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AIR QUALITY MONITORING SYSTEM

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ABSTRACT

Air pollution has become a significant environmental and public health concern [10] due to rapid industrialization, urban expansion, and the increasing number of vehicles. Continuous exposure to polluted air can lead to severe health issues [10], including respiratory diseases, cardiovascular disorders [10], and reduced quality of life. In this paper, a cost-effective and efficient Air Quality Monitoring System based on Internet of Things (IoT) technology [2] is presented. The proposed system employs MQ-series gas sensors [3] to detect harmful gases and a DHT11 sensor [4] to measure temperature and humidity. An ESP32 microcontroller [2][9] is used for data acquisition, processing, and wireless communication [2][9].

The system is capable of continuously monitoring environmental parameters and providing real-time data to users through a display interface or wireless transmission. Additionally, it incorporates an alert mechanism that activates when pollutant levels exceed predefined safety thresholds. The collected data can be further utilized for analysis and decision-making to improve air quality management. Experimental results indicate that the system performs reliably under different environmental conditions and provides accurate and timely information. Due to its low cost, portability, and scalability, the proposed system can be effectively deployed in homes, industries, and public spaces for continuous air quality monitoring and environmental awareness.

I. INTRODUCTION

Air quality is a critical factor in maintaining a healthy environment for humans, animals, and ecosystems. In recent years, rapid industrialization, urbanization, and increased vehicular emissions have significantly contributed to the deterioration of air quality. The presence of harmful pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM2.5 and PM10) poses serious health risks, including respiratory diseases, lung infections, and cardiovascular disorders. Therefore, continuous monitoring of air quality has become essential for ensuring public health and environmental sustainability [10].

Traditional air quality monitoring systems are often expensive, bulky, and limited to specific locations [6][7], making them unsuitable for widespread deployment. With the advancement of Internet of Things (IoT) technology [2], it is now possible to develop low-cost, compact, and efficient air quality monitoring systems [6][7] capable of providing real-time data and remote accessibility [6][7]. These systems enable continuous observation of environmental parameters and help in early detection of hazardous conditions.

In this work, an IoT-based Air Quality Monitoring System [2][6][7] is proposed, which utilizes MQ-series gas sensors [3] and a DHT11 sensor [4] to measure air pollutants, temperature, and humidity. The system is built around an ESP32 microcontroller [2][9] that processes sensor data and enables wireless communication [2][9]. It provides real-time monitoring, visual display of data, and alert mechanisms when pollutant levels exceed predefined thresholds.

The main objective of this project is to design a reliable, cost-effective, and scalable solution for monitoring air quality in indoor and outdoor environments. The proposed system can be deployed in residential areas, industrial zones, and public places to promote environmental awareness and support preventive measures against air pollution.

II. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Air pollution has become a major concern in modern society due to rapid industrial growth, urbanization, and increasing vehicular emissions. The continuous release of harmful gases and particulate matter into the atmosphere has led to a significant decline in air quality, adversely affecting human health and the environment. Conventional air quality monitoring systems are typically expensive, complex, and limited to fixed locations, making them inaccessible for widespread and real-time usage.

Moreover, the lack of affordable and portable monitoring solutions prevents individuals and small organizations from assessing air quality in their immediate surroundings. In many cases, people remain unaware of the pollution levels they are exposed to, which increases the risk of long-term health issues. Therefore, there is a need for a cost-effective, compact, and real-time air quality monitoring system that can provide accurate environmental data and timely alerts.

B. Objectives

The main objectives of the proposed Air Quality Monitoring System are as follows:

1. To design and develop a low-cost and efficient system for monitoring air quality parameters [6][7].
2. To measure key environmental factors such as gas concentration, temperature, and humidity using appropriate sensors.
3. To implement real-time data acquisition and processing using a microcontroller (ESP32).
4. To provide real-time visualization of air quality data through a display interface.
5. To develop an alert mechanism that notifies users when pollution levels exceed predefined safe limits.
6. To enable wireless communication [2][9] for remote monitoring and data transmission.
7. To create a scalable system that can be extended for IoT-based environmental monitoring applications [2][6][7].

