Cost-Effective Sensors Interfaced with a Microcontroller Equipped with Wi-Fi Capability, Enabling Seamless Transmission of Collected Data to a Cloud-Based Dashboard for Real-Time Visualization and Analytical Assessment

[1]M L Sharma, [2]Sunil Kumar, [3]Soumi Ghosh, [4]Jatin Danu, [5]Madhav Chhabra, [6]Gatik Chanana

[1,2,3]Faculty, Maharaja Agrasen Institute of Technology, Delhi

[4,5,6]Research Scholar, Maharaja Agrasen Institute of Technology, Delhi

[1]madansharma.20@gmail.com, [2]sunilkumar@mait.ac.in, [3]ghoshdrsoumi@gmail.com,

[4]jatindanu2603@gmail.com, [5]madhavchhabra2@gmail.com, [6]chananagatik@gmail.com

Abstract

Indoor air quality has emerged as a major public health and environmental priority in recent years, driven by rapid urban expansion, increased industrial activities, and the growing amount of time people spend within enclosed buildings. Numerous studies reveal that the concentration of harmful pollutants indoors can often exceed outdoor levels, leading to respiratory illnesses, reduced concentration and productivity, and long-term adverse effects on human well-being. To address this issue, the present work introduces an IoT-enabled indoor air quality monitoring system designed to continuously track key environmental parameters such as temperature, humidity, carbon dioxide levels, and particulate matter (PM2.5/PM10). The system incorporates cost-effective sensors interfaced with a microcontroller equipped with Wi-Fi capability, enabling seamless transmission of collected data to a cloud-based dashboard for real-time visualization and analytical assessment. The stored information supports remote access, automated warning alerts, and informed decision-making related to ventilation improvement and environmental control. Performance evaluation indicates that the proposed model delivers accurate, reliable, and stable measurements suitable for deployment in residential, educational, healthcare, commercial, and industrial infrastructure. By providing a scalable, affordable, and user-friendly solution, this work supports the development of smart infrastructure and contributes toward sustainable environmental management.

Keywords : IoT, Indoor Air Quality Monitoring, Environmental Sensing, Cloud Dashboard, Real-Time Data Acquisition, Air Pollution Control, Smart Environment, Wireless Sensor Network, Particulate Matter (PM2.5/PM10), CO_2 Concentration Analysis, Smart Cities

1. INTRODUCTION

Air quality is a crucial environmental factor that significantly influences public health and overall quality of life. With rapid industrial growth, urban congestion, and increasing population density, the presence of hazardous pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM2.5 and PM10) has risen sharply, posing serious threats to human health. Research suggests that indoor environments can sometimes contain higher pollutant concentrations than the outdoors due to inadequate ventilation, accumulation of dust, chemical emissions from household materials, and combustion by-products. Since people typically spend nearly 80–90% of their daily time indoors, the need for continuous monitoring and effective indoor air management has become more critical than ever.

Conventional air-quality measurement tools often rely on high-precision laboratory instruments, which are costly and impractical for everyday use. However, recent advancements in Internet of Things (IoT) technology present affordable and scalable alternatives capable of providing real-time pollutant tracking, automated alerting mechanisms, and cloud-based data analytics. Numerous recent studies involving smart sensor networks, low-power embedded systems, and cloud-integrated dashboards highlight the growing importance of IoT-driven solutions in promoting healthy smart-environment infrastructure.

In addressing this need, the present research proposes an IoT-based indoor air quality monitoring system that employs a network of environmental sensors and wireless communication to measure and publish real-time air-quality parameters through a cloud dashboard. The primary goal of this system is to deliver an accessible, cost-efficient, and reliable platform suitable for deployment in smart homes, educational institutions, healthcare facilities, and commercial buildings.

Figure 1. Sources of indoor air pollution

2. LITERATURE REVIEW

Indoor air quality monitoring has attracted considerable research interest in recent years, largely due to rising health concerns and the growing impact of environmental pollution. A significant portion of recent studies has focused on developing sensor-based monitoring systems integrated with IoT technologies to enable continuous remote surveillance of indoor atmospheric conditions. In the study conducted by **Norlyana Azemi et al. (2021)**, a compact portable IAQ monitoring device was developed and connected to a cloud platform, demonstrating the effectiveness of wireless sensing networks in real-time environmental assessment. In another contribution, **Jo et al. (2020)** designed an IoT-driven monitoring platform that utilized gas sensors and cloud storage to provide real-time visualization, historical data logging, and analytical interpretation, supporting predictive environmental control strategies. Furthermore, a recent investigation published in **Procedia Computer Science (2023)** introduced an improved IoT-enabled monitoring solution with enhanced sensitivity and accuracy, emphasising the role of sensor calibration and long-term measurement stability.

