IoT-Powered Environmental Monitoring: Observing Indoor Air Quality Over Time

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***Abstract*—Indoor air quality has become an increasingly critical concern, particularly in enclosed environments such as laboratories, offices, and auditoriums, where effective monitoring systems are essential. High concentrations of carbon dioxide, together with changes in temperature and humidity, can negatively impact human health. This paper presents a comprehensive environmental monitoring system that continuously tracks CO_2 concentrations, temperature, and humidity using an integrated approach with Raspberry Pi and Arduino technology. The system employs a DHT11 sensor to measure temperature and humidity and an MQ135 sensor for CO_2 detection. Data collected from these sensors is transmitted in real-time to the cloud platform, where it is visualized for easy analysis. Additionally, the development of a mobile application allows users to remotely access this data, ensuring that individuals remain informed about indoor air quality at all times. The system's scalability and adaptability make it suitable for diverse applications, promoting better indoor air quality management. By facilitating continuous monitoring of environmental parameters, it aims to provide enhanced health and comfort in enclosed spaces.**

***Index Terms*—Carbon dioxide (CO_2), temperature monitoring, humidity monitoring, environmental monitoring system, Raspberry Pi, Arduino, DHT11 sensor, MQ135 sensor, real-time data, mobile application.**

I. Introduction

Environmental monitoring plays a vital part in securing ecosystems and mortal well- being. With the growing enterprises of climate change, rising pollution situations, and niche declination, the need for nonstop and accurate data collection has come more critical than ever. Parameters similar as temperature, moisture, and CO_2 situations serve as pointers of environmental quality, furnishing precious perceptivity into both natural processes and the impacts of mortal conditioning. Real- time monitoring of these factors enables timely interventions for conservation, ensures compliance with non-supervisory norms, and mitigates pitfalls to public health. The emergence of the Internet of effects (IoT) has significantly converted environmental monitoring.

Using interconnected sensors, IoT systems can gather, analyze, and visualize data in real time, providing detailed insights into environmental conditions across multiple locations[1]. Studies have shown how similar systems contribute to dependable dimension and reporting of environmental parameters, ranging from air quality to noise situations [3]. With IoT-enabled pall integration, data can be transmitted to platforms similar as ThingSpeak, where it's reused, stored, and made accessible for remote monitoring via smartphones and analogous bias [2]. This remote availability enhances decision- making in disciplines including husbandry, civic planning, and artificial operation [8]. tackle platforms play an essential part in IoT-grounded monitoring.

Low- cost microcontrollers similar as Arduino have been extensively espoused for their simplicity and inflexibility, while single- board computers like Raspberry Pi give lesser computational capacity andmulti-sensor integration capabilities [9]. For sensing operations, devices such as the DHT11 are commonly used to measure temperature and humidity [7], the MQ135 is applied for detecting CO_2 and air quality parameters [6], and the LM393 is utilized for monitoring sound levels [8]. Systems may operate as standalone units with original data storehouse [6], or as pall- integrated infrastructures able of comprehensivemulti-parameter monitoring [5].

Recent exploration has also demonstrated pall- grounded IoT environmental systems that combine multiple detectors with wireless data transmission. In one study, an Arduino board was integrated with DHT11 and MQ135 sensors to measure temperature, humidity, and CO_2 levels in real time [4]. Other workshop have stressed the integration of multiple parameters, including air quality and pressure measures, with visualization and analysis carried out on pall platforms [10]. These studies illustrate the growing eventuality of IoT-grounded monitoring results, where affordable tackle and scalable pall services combine to produce dependable and accessible environmental monitoring fabrics. The present work builds on these advancements by fastening specifically on inner air quality monitoring. By integrating Raspberry Pi and Arduino with detectors similar as DHT11 and MQ135, our system provides real- time monitoring of temperature, moisture, and CO_2 attention. Data is transmitted to a pall platform for visualization and analysis, and can be penetrated ever through mobile bias. This armature not only ensures accurate and nonstop environmental monitoring but also addresses the critical challenge of inner CO_2 accumulation in enclosed spaces, which has direct counteraccusations for mortal health, comfort, and productivity.