III. BACKGROUND AND DESIGN RATIONALE

A. Background

Air pollution monitoring has gained significant importance in recent years due to its direct impact on human health and environmental sustainability. Pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM2.5 and PM10) are commonly found [5][10] in urban and industrial environments. Exposure to these pollutants can lead to severe health complications, including respiratory disorders, cardiovascular diseases, and reduced life expectancy.

Conventional air quality monitoring systems are generally based on high-precision instruments installed at fixed monitoring stations. Although these systems provide accurate data, they are expensive, require regular maintenance, and offer limited spatial coverage. As a result, they are not suitable for real-time, localized monitoring.

With the advancement of embedded systems and Internet of Things (IoT) technology [2], low-cost sensor-based monitoring solutions have emerged as a viable alternative [6][7]. These systems enable continuous monitoring, real-time data acquisition, and remote accessibility, making them suitable for widespread deployment in both indoor and outdoor environments.

B. Design Rationale

The design of the proposed Air Quality Monitoring System is based on achieving a balance between cost, performance, and ease of implementation. Low-cost MQ-series gas sensors [3] are selected due to their availability and ability to detect various gases, while the DHT11 sensor [4] is used for measuring temperature and humidity. Although these sensors may have limitations in terms of precision compared to industrial-grade devices, they are sufficient for general-purpose monitoring and educational applications.

The ESP32 microcontroller [2][9] is chosen as the core processing unit due to its high computational capability, low power consumption, and built-in Wi-Fi and Bluetooth features. This enables seamless data processing and wireless communication [2][9] without the need for additional modules.

The system is designed to provide real-time monitoring and immediate user feedback through a display and alert mechanism. Threshold-based alerts ensure that users are notified when pollutant levels exceed safe limits. Additionally, the modular architecture of the system allows easy integration with cloud platforms and future scalability.

Overall, the design focuses on developing a compact, energy-efficient, and user-friendly system that can be deployed in various environments to promote awareness and facilitate proactive air quality management.

IV.SYSTEM RCHITECTURE

The proposed Air Quality Monitoring System is designed using a modular architecture that integrates sensing, data processing, communication, and user interface components. The system ensures continuous monitoring of environmental parameters and provides real-time feedback to users.

A. Overall Architecture

The system consists of the following main functional blocks:

Sensor Unit

Signal Conditioning Unit

Microcontroller Unit

Communication Module

Display and Alert System

Power Supply Unit

These components work together to acquire, process, and transmit environmental data efficiently.

B. Sensor Unit

The sensor unit is responsible for collecting environmental data. MQ-series gas sensors [3] are used to detect harmful gases such as carbon monoxide and other pollutants, while the DHT11 sensor [4] measures temperature and humidity. The sensors generate analog or digital signals corresponding to the measured parameters.

C. Signal Conditioning Unit

V. HARDWARE DESIGN

The hardware design of the proposed Air Quality Monitoring System focuses on developing a compact, efficient, and cost-effective solution for real-time environmental monitoring. The system integrates various sensors, a microcontroller, and supporting components to ensure accurate data acquisition and processing.

A. Microcontroller Unit

The ESP32 microcontroller [2][9] serves as the central processing unit of the system. It is selected due to its high performance, low power consumption, and integrated Wi-Fi and Bluetooth capabilities. The ESP32 reads data from the sensors, processes the information, and controls communication and output operations.

B. Gas Sensor (MQ-Series)

MQ-series gas sensors [3] are used to detect the presence of harmful gases such as carbon monoxide and alcohol vapors. These sensors operate based on changes in resistance when exposed to specific gases. The output is analog in nature and is interfaced with the microcontroller through its analog input pins.