While these research efforts highlight the importance and potential of IoT-based approaches for indoor air quality assessment, existing systems still encounter several limitations, such as high deployment cost, limited scalability, lack of integrated alert mechanisms, and restricted remote accessibility. Many available solutions also struggle to offer user-friendly dashboards capable of presenting detailed pollutant trends and automated warnings.

Comparison of IOT-based Indoor Air Quality Monitoring Research

Year	Sensors Used	Cloud Dashboard Support	Real-Time Alerts	Key Limitations
2021	**Norlyana Azemi et. 2021**	CO, CO2, Temp, Humid,	No	Limited sensor range, no remote control
2020	CO, CO2, Temp, Humid, Dust, VOCs	Yes (Blynk)	~150	No
2020	**Jo at. 2020**	Yes (ThingSeak	~200	Yes
2023	CO, CO2, O3, Temp, Hurid, PM1, PM1, PM1, P2.5, PM10	Proporarly hardware, scalabilty issues	~100 (Est.)	Yes (SMS/Email)
	Proposed System	Yes (Custom/AWS AWS)		Initial calibration effort

Table 1: Comparative analysis of selected studies and the proposed system

To overcome these shortcomings, the present study proposes a **cost-efficient, cloud-integrated indoor air quality monitoring system** designed to provide real-time data visualisation and continuous accessibility. The system is engineered for quick deployment and scalability, making it suitable for diverse application domains including residential buildings, educational institutions, healthcare facilities, commercial offices, and industrial environments. By improving the availability and usability of air-quality information, the proposed solution aims to support proactive environmental management and promote healthier indoor living conditions.

3. PROPOSED SYSTEM

The proposed IoT-based indoor air quality monitoring system is developed to measure and evaluate key environmental parameters such as carbon dioxide (CO_2), particulate matter (PM2.5 and PM10), temperature, and humidity in real time. These parameters are sensed through low-cost, reliable electronic sensors connected to a microcontroller equipped with built-in Wi-Fi connectivity. The acquired data is processed, formatted, and transmitted to a cloud platform where it is stored and visualized through an interactive dashboard, enabling continuous environmental tracking and analytical assessment.

The system enables users to remotely observe indoor air quality conditions through smartphones or computers from any location. When pollutant levels exceed predefined safe thresholds, the system can generate immediate alert notifications, allowing timely corrective actions such as improving ventilation, activating air purification systems, or adjusting HVAC settings. Designed with versatility in mind, the solution is compact, energy-efficient, and scalable, making it suitable for deployment in residential buildings, educational institutions, hospitals, offices, and industrial facilities.