II. Related Works

Several research efforts have focused on IoT-based environmental monitoring, each presenting unique system architectures and features. This section reviews significant studies, their contributions and highlights how our work builds on these foundations to deliver a focused solution for monitoring CO_2, temperature, and humidity in indoor environments.

A notable study [1], developed an IoT-based monitoring system that used sensor networks to measure temperature and humidity, with data transmitted wirelessly to cloud platforms. The system enabled access through smartphones and demonstrated potential for automated actuation, such as heating or cooling adjustments. Despite its scope, it focused primarily on general monitoring without focusing on critical indoor air quality parameters such as CO_2 .Our work extends this direction by explicitly addressing enclosed-space CO_2 accumulation, a key factor in indoor comfort and safety. In [2], a real-time environmental monitoring solution was designed using Arduino UNO, DHT11 sensors, and ESP8266 Wi-Fi to transmit temperature and humidity readings to the ThingSpeak cloud. An Android application was also integrated to display data to users. This system demonstrated the feasibility of cloud–mobile integration for environmental monitoring. However, it did not incorporate gas sensors. Our project enhances this framework by adding CO_2 monitoring through MQ135, expanding its relevance for indoor air quality assessment.

The comprehensive review in [3] provided insights into IoT-based environmental systems applied to air quality, water management, and waste control. Importantly, it discussed integration with artificial intelligence and machine learning for predictive analytics, showing the possibility of forecasting environmental hazards. Although the study focused on broader applications, its suggestion of predictive modeling is particularly relevant to our project, as it opens the scope for future extensions where CO_2 buildup in enclosed spaces could be predicted and mitigated proactively. In [4], a multi-sensor IoT monitoring system was implemented using Arduino UNO and sensors including DHT11 (temperature, humidity),MQ135 (air quality/ CO_2), MQ9 (gas detection), and BMP180 (pressure). Data was sent via ESP8266 to the ThingSpeak platform for visualization. This work highlights the value of multi-parameter integration and directly validates our approach of including MQ135 alongside DHT11 in a combined indoor monitoring setup.

Similarly, [5] developed an IoT system using Arduino UNO, DHT11, and MQ135 sensors with data transmission through ESP8266 to ThingSpeak. The project emphasized affordability and user-friendliness, making the solution accessible for widespread use. While effective, it maintained a small-scale focus. Our project draws from this simplicity but builds on it by integrating the Raspberry Pi for higher computational ability and more robust remote accessibility. Paper [6] focused specifically on the MQ135 sensor for CO_2 measurement, experimenting with different load resistances to calibrate and improve accuracy. This contribution is significant because it directly informs the calibration strategies in our system, ensuring that CO_2 readings in indoor environments are both precise and reliable.The work in [7] introduced a low-cost setup for monitoring temperature and humidity using Arduino Nano, DHT11, DS3231 RTC, and an LCD display. The system enabled local logging and time-stamped recording of environmental data. Although it did not include cloud connectivity, it stressed the importance of accurate, time-series monitoring. This aligns with our approach of enabling both real-time cloud access and historical data visualization for long-term indoor air quality analysis.

In [8], a Raspberry Pi-based system was proposed to monitor air and sound pollution. The system integrated MQ135, LM393, and DHT11 sensors, transmitting results to the cloud for analysis. This study demonstrated the capacity of the Raspberry Pi to handle multisensor inputs and more computationally demanding tasks compared to only Arduino systems. Our project leverages this strength of Raspberry Pi as the central hub for integrating CO_2, temperature, and humidity monitoring. Paper [9] reviewed the Raspberry Pi platform and highlighted its versatility in IoT, automation, and monitoring systems. It reinforced the idea that Raspberry Pi is not only cost-effective but also scalable for advanced applications, confirming its suitability as the backbone of our project's architecture. Finally, [10] presented recent advancements in environmental sensor technology, emphasizing improvements in sensitivity, energy efficiency, and self-calibration. These insights are important for the future directions of our project, where the adoption of advanced sensors could further increase the reliability and precision of long-term monitoring of indoor air quality.

