smoke. The open-air setting and the lack of continuous smoke-producing activities help to keep the smoke levels relatively low. In the chemical testing lab, the smoke levels were moderate. This reflects the controlled use of chemicals and the effectiveness of ventilation measures in place to manage smoke emissions and maintain a safe working environment. These results underscore the importance of implementing targeted strategies to manage AQI and smoke levels in different environments, ensuring optimal air quality and safety standards are maintained.

Carbon Monoxide (CO)

The carbon monoxide (CO) levels in the parking lot, chemical testing lab, and cloud kitchen were measured and compared against standard values. The analysis highlights distinct variations in CO concentrations across these environments. In the parking lot, CO levels were the highest. This is primarily due to the usage of fuel-burning machinery and equipment, such as vehicles and maintenance tools. The insufficient ventilation in enclosed or semi-enclosed parking areas, combined with higher occupancy levels, contributes significantly to elevated CO levels. In the chemical testing lab, CO levels were moderate. The controlled ventilation systems and strict experimental conditions help to manage and mitigate CO emissions, ensuring that the environment remains within acceptable safety standards. These measures are essential for maintaining air quality and protecting the health of laboratory personnel (Figure 4). In the cloud kitchen, CO levels were also high. This is attributed to inadequate ventilation and the presence of multiple combustion sources, such as gas stoves and ovens, which release CO during cooking processes.

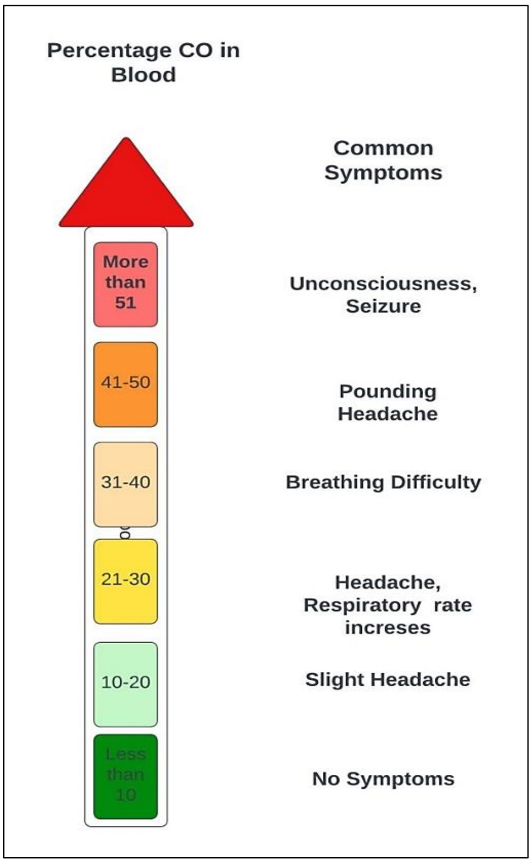

Figure 4: CO Percentages in Blood and its Symptoms

The enclosed nature of many kitchen spaces can exacerbate the accumulation of CO, making effective ventilation crucial. These findings underscore the need for targeted interventions to manage CO levels in different environments. Improving ventilation, monitoring CO concentrations regularly, and implementing strategies to reduce emissions from combustion sources are essential steps to ensure safe air quality standards and protect occupant health. The comparative analysis of environmental data from the parking lot, chemical testing lab, and cloud kitchen reveals distinct conditions specific to each location. The system monitors air quality parameters such as CO, LPG, smoke, and AQI within limits set by regulatory bodies like NAAQS and WHO, supporting environmental compliance and early warnings. While not as precise as government-grade instruments, the system's sensors can be calibrated for localized monitoring and cloud-based reporting, ensuring regulatory adherence. The cloud kitchen exhibits the highest temperature, attributed to the constant use of heat-generating appliances such as stoves and ovens. The chemical testing lab maintains a moderate temperature due to effective climate control measures essential for precise experimental conditions. The parking lot, while exposed to direct sunlight and machinery heat, shows the lowest temperature among the three locations. Humidity levels are highest in the parking lot, likely due to moisture from vehicle emissions and water-based activities. The chemical testing lab has the lowest humidity, reflecting controlled ventilation and humidity regulation critical for accurate experiments. The cloud kitchen experiences moderate humidity influenced by cooking fumes and controlled ventilation systems. The cloud kitchen records the highest AQI, indicating poorer air quality due to various pollutants from cooking activities. The chemical testing lab shows a moderate AQI, benefiting from controlled air quality measures. The parking lot has the lowest AQI, staying below the threshold of 100, indicating acceptable air quality despite occasional emissions from vehicles.