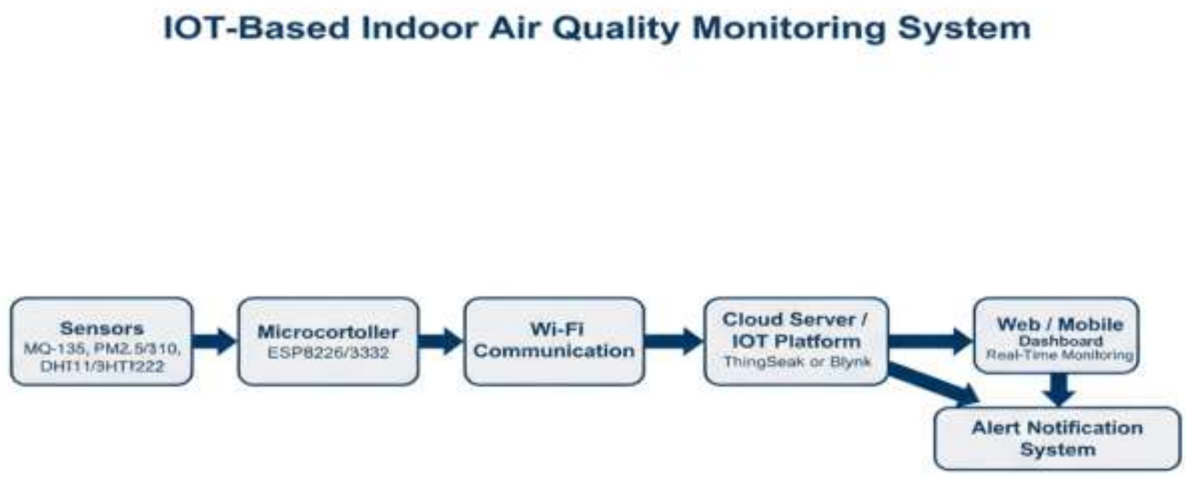


Figure 2. Block Diagram of the Proposed IoT-Based Indoor Air Quality Monitoring System

---

3.1 Objectives of the Proposed System

The major objectives of the proposed indoor air quality monitoring system include:

- To continuously and accurately measure essential indoor environmental parameters.
- To provide access to real-time and historical data through a cloud-integrated dashboard.
- To offer an affordable, user-friendly, and scalable monitoring alternative.
- To send real-time notifications when pollutant levels exceed acceptable limits.
- To support improved decision-making for ventilation, filtration, and smart automation control.

3.2 Advantages

The proposed system offers several significant advantages, including:

- **Cost-effective** when compared to professional laboratory-grade instruments.
- **Easy installation and low maintenance**, suitable for non-technical users.
- **Remote monitoring capability** with long-term cloud data storage.
- **Ideal for health-oriented real-time applications** such as classrooms, hospitals, and workplaces.

4. SYSTEM ARCHITECTURE AND METHODOLOGY

The system architecture comprises three core operational phases: **data acquisition**, **data transmission**, and **data visualization**. A network of environmental sensors continuously collects information regarding air quality parameters, which are then processed by a microcontroller equipped with Wi-Fi capability. The processed data is transmitted to a cloud platform, where it is stored, analyzed, and presented to the user through an interactive dashboard interface. This architecture enables seamless end-to-end monitoring and provides real-time awareness of indoor environmental conditions.

4.1 Methodology Workflow

The functional workflow of the proposed air quality monitoring system is structured as follows:

- **Sensing:** Dedicated environmental sensors measure pollutant concentrations and atmospheric conditions such as temperature, humidity, CO_2, and particulate matter.
- **Processing:** The microcontroller filters raw sensor outputs, calibrates values, and converts them into standardized digital data suitable for transmission.
- **Transmission:** The processed readings are communicated wirelessly to a cloud storage platform via Wi-Fi using HTTP or MQTT protocols.
- **Visualization:** The cloud dashboard displays numerical data, graphical trends, and air-quality status indicators along with warning messages if values exceed safe thresholds.
- **Response:** Based on system alerts, users may implement corrective measures such as improving ventilation, operating air purifiers, or activating HVAC control systems.

Figure 3. System Architecture and Workflow of the Proposed IoT-Based Indoor Air Quality Monitoring System

4.2 Environmental Data Parameters

Temperature	°C	Affects thermal comfort and indoor ventilation performance
Humidity	%RH	High humidity increases risk of bacteria and mold growth leading to respiratory issues
Carbon Dioxide	CO_2 (ppm)	High levels cause headaches, fatigue, low concentration, and oxygen deprivation
Particulate Matter	PM2.5 / PM10 (µg/m³)	Can penetrate lungs and bloodstream, causing asthma and long-term diseases

These selected parameters directly influence human comfort, productivity, and long-term health, making their continuous monitoring essential for sustainable living environments.

4.3 Cloud Dashboard

The system utilizes a cloud-based monitoring dashboard to provide:

- **Remote accessibility** from any connected device (mobile or web interface)
- **Graphical visualization of pollutant variations** and historical trend analysis
- **Automatic data logging** to support research and predictive analytics
- **Real-time alert generation** when pollution exceeds predefined safe limits

Common IoT platforms suitable for integration include **ThingSpeak**, **Blynk**, and custom **MQTT-based servers**, which support scalable deployment and secure data access.

5. HARDWARE AND SOFTWARE IMPLEMENTATION

The implementation of the proposed indoor air quality monitoring system consists of both hardware integration and software development. The hardware subsystem performs real-time environmental sensing and data acquisition, while the software subsystem manages data processing, wireless transmission, cloud storage, and graphical dashboard visualization.