The reviewed literature demonstrate strong progress in IoT-based monitoring, from simple Arduino-based sensor systems to more advanced Raspberry Pi and cloud-based architectures. However, most systems focus on general environmental monitoring or lack specific attention to CO_2 accumulation in indoor spaces. Our project addresses this gap by combining Raspberry Pi and Arduino with sensors (DHT11 and MQ135) and integrating cloud visualization and mobile access. This ensures complete monitoring of temperature, humidity, and CO_2, with the potential for future predictive modeling and automated ventilation responses

III. Methodology

A. Sensors

This project includes real-time environmental monitoring at two different locations with modules of Raspberry Pi integrated into it with a temperature sensor, humidity sensor, and gas sensor. Data is collected from both digital and analog sensors using the Arduino Uno as an Analog-to-Digital Converter to break down analog signals. The acquired data is transmitted to ThingSpeak for storage and visualizations, this in real-time and the output will be monitored remotely through a mobile application as shown in Fig.1.

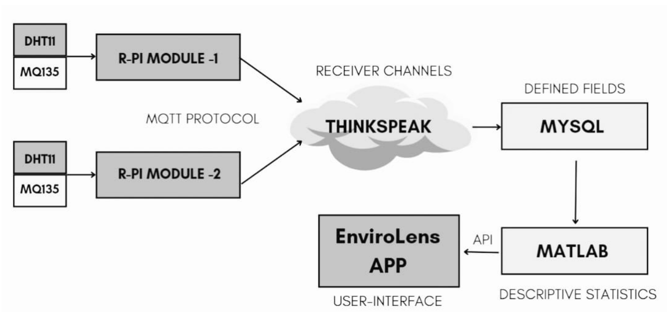

Fig. 1. Block diagram of the proposed system.

A detailed description of the components used and the several backend processes inside the system. Sensor Modules: The system uses two Raspberry Pi modules, each Raspberry Pi is designed to get the data from sensors at regular intervals in such a manner that real-time data collection regarding the environment from two different locations is ensured.

These R- Pi modules are combined with two kinds of sensors: DHT11 Sensor: This sensor measures the temperature and humidity levels with the ability to provide real-time digital values of temperature in degrees Celsius and humidity in percentage. It makes it even more suitable for real-time environmental monitoring. The DHT11 sensor is so precise, and its simplicity has earned it extensive application in environmental sensing. MQ135 Sensor: The MQ135 sensor measures CO_2 concentrations and produces analog signals. The Arduino reads the analog voltage signal given by the MQ135 at its analog pin, and the signal is further converted into a digital signal; afterward, it transmits the digital data to the Raspberry Pi via USB. This system reads temperature, humidity, and gas values and prints them every 2 seconds; it then sends data to ThingSpeak every 15 seconds.

B. Data Communication

Sensor data collected by the Raspberry Pi modules is sent, in real time, to the ThingSpeak Cloud Platform via the HTTP POST request method. It is a widely used platform for IoT applications, owing to its feature of easily handling and visualizing data. The WRITE API method is used to send data from the Raspberry Pi to ThingSpeak. This is ensured by embedding the API key with each of the POST requests so that data transfer is safe and authenticated. The data is

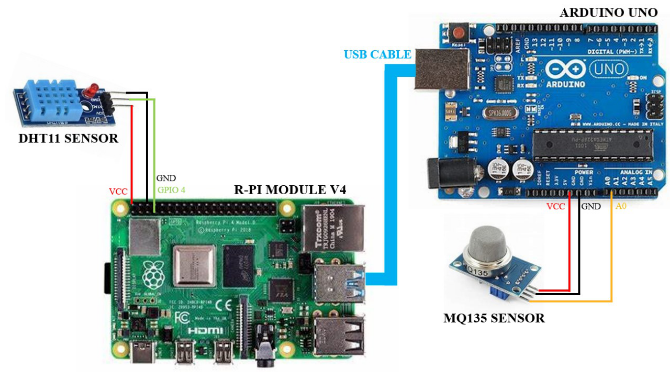

Fig. 2. The hardware setup for the data collection process.

arranged in particular fields in a pre-programmed channel on ThingSpeak: Field1 and Field2 for temperature from Location 1 and Location 2, Field3 and Field4 for humidity from Location 1 and Location 2, and Field5 and Field6 for CO_2 concentrations from Location 1 and Location 2 sensed by the MQ135 sensor.