C. Temperature and Humidity Sensor (DHT11)

The DHT11 sensor [4] is used to measure ambient temperature and humidity. It provides calibrated digital output, which simplifies interfacing with the ESP32. This sensor also plays an important role in environmental compensation, as temperature and humidity can influence gas sensor readings.

D. Display Module

A display unit, such as a 16×2 LCD or OLED display [1][8], is used to show real-time environmental parameters. It provides users with immediate visual feedback regarding air quality conditions, making the system more user-friendly.

E. Alert System

An alert mechanism is incorporated using components such as LEDs or buzzers [1][8]. This system is activated when the measured pollutant levels exceed predefined threshold values, ensuring timely notification to users about hazardous conditions.

F. Power Supply

The system is powered using a regulated power supply, which may include a battery or an external adapter. Proper voltage regulation is ensured to maintain stable operation of the sensors and microcontroller.

G. Interfacing and Circuit Design

All components are interconnected using a breadboard and connecting wires during the prototyping phase. The sensors are interfaced with the ESP32 through analog and digital input pins. Proper grounding and power connections are maintained to ensure reliable performance. The overall circuit design is simple, modular, and suitable for further expansion.

H. Design Considerations

Several factors were considered during hardware design:

* Sensor accuracy and calibration requirements
* Power efficiency for continuous operation
* Compact and portable design
* Ease of integration with communication modules

The final hardware setup ensures reliable data acquisition while maintaining low cost and simplicity, making it suitable for practical deployment.

VI. SOFTWARE DESIGN AND CONTROL LOGIC

The software design of the proposed Air Quality Monitoring System focuses on efficient data acquisition, processing, decision-making, and communication. The control logic is implemented within the ESP32 microcontroller [2][9] using embedded programming techniques to ensure reliable and real-time system operation.

A. Software Architecture

The software is structured into multiple functional modules, including:

* Sensor data acquisition
* Data processing and calibration
* Decision-making and control
* Display and alert handling

* Communication and data transmission

This modular approach enhances system reliability, scalability, and ease of maintenance.

B. Data Acquisition

The ESP32 continuously reads data from the MQ-series gas sensors [3] and the DHT11 sensor [4]. Analog signals from gas sensors are converted into digital values using the microcontroller's ADC, while the DHT11 provides digital output directly. Sampling is performed at regular intervals to ensure up-to-date monitoring of environmental conditions.

C. Data Processing and Calibration

The raw sensor data is processed to obtain meaningful values. Calibration techniques are applied to improve accuracy, including offset correction and environmental compensation based on temperature and humidity. Filtering methods may also be used to reduce noise and fluctuations in sensor readings.

D. Control Logic

The system operates based on predefined threshold values for different environmental parameters. The control logic compares real-time sensor readings with these thresholds. If the measured values exceed safe limits, the system triggers appropriate actions such as activating alerts or sending notifications.

E. Display and User Interface

Processed data is displayed on an LCD or OLED screen, providing real-time information about air quality parameters. The interface is designed to be simple and user-friendly, allowing users to easily interpret the readings.

F. Alert Mechanism

An alert system is implemented using LEDs or buzzers [1][8]. When pollutant levels exceed predefined thresholds, the system generates immediate alerts to warn users about unsafe environmental conditions.

G. Communication Protocol

The ESP32 utilizes its built-in Wi-Fi capability to transmit data to external devices or cloud platforms. Data can be sent periodically or in real time, enabling remote monitoring and analysis. Standard communication protocols such as HTTP or MQTT [2][9] may be used for efficient data transfer.

H. System Workflow

1. Initialize sensors and communication modules
2. Continuously read sensor data
3. Process and calibrate the data

4. Compare values with predefined thresholds
5. Display results on the screen
6. Trigger alerts if necessary
7. Transmit data wirelessly for remote monitoring

I. Reliability and Performance Considerations

The software is designed to ensure stable and continuous operation. Error handling mechanisms are incorporated to manage sensor failures or communication issues. Efficient coding practices are used to optimize memory usage and processing speed.