5.1 Hardware Components

The system utilizes compact, low-cost sensing modules interfaced with a Wi-Fi-enabled microcontroller. The table below summarizes the primary hardware components used in the prototype model.

Microcontroller (ESP8266 / ESP32 / Arduino)	Central control unit responsible for sensor interfacing, data processing, and Wi-Fi communication
MQ-135 / CO_2 Gas Sensor	Detects concentration of toxic gases and carbon dioxide levels in ppm
PM2.5 / PM10 Dust Sensor	Measures fine particulate matter responsible for respiratory health issues

DHT11 / DHT22 Sensor	Monitors temperature and relative humidity levels
Regulated Power Supply	Provides stable electrical power to all modules

The selected hardware provides accuracy, portability, low power consumption, and easy deployment for real-time air quality assessment.

5.2 Software Components

The software platform consists of microcontroller firmware, IoT communication protocols, and a cloud-based user interface. The table below outlines the software tools involved:

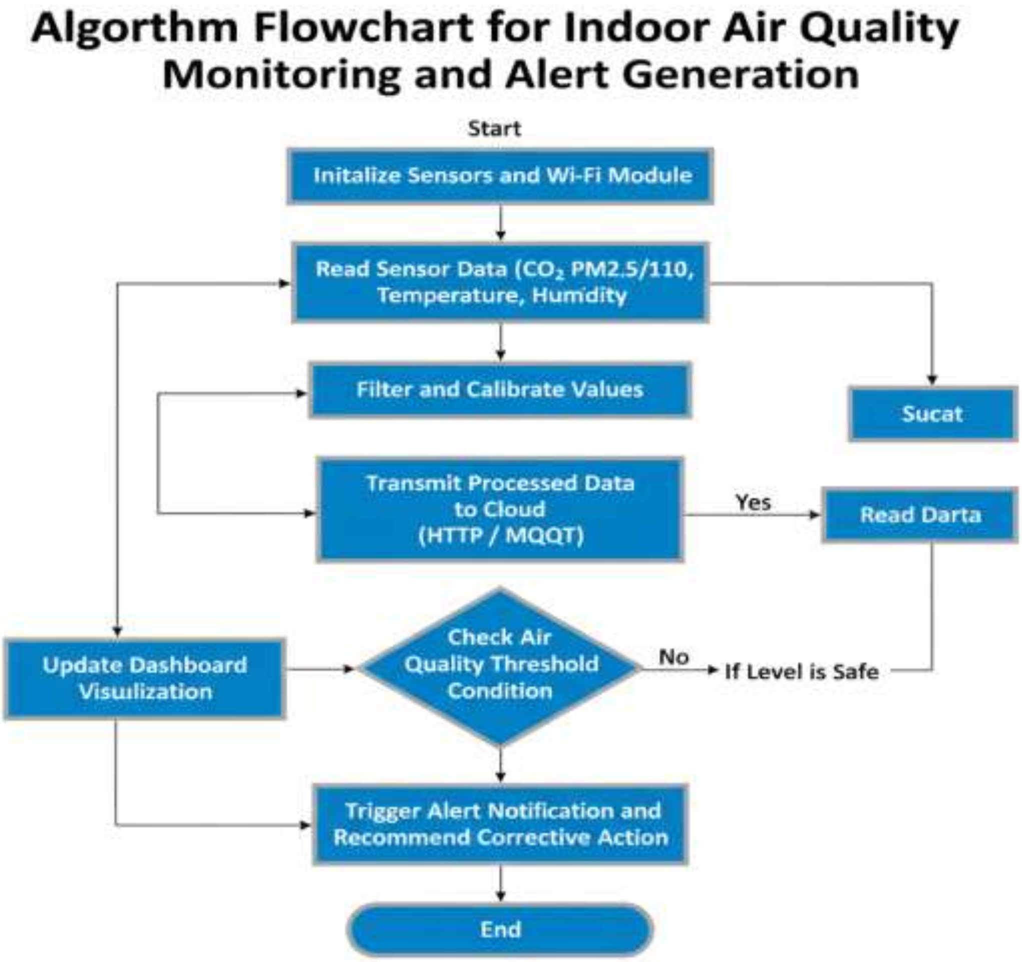
Arduino IDE	Used for programming, compiling, and uploading firmware to the microcontroller
Cloud IoT Platform (ThingSpeak / Blynk / MQTT Server)	Real-time data visualization, graph plotting, storage, and historical analysis
HTTP / MQTT Protocol	Enables fast and reliable wireless transmission of sensor data to cloud dashboards