C. Cloud Data Handling and Visualization

The ThingSpeak platform natively includes in its offering the functionalities of data visualization. The system is designed specifically to automatically generate line plots in MATLAB to visualize temperature and humidity and the build-up of CO_2 concentration in both locations with the increase in time. Data is retrieved and plotted as a timeseries: The x-axis depicts time, and the y-axis represents the corresponding sensor reading. Three line plots are generated for each parameter: temperature, humidity, and CO_2, for both locations. For the long term, the collected sensor readings in ThingSpeak are uploaded to a MySQL database so that there is proper data storage. Hence, large quantities of huge sensor data can be stored in a scalable and structured manner. The data in the MySQL database are arranged in pre-defined fields; thus all readings from sensors in this example, temperature, humidity, and concentration of CO_2, are easily available for queries and analysis.

D. Mobile Application – EnviroLens:

As an extension toward the accessibility of the user, the EnviroLens app has been developed using Kotlin. Through the EnviroLens app, it does allow the user to easily monitor temperature, humidity, and CO_2 level from the two locations, and this will give remote access to the data collected through a mobile interface. The structure and style of the pages are defined by XML files used to design the app that should be found in the layout folder. The functionality is mainly achieved in the main .kt files, where data is fetched from ThingSpeak using its READ API key to retrieve graphs and sensor readings of the fields configured. The application's activities (pages) run in correct order due to AndroidManifest.xml. Testing and deploying of the application requires that the mobile device be plugged into a PC through USB to run the application.

IV. Results and Discussion

It captures data in real time and storage and visualization of environmental data in the two locations. The sensor data by different ventilation conditions that is, no ventilating, partial ventilating, complete ventilating of stability of pattern temperature, variation of the humidity, as well as fluctuation in the CO_2 levels in each field, from two indoor rooms has been collected and observed.

TABLE I
Environmental Parameter Observations under Different Ventilation Conditions

Parameter (Sensor)	Condition	Observation
Temperature (RPi 1, DHT11)	No Ventilation	∼30°C, stable
	Moderate Vent.	29.0–29.9°C, stable
	With Vent.	∼29°C, minimal variation
Temperature (RPi 2, DHT11)	No Ventilation	∼29°C rising to 30°C
	Moderate Vent.	Similar to RPi 1, stable
	With Vent.	∼29°C, constant
Humidity (RPi 1, DHT11)	No Ventilation	Fluctuates around 80%
	Moderate Vent.	Decreases 78% → 72%
	With Vent.	Increases 72% → 75%
Humidity (RPi 2, DHT11)	No Ventilation	Stable at ∼75%
	Moderate Vent.	Decreases 74.5% → 72%
	With Vent.	Fluctuates 71–70%
CO_2 (RPi 1, MQ135)	No Ventilation	∼108 ppm, minimal fluctuation
	Moderate Vent.	Mostly steady, minor oscillations
	With Vent.	102–104 ppm, no major change
CO_2 (RPi 2, MQ135)	No Ventilation	Starts ∼212 ppm, steadily increases
	Moderate Vent.	Minor fluctuations, unaffected
	With Vent.	214–216 ppm, remains stable

A. No Ventilation

In closed environments without ventilation, temperature remained steady around 30 °C at Location 1 and increased slightly from 29 °C to 30 °C at Location 2, indicating heat accumulation over time. Humidity values stayed relatively high, with Location 1 fluctuating around 80% and Location 2 maintaining about 75%. CO_2 levels showed a clear buildup effect: while values at Location 1 stabilized near 108 ppm, Location 2 recorded a gradual rise from 212 ppm, highlighting the impact of poor air circulation on gas concentration.