VII. PROTOTYPE IMPLEMENTATION

The prototype of the proposed Air Quality Monitoring System was developed to validate the design and functionality of the system in a real-world environment. The implementation integrates hardware components with embedded software to achieve continuous monitoring and real-time data processing.

A. Hardware Setup

The prototype was assembled using an ESP32 microcontroller [2][9], MQ-series gas sensor, DHT11 temperature and humidity sensor, display module, and alert components such as LEDs or a buzzer. All components were connected using a breadboard and interfacing wires [1][8] to allow easy testing and modification. Proper power supply connections were ensured to maintain stable operation of the system.

B. Sensor Integration

The MQ-series gas sensor was interfaced with the analog input pin of the ESP32 to detect the concentration of harmful gases. The DHT11 sensor [4] was connected to a digital input pin to measure temperature and humidity. Appropriate libraries and drivers were used to facilitate communication between the sensors and the microcontroller.

C. Software Implementation

The system was programmed using embedded C/C++ in the Arduino IDE environment [1][8]. The software includes routines for sensor initialization, data acquisition, processing, and decision-making. Calibration and threshold-based logic were implemented to ensure meaningful interpretation of sensor data.

D. Real-Time Monitoring

The prototype continuously collects environmental data and displays it on the connected display module. The readings are updated at regular intervals, providing users with real-time information about air quality conditions. The system also supports wireless data transmission through the ESP32's built-in Wi-Fi feature.

E. Alert Mechanism

An alert system was implemented to notify users when pollutant levels exceed predefined safety limits. The alert is generated using visual indicators (LEDs) and/or audible signals (buzzer), ensuring immediate awareness of hazardous conditions.

F. Testing and Validation

The prototype was tested under different environmental conditions [6][7] to evaluate its performance. Variations in gas concentration, temperature, and humidity were observed and recorded. The system responded effectively to changes in environmental parameters and successfully triggered alerts when threshold values were exceeded.

G. Implementation Outcome

The prototype demonstrated reliable performance in monitoring air quality parameters and providing real-time feedback. The integration of hardware and software components was successful, validating the feasibility of the proposed system for practical applications.

VIII. TESTING AND VALIDATION

The developed Air Quality Monitoring System was subjected to a series of tests to evaluate its performance, accuracy, and reliability under different environmental conditions. The testing process was carried out to validate the proper functioning of both hardware and software components.

A. Testing Methodology

The system was tested in various indoor and semi-outdoor environments to observe its response to changes in air quality parameters. Sensor readings for gas concentration, temperature, and humidity were recorded at regular intervals. Different conditions, such as the presence of smoke, alcohol vapors, and variations in ambient temperature, were introduced to analyze system behavior.

B. Sensor Performance Evaluation

The MQ-series gas sensor demonstrated sensitivity to changes in gas concentration, with noticeable variations in output when exposed to pollutants. The DHT11 sensor [4] provided stable readings for temperature and humidity. Although minor fluctuations were observed due to environmental factors, the overall performance of the sensors was consistent and acceptable for monitoring purposes.

C. System Accuracy and Response

The system showed a prompt response to changes in environmental conditions. When pollutant levels increased beyond predefined thresholds, the alert mechanism was activated immediately. The real-time display updated sensor readings accurately, allowing users to monitor air quality effectively.

D. Validation of Alert Mechanism

The alert system, consisting of LEDs and/or a buzzer, was tested by artificially increasing pollutant levels. The system successfully triggered alerts when the measured values exceeded safe limits, confirming the effectiveness of the control logic.

E. Communication Testing

Wireless communication [2][9] using the ESP32 was tested to ensure reliable data transmission. The system successfully transmitted data to external devices or platforms, enabling remote monitoring. No significant data loss or delay was observed during testing.