5.3 Algorithm

The operational logic of the proposed system is summarized in the following algorithmic steps:

1. **Initialize** all sensors and configure Wi-Fi connection.
2. **Acquire** real-time readings from gas, particulate, temperature, and humidity sensors at predefined sampling intervals.
3. **Filter** and **calibrate** raw data for noise reduction and improved accuracy.
4. **Transmit** processed values to the cloud platform using HTTP or MQTT protocol.
5. **Visualize** real-time graphical outputs on the dashboard and **store** data for trend analysis.

Figure 3: Algorithm Flowchart for Indoor Air Quality Monitoring and Alert Generation



6. RESULTS AND DISCUSSION

The proposed IoT-based indoor air quality monitoring system was deployed inside a closed indoor environment to evaluate its performance in real-time conditions. The sensors captured live values of temperature, humidity, CO_2 concentration, and particulate matter (PM2.5) at one-minute intervals and transmitted them to the cloud dashboard. The monitored data helped analyze variations in indoor air quality with respect to human activity and ventilation patterns.

6.1 Sample Experimental Readings

The table below presents sample readings collected over a 30-minute observation period:

Time (min)	**Temp (°C)**	**Humidity (%)**	**CO_2 (ppm)**	**PM2.5 (µg/m³)**	**Air Quality Status**
0	26.1	54	520	18	Good
5	26.3	56	680	21	Moderate
10	27.0	57	910	25	Unhealthy for Sensitive Groups
15	27.2	58	1120	32	Unhealthy

20	27.5	59	1185	36	Unhealthy
25	26.8	58	840	28	Moderate
30	26.4	55	600	20	Good

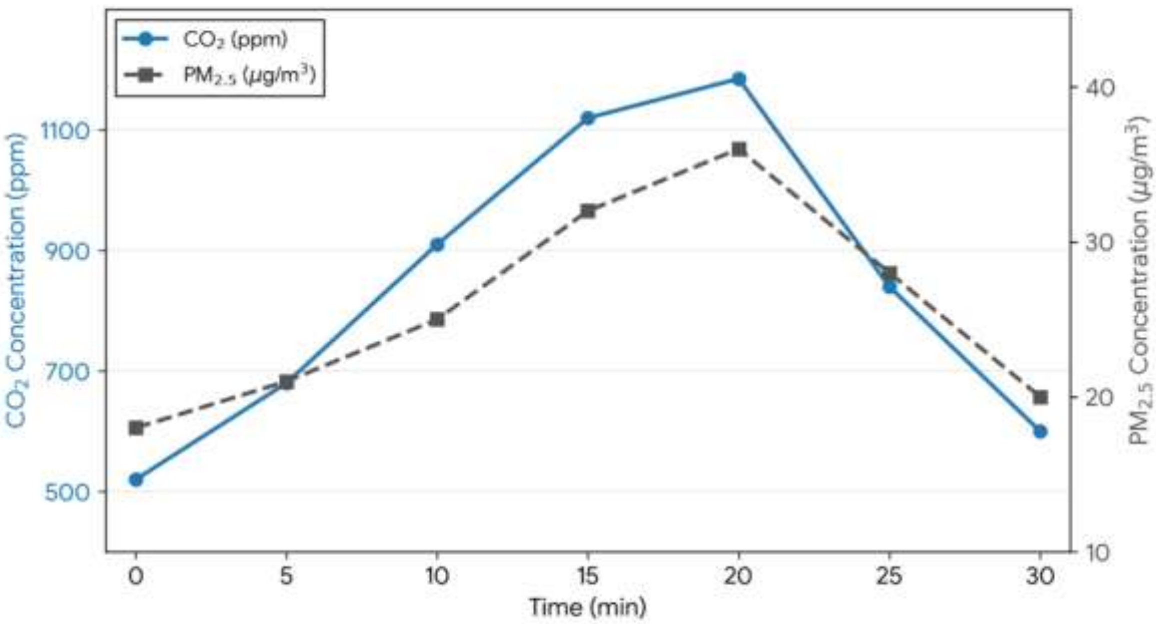


Figure 4: Variation of CO_2 and PM2.5 levels with respect to time during indoor monitoring experiment