B. With Moderate Ventilation

With moderate airflow, temperature readings were relatively stable, showing only minor variations between 29.0 °C and 29.9 °C at both locations. A more noticeable effect was observed in humidity: Location 1 dropped from 78% to 72%, while Location 2 decreased from 74.5% to 72%, demonstrating that ventilation reduced moisture levels in the room. CO_2 concentrations exhibited only slight oscillations, with no significant overall reduction, suggesting that ventilation influenced humidity more strongly than gas levels.

C. With Ventilation

When full ventilation was introduced, temperature remained largely unchanged at approximately 29 °C. Humidity trends were less consistent: Location 1 increased from 72% to 75%, while Location 2 fluctuated around 70–71%, indicating that airflow patterns can alter moisture distribution. CO_2 concentrations stayed nearly constant, between 102–104 ppm at Location 1 and 214–216 ppm at Location 2, confirming that short-term ventilation alone does not substantially reduce CO_2 levels.

After comparing the two monitored locations we got the following observations. CO_2 concentration was significantly higher at Location 2 (around 225 ppm) than Location 1 (approximately 100 ppm), indicating either insufficient ventilation or the presence of additional gas-emitting sources. Temperature at Location 1 averaged about 30 °C, slightly higher than the 25 °C observed at Location 2, suggesting different heat retention characteristics. Humidity levels were similar across both sites, but Location 1 displayed a small decrease from 78% to 75%, while Location 2 remained stable around 75%. The elevated CO_2 concentration at Location 2 points to potentially inadequate ventilation and highlights the importance of monitoring air quality in enclosed environments.

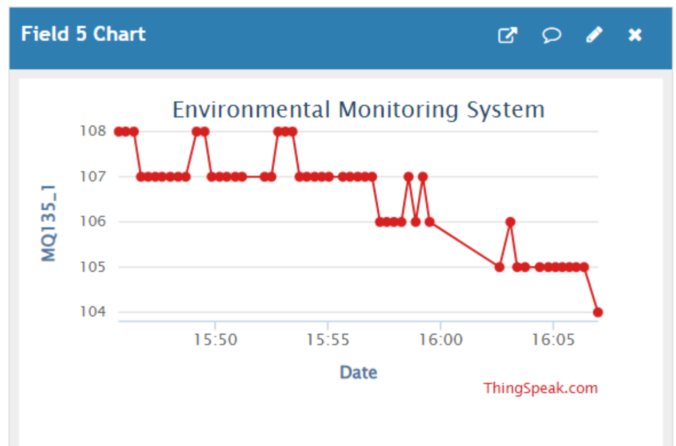

Fig. 3. Graph visualization of CO_2 in ThingSpeak (Location 1).

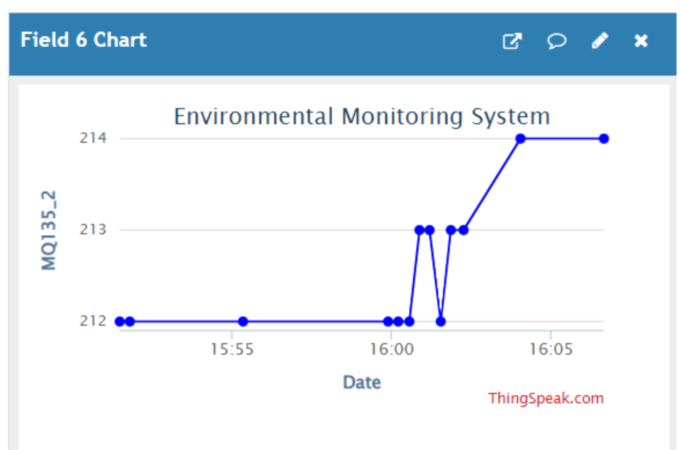

Fig. 4. Graph visualization of CO_2 in ThingSpeak (Location 2).

Fig. 5. Logo of our app.