(Figure 5) Smoke concentrations are within the acceptable limit of 70 parts per million (PPM) across all locations. The cloud kitchen, however, shows the highest smoke levels due to exposure to cooking-related contaminants and potential pollution sources. The parking lot maintains controlled smoke levels with infrequent use of liquefied petroleum gas (LPG) and smoke sources. The chemical testing lab shows moderate smoke levels, reflecting controlled use of chemicals and ventilation measures.CO concentrations are safely below the standard threshold of 35 PPM in all locations. The parking lot exhibits the highest CO levels, primarily due to emissions from surrounding vehicles and machinery. The chemical testing lab shows moderate CO levels, managed by controlled ventilation systems. The cloud kitchen also shows high CO levels, attributed to inadequate ventilation and combustion sources during cooking activities. The detailed parameter readings are presented in the (Table 1) below.

Table 1: Indoor Air Quality Parameter Outputs

Sr. No.	Parameter	Standard Values	Units	Actual Result		
				Location 1	Location 2	Location 3
1	Temperature	19-33	°C	34.53	36.5	37.4
2	Humidity	Below 60	%	48	43.71	47
3	AQI	Below 100	-	57.16	54.66	64.93
4	LPG	Below 70	ppm	13.91	19.4	23.6
5	CO	Below 35	ppm	19.66	15.86	15.09

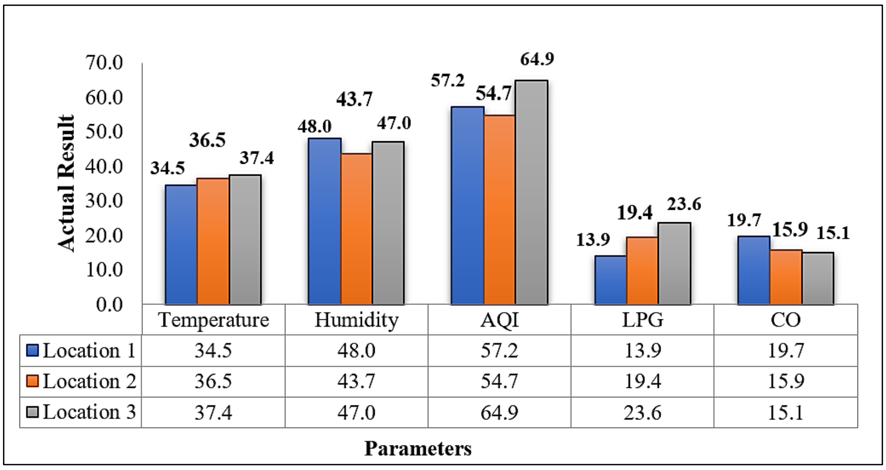

Figure 5: Analysis of Indoor Air Quality

The unique environmental characteristics of each location are evident from the data. The Cloud kitchen's high temperature and pollution levels suggest problems with ventilation and emissions control, necessitating further investigation and mitigation. The Parking lot's high CO and humidity levels indicate the need for improved ventilation. The Chemical testing lab's controlled environment, reflected by the lowest CO level and moderate parameter values, serves as a model for maintaining optimal conditions in similar settings. These results underscore the importance of continuous monitoring and proactive measures to maintain safe and healthy environments across different operational areas. The integration of IoT-based air quality monitoring systems, as demonstrated in this study, provides a scalable and effective solution for real-time environmental monitoring and management. This study's limitations include reliance on low-cost sensors requiring calibration due to drift, and network dependency, with future improvements targeting sensor accuracy, AI integration, energy efficiency, and expanded environmental parameters.

Conclusion

The research presents a robust air quality monitoring system leveraging the ESP32 microcontroller, along with MQ135, MQ7, and MQ2 sensors, to facilitate real-time detection of indoor pollutants. The integration of an LCD for immediate environmental feedback and the ThingSpeak platform for advanced data storage and analysis significantly enhances the system's utility for proactive air quality management. The methodology employed involved deploying the system across three distinct locations—a cloud kitchen, a parking lot, and a chemical lab—to evaluate and compare the measured environmental parameters against industry standards. The results indicated noteworthy trends: temperatures exceeded the average by 4.64%, 10.61%, and 13.33% at the respective locations; humidity levels were substantially below the average of 60% by 20%, 27.15%, and 21.67%; the Air Quality Index (AQI) was also significantly lower, showing values 42.84%, 45.34%, and 35.7% below the standard of 100. Additionally, smoke levels fell 80.13%, 72.29%, and 66.29% below the normative value of 70 PPM, while carbon monoxide (CO) concentrations were 43.83%, 54.69%, and 56.88% below the established limit of 35 PPM. The outcome reveal that the cloud kitchen environment demonstrated the highest levels of temperature, humidity, AQI, and smoke, underscoring the critical need for continuous monitoring and effective mitigation strategies to ensure health and safety in such sensitive areas. This research not only contributes to the existing body of knowledge regarding indoor air quality management but also highlights the potential of integrating IoT technologies in environmental monitoring systems to enhance public health outcomes. Future research should aim to enhance sensor calibration, integrate AI for better predictions, improve energy efficiency, expand for large-scale use, refine user interfaces, ensure environmental compliance, and integrate with smart city frameworks for improved air quality management.