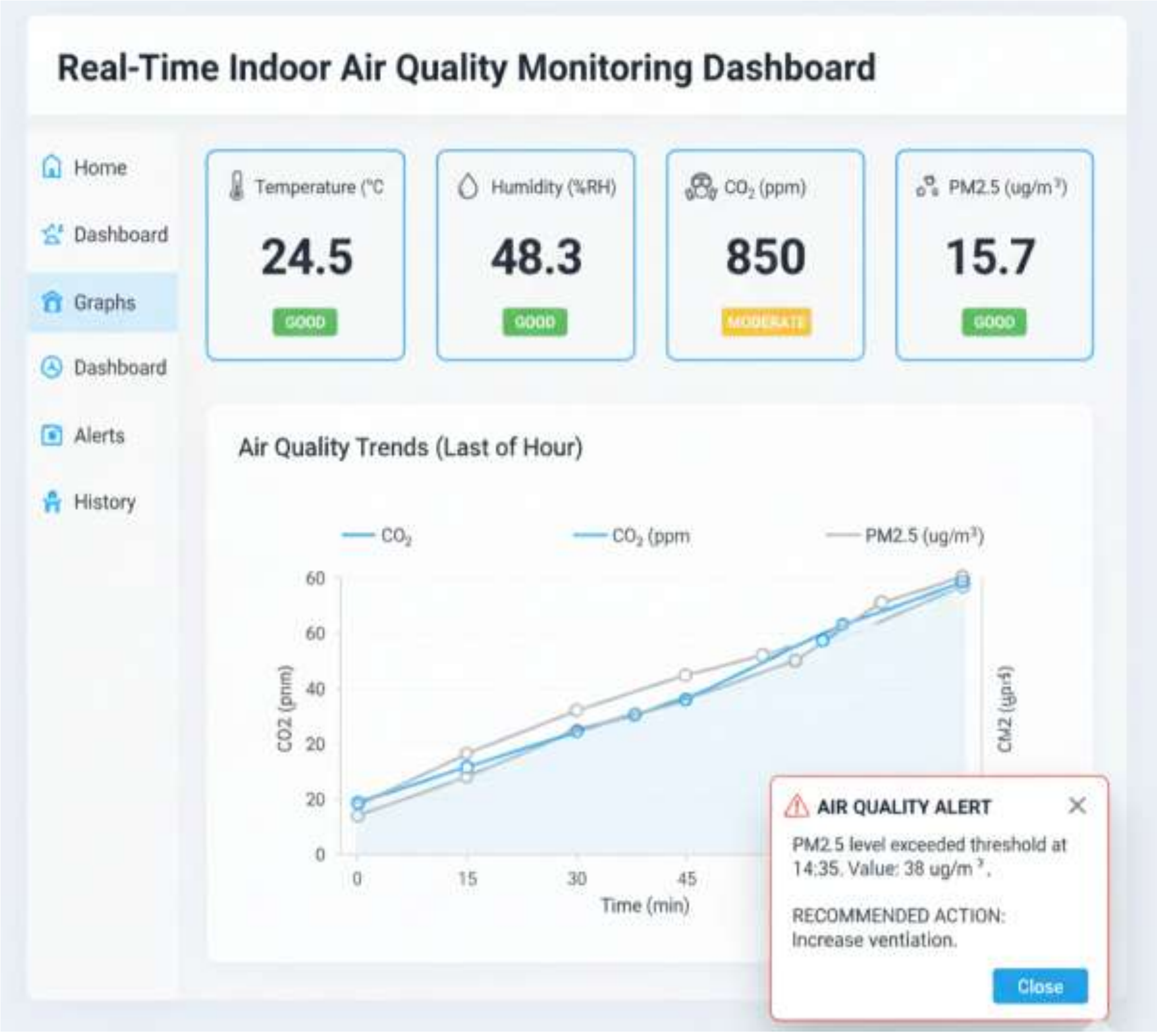


Figure 5: Cloud dashboard interface showing real-time visualization of IAQ parameters and alert status

6.2 Discussion of Results

Initial readings indicate acceptable environmental conditions, but increased CO_2 levels after 10–15 minutes reflect poor ventilation, likely caused by occupancy and closed surroundings. PM2.5 values also showed a gradual increase due to dust suspension and movement. The system successfully detected deterioration in air quality and updated the real-time status on the cloud dashboard.