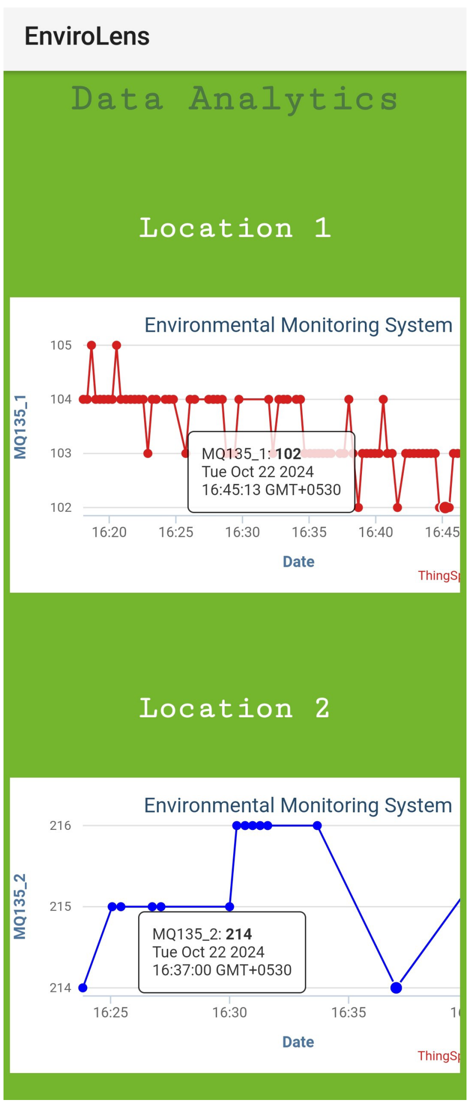

Fig. 6. Graph visualization in EnviroLens App.

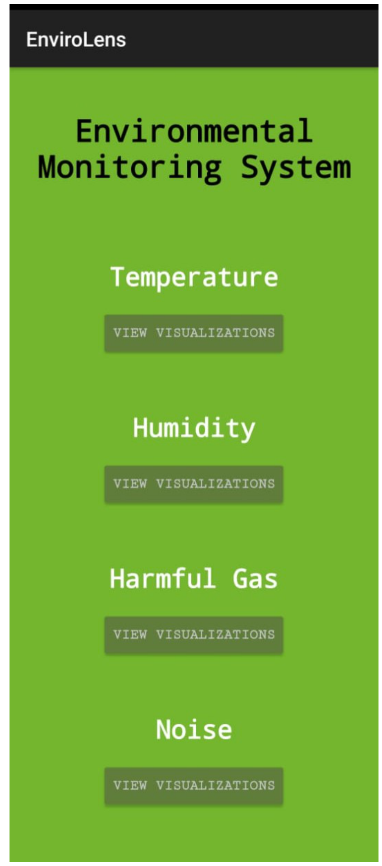

Fig. 7. EnviroLens showing parameter selection for visualization.

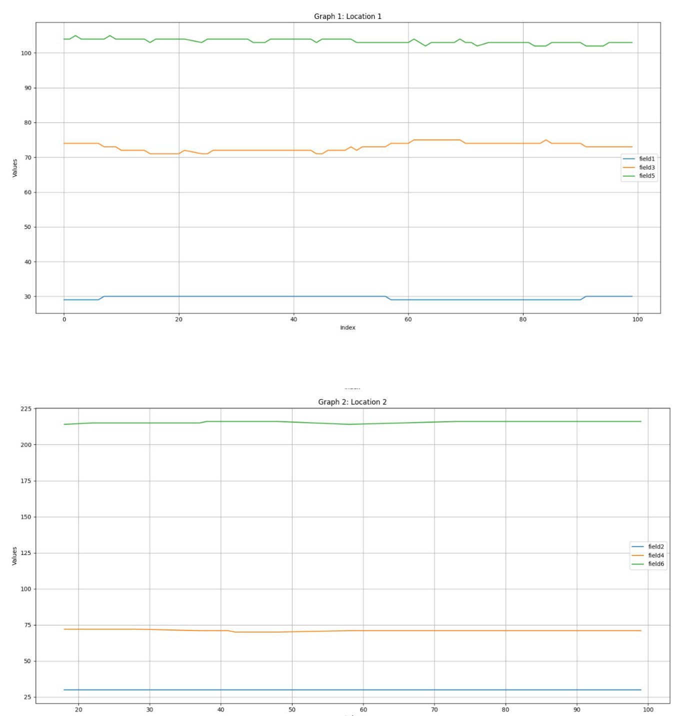

Fig. 8. MATLAB-generated line plots showing temperature, humidity, and CO_2 concentration trends over time at both locations.