Abbreviations

PPM: Parts Per Million, AQI: Air Quality Index, IoT: Internet of Things, LCD: Liquid Crystal Display, CO: Carbon Monoxide, LPG: Liquefied Petroleum Gas, IDE: Integrated Development Environment.

Acknowledgement

The authors are thankful to Pimpri Chinchwad Education Trust and Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, Maharashtra, India to their continuous supports. Also, the authors extend gratitude to all those researchers, scientist and authors who are having great research work in this field.

Author Contributions

Authors contributed equally to conceptualization, data analysis, and manuscript writing for this study.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

Not Applicable.

Funding

No funding received.

References

1. Dhingra S, Madda RB, Gandomi AH, Patan R, Daneshmand M. Internet of things mobile-air pollution monitoring system (IoT-Mobair). IEEE Internet Things J. 2019;6(3):5577–84.
2. De Giuli V, Zecchin R, Salmaso L, Corain L, De Carli M. Measured and perceived indoor environmental quality: Padua Hospital case study. Build Environ. 2013;59:211–26.
3. Zhao L, Wu W, Li S. Design and Implementation of an IoT-Based Indoor Air Quality Detector With Multiple Communication Interfaces. IEEE Internet Things J. 2019;6(6):9621–32.
4. Ha QP, Metia S, Phung MD. Sensing Data Fusion for Enhanced Indoor Air Quality Monitoring. IEEE Sens J. 2020;20(8):4430–41.
5. Arif M, Katafygiotou M, Mazroei A, Kaushik A, Elsarrag E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. International Journal of Sustainable Built Environment. 2016 Jun 1;5(1):1.
6. Kumar P, Martani C, Morawska L, Norford L, Choudhary R, Bell M, Leach M. Indoor air quality and energy management through real-time sensing in commercial buildings. Energy and Buildings. 2016 Jan 1;111:145-53.
7. Jayadeva SM, Gnanasekar AK, Sunagar P, Harshith N, Salvi SS, Kumar A. Analysis of smart city environment by artificial intelligent techniques. AIP Conf Proc. 2023;2831(1). https://pubs.aip.org/aip/acp/article-abstract/2831/1/020010/2911889
8. Karami M, McMorrow GV, Wang L. Continuous monitoring of indoor environmental quality using an Arduino-based data acquisition system. J Build Eng. 2018;19:412–9.

9. Sai KB, Mukherjee S, Sultana HP. Low cost IoT based air quality monitoring setup using Arduino and MQ series sensors with dataset analysis. Procedia Computer Science. 2019 Jan 1;165:322-7.
10. Listyarini S, Warlina L, Sambas A. Air Quality Monitoring System in South Tangerang Based on Arduino Uno: From Analysis to Implementation. IOP Conf Ser Mater Sci Eng. 2021;1115(1):012046.
11. Senthilnathan K, Iyswarya Annapoorani K. Arti fi cial Neural Network Control Strategy for Multi-converter Uni fi ed Power Quality Conditioner for Power Quality Improvements in 3-Feeder System. Adv Intell Syst Comput. 2016;394:1105–11.
12. Natarajan S, Jeelani SH, Sunagar P, Magade S, Salvi SS, Bhattacharya S. Investigating Conventional Concrete using Rice Husk Ash (RHA) as a Substitute for Finer Aggregate. InJournal of Physics: Conference Series. 2022 Jul 1;2272(1):012030.
13. Saini J, Dutta M, Marques G. Indoor air quality monitoring systems based on internet of things: A systematic review. Int J Environ Res Public Health. 2020;17(14):1–22.
14. Saini J, Dutta M, Marques G. A comprehensive review on indoor air quality monitoring systems for enhanced public health. Sustain Environ Res. 2020;30(1):1–12.
15. Marques G and Pitarma R. An Internet of Things-based environmental quality management system to supervise the indoor laboratory conditions. Appl Sci. 2019;9(3) :1–17.
16. Salvi S, Sabale R, Bobade S, Dhawale A. Innovative Use of Eco-Enzymes for Domestic Wastewater Purification. J Environ Nanotechnol. 2024;13(3):435–439.
17. Wang B, Kong W, Guan H, Xiong NN. Air Quality Forecasting Based on Gated Recurrent Long Short Term Memory Model in Internet of Things. IEEE Access. 2019;7:69524–34.
18. Madureira J, Paciência I, Pereira C, Teixeira JP, Fernandes ED. Indoor air quality in Portuguese schools: levels and sources of pollutants. Indoor air. 2016 Aug;26(4):526-37.
19. Marques G, Pires IM, Miranda N, Pitarma R. Air quality monitoring using assistive robots for ambient assisted living and enhanced living environments through internet of things. Electron. 2019;8(12):1–17.