When windows were opened at the 20-minute mark, CO_2 concentration dropped from 1185 ppm to 840 ppm within five minutes, demonstrating the effectiveness of ventilation as a corrective response. The experiment validates that the system can provide meaningful insights and help improve indoor living conditions.

According to **World Health Organization (WHO)** guidelines, PM2.5 levels above 25 µg/m³ and CO_2 above 1000 ppm are considered unhealthy. The proposed system accurately identified when parameters exceeded safe limits and triggered alert notifications through the dashboard.

Overall, results indicate the system's capability to:

- Detect environmental changes in real time.
- Provide timely information for health-based decision making.

7. COMPARATIVE ANALYSIS

To evaluate the effectiveness of the proposed IoT-based indoor air quality monitoring system, a comparative analysis was conducted against existing solutions reported in recent research works. The comparison focuses on key performance factors, including **real-time monitoring capability, cloud dashboard integration, system cost, sensor calibration accuracy, alert mechanism, and scalability**.

Comparative Study of IAQ Monitoring Systems

Real-time Monitoring	Yes	Yes	Yes	Yes
Cloud Dashboard	No	Yes	Limited	Fully Integrated
Cost	Medium	High	High	Low
Sensor Calibration	Basic	Good	Good	Improved
Alert System	Not Included	Limited	Not Mentioned	Included
Scalability	Limited	Limited	Medium	High

Table 2: Comparative Performance Evaluation of Indoor Air Quality Monitoring Systems

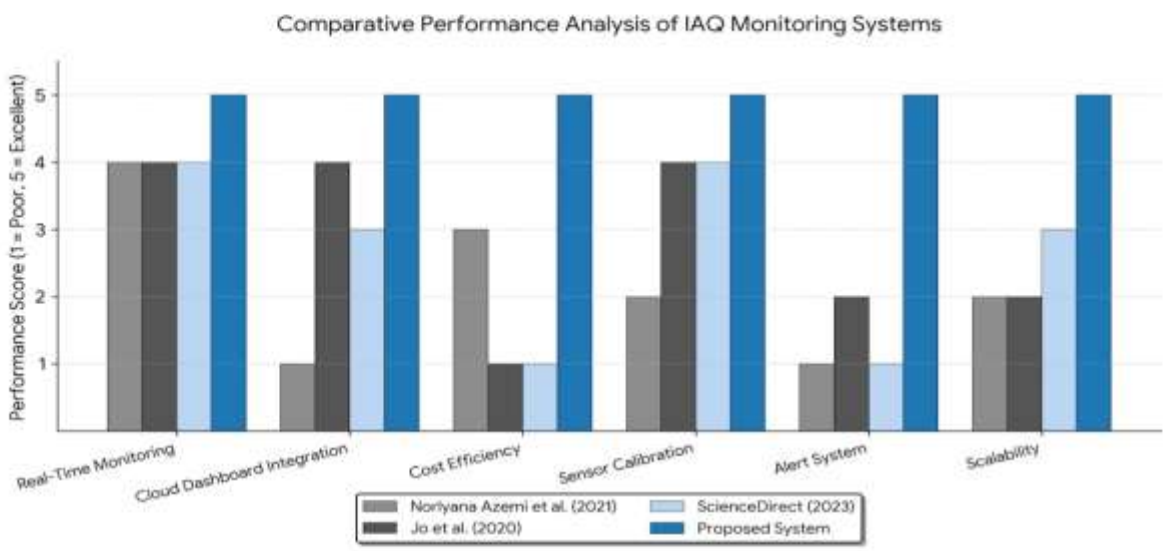


Figure 6: Comparative Performance Analysis of Indoor Air Quality Monitoring Systems Across Different Studies

Discussion

The comparative findings indicate that although several existing IAQ monitoring systems support real-time sensing and acceptable sensing accuracy, they commonly lack comprehensive cloud integration, effective alert mechanisms, and cost-efficiency. Both Jo et al. (2020) and ScienceDirect (2023) approaches exhibit good sensor performance but are limited by high implementation cost and reduced scalability, making them less suitable for deployment in general household or institutional environments.