V. Conclusion

This project introduces an environmental monitoring system, developing a robust and scalable IoT solution to effectively monitor in real time key environmental parameters like temperature, humidity, CO2 concentration levels, and sound. Using the application of two Raspberry Pi setup configurations at diverse locations while using DHT11 and MQ135 the system continues collecting data and sends it to the ThingSpeak cloud for subsequent real-time visualization and analysis

The outcomes of this project highlight its effectiveness for indoor environments where air quality plays a crucial role in human health, comfort, and productivity. The system offers significant value for use in classrooms, laboratories, offices, and other enclosed spaces, where it can assist in identifying poor ventilation, rising CO_2 accumulation, or fluctuating humidity levels. Its ability to remotely visualize and track environmental parameters also makes it highly practical for decision-making and environmental awareness. Beyond its immediate functionality, the project demonstrates scalability and adaptability. Additional sensors can easily be integrated to monitor pollutants such as particulate matter, volatile organic compounds, and toxic gases, thereby broadening its application to industrial or urban monitoring contexts. Incorporating predictive analytics and machine learning could further enhance its capabilities, enabling early detection of air quality risks and automated responses such as ventilation control.

Overall the proposed system provides a cost-effective and flexible framework for sustainable environmental monitoring. By bridging real-time sensing, cloud integration, and mobile accessibility, it contributes to building healthier indoor environments while laying the foundation for smarter, automated environmental management in the future.

References

[1] Prof. (Dr.) Vijay Mane, R. Selkar, V. Shelgaonkar, B. Shah, and A. Sayyed. 2022. "Environmental Monitoring Using Internet of Things." International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE) 11: 149-156.

[2] S. Zafar, G. Miraj, R. Baloch, D. Murtaza, and K. Arshad. 2018. "An IoT Based Real-Time Environmental Monitoring System Using Arduino and Cloud Service." Engineering, Technology & Applied Science Research 8: 3238-3242.

[3] S. R. Laha, B. K. Pattanayak, and S. Pattna. 2022. "Advancement of Environmental Monitoring System Using IoT and Sensor: A Comprehensive Analysis." AIMS Environmental Science 9: 700-800.

[4] V. Naveen and N. P. Babu. 2020. "IoT Based Environmental Monitoring System for Real Time Using Arduino." Journal of Emerging Technologies and Innovative Research (JETIR) 7: 192-196.

[5] R. Deekshath, P. Dharanya, K. R. D. Kabadia, G. D. Dinakaran, and S. Shanthini. 2018. "IoT Based Environmental Monitoring System Using Arduino UNO and Thingspeak." International Journal of Science Technology & Engineering 4: 68-75.

[6] M. C. Bhosale, N. M. Kulkarni, A. D. Shaligram, and S. Pustake. 2023. "Measurement of CO2 Gas Concentration Using MQ135 Sensor For Air Pollution Monitoring." International Conference on Recent Trends in Science and Technology, Sagli, India.

[7] K. P. Kuria, O. O. Robinson, and M. M. Gabriel. 2020. "Monitoring Temperature and Humidity Using Arduino Nano and Module-DHT11 Sensor with Real Time DS3231 Data Logger and LCD Display." International Journal of Engineering Research & Technology (IJERT) 9: 416-422.

[8] M. Y. A. Tariq. 2021. "A Raspberry Pi Controlled Cloud Based Air and Sound Pollution Monitoring System with Temperature and Humidity Sensing." International Journal of Creative Research Thoughts 9: 2320-2882.

[9] H. D. Ghael, L. Solanki, and G. Sahu. 2021. "A Review Paper on Raspberry Pi and Its Applications." International Journal of Advances in Engineering and Management (IJAEM) 2: 225-227.

[10] K. Long. 2024. "Advancements in Environmental Sensor Technology: Analysis, Applications, and Future Prospects." Highlights in Science Engineering and Technology 97: 21-28.