In contrast, the proposed system offers improved functionality by incorporating **full cloud dashboard compatibility**, **automated alert notification**, and **low-cost hardware** without sacrificing performance. Additionally, enhanced calibration and modular scalability allow the design to be expanded for smart city applications, educational buildings, hospitals, and industrial monitoring.

Thus, the comparative evaluation demonstrates that the proposed solution provides a more practical, flexible, and affordable alternative to existing IAQ monitoring systems.

8. CONCLUSION

This work presented an IoT-based indoor air quality monitoring system designed to continuously measure and analyze critical environmental parameters, including CO_2 concentration, PM2.5 particulate matter, temperature, and humidity. By integrating low-cost sensing modules with Wi-Fi-enabled microcontroller hardware and a cloud-based dashboard, the system provides real-time pollutant tracking, historical data visualization, and remote accessibility through smart devices.

Experimental evaluation demonstrated that the system effectively identifies rapid fluctuations in indoor air quality influenced by human activity and ventilation behavior. The cloud platform accurately highlighted threshold violations and generated instant alerts, enabling timely corrective action such as window ventilation or activation of air purification systems.

Overall, the proposed solution offers a reliable, scalable, and cost-efficient alternative to traditional laboratory-grade monitoring equipment. Its portability, low power consumption, and seamless cloud connectivity make it suitable for deployment in **homes, offices, schools, hospitals, and industrial facilities**. With increased focus on health-centric environments and smart infrastructure, the system contributes to sustainable smart-city development and can be expanded with features such as machine learning-based prediction and automated HVAC control in future work.

9. FUTURE SCOPE

The proposed IoT-based indoor air quality monitoring system demonstrates promising potential for real-time environmental sensing and health-centric decision support. However, several enhancements can further improve system performance, intelligence, and large-scale applicability. Future developments may include:

- **Integration of AI- and machine learning-based predictive models** to forecast pollution trends, recognize patterns, and generate proactive warnings before hazardous levels occur.
- **Development of mobile applications** with personalized notifications and voice assistant integration for improved user interaction and accessibility.
- **Automated control of ventilation and air purification systems**, enabling closed-loop smart-home automation where corrective actions are triggered without user intervention.
- **Incorporation of edge computing** to perform on-device processing for reduced cloud dependency, faster response time, and enhanced data security.
- **Deployment of solar-powered or battery-optimized modules** to enhance power efficiency and enable long-term standalone operation.
- **Integration with central government or smart-city environmental monitoring networks**, allowing large-scale data sharing, analytics, and public health collaboration.

These advancements will extend system usability across residential, commercial, industrial, and public infrastructure environments, contributing to smart-city development and sustainable digital health ecosystems.

REFERENCE LIST

[1] N. Azemi, S. M. B. S. Hassan, N. A. M. Alduais, and M. F. R. Yusof, "Smart indoor air quality monitoring system," Journal of Physics: Conference Series, vol. 1755, pp. 1–9, 2021.

[2] S. Jo, H. J. Lee, and J. W. Park, "Development of an IoT-based indoor air quality monitoring platform," Journal of Sensors, vol. 2020, pp. 1–10, 2020.

[3] M. H. H. Mohd, R. Sallehudin, A. A. Yaacob, and A. Z. Jusoh, "IoT-based real-time environmental monitoring system," Procedia Computer Science, vol. 218, pp. 274–281, 2023.

[4] World Health Organization (WHO), "WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide," 2021.

[5] ThingSpeak IoT Analytics Platform, MathWorks, 2024. [Online]. Available: https://thingspeak.com

[6] Arduino, "DHT11 Temperature and Humidity Sensor Datasheet," 2022.

[7] Winsen Electronics Technology, "MQ-135 Gas Sensor Technical Datasheet," 2022.

[8] A. Zanella et al., "Internet of Things for smart cities," IEEE Internet of Things Journal, vol. 1, no. 1, pp. 22–32, 2014.

[9] S. Kumar and P. Sharma, "Cloud-based environmental monitoring using sensor networks," International Journal of Computer Applications, vol. 182, no. 45, pp. 15–20, 2021.