F. Limitations Observed

Some limitations were identified during testing:

* MQ-series sensors require proper calibration [3] for higher accuracy
* Environmental factors such as humidity can affect sensor readings
* DHT11 has limited precision [4] compared to advanced sensors

G. Overall Validation

The testing results confirm that the proposed system operates reliably and meets the intended objectives. It is capable of continuously monitoring air quality parameters, providing real-time data, and generating timely alerts. The system is suitable for practical applications in indoor and small-scale outdoor environments.

IX. DISCUSSION

The implementation of the proposed Air Quality Monitoring System demonstrates the feasibility of using low-cost sensors and IoT-enabled microcontrollers for real-time environmental monitoring. The system successfully integrates hardware and software components to provide continuous measurement of air quality parameters such as gas concentration, temperature, and humidity.

The results obtained from testing indicate that the system is capable of detecting variations in environmental conditions with reasonable accuracy. The MQ-series gas sensors [3] showed adequate sensitivity to the presence of pollutants, while the DHT11 sensor [4] provided stable measurements of temperature and humidity. Although these sensors are not as precise as industrial-grade instruments, they are sufficient for general-purpose monitoring and awareness applications.

One of the key strengths of the system is its real-time monitoring capability combined with an effective alert mechanism. The immediate response to threshold violations ensures that users are promptly informed about unsafe environmental conditions. Additionally, the integration of wireless communication [2][9] through the ESP32 enhances the system's functionality by enabling remote access and data transmission.

However, certain limitations were observed during the study. The accuracy of MQ-series sensors is influenced by environmental factors such as humidity and temperature, and they require proper calibration for reliable results. The DHT11 sensor [4] also has limited precision compared to more advanced alternatives. Furthermore, the system currently provides localized monitoring and may require further enhancements for large-scale deployment.

Despite these limitations, the proposed system offers a practical and scalable solution for air quality monitoring. Its low cost, ease of implementation, and modular design make it suitable for applications in homes, educational institutions, and small industries. Future improvements, such as the use of high-precision sensors and advanced data analytics, can further enhance the performance and applicability of the system.

X. LIMITATIONS AND FUTURE WORK

A. Limitations

Although the proposed Air Quality Monitoring System demonstrates effective performance for real-time environmental monitoring, several limitations were identified during its design and implementation:

1. Sensor Accuracy: The MQ-series gas sensors [3] used in the system provide approximate measurements and require proper calibration for improved accuracy. Their readings may vary due to environmental conditions.
2. Environmental Sensitivity: Factors such as temperature and humidity can significantly affect sensor performance, leading to fluctuations in the measured values.
3. Limited Precision of DHT11: The DHT11 sensor [4] offers basic temperature and humidity measurements but lacks the precision of more advanced sensors.
4. Lack of Standard AQI Calibration: The system does not fully implement standardized Air Quality Index (AQI) calculations based on official environmental guidelines.

5. Scalability Constraints: The current prototype is designed for small-scale or localized monitoring and may require modifications for large-scale deployment.
6. Power Dependency: The system relies on a continuous power supply, limiting its portability and long-term outdoor usage without additional power management solutions.

B. Future Work

To overcome the above limitations and enhance the system's performance, several improvements can be considered in future developments:
1. Integration of High-Precision Sensors: Replacing MQ-series sensors with advanced electrochemical or optical sensors can improve measurement accuracy.
2. Advanced AQI Computation: Implementing standard AQI calculation methods based on government or international guidelines for better interpretation of air quality data.
3. IoT and Cloud Integration: Expanding the system to include cloud platforms for large-scale data storage, visualization, and analysis.
4. Mobile Application Development: Designing user-friendly mobile applications for real-time monitoring, alerts, and historical data tracking.
5. Machine Learning Integration [7]: Applying predictive models to forecast air pollution levels and provide early warnings.
6. Energy-Efficient Design: Incorporating solar power or low-power techniques to enable continuous and sustainable operation.
7. Scalable Network Deployment: Developing a network of multiple monitoring nodes for smart city applications [7] and large-area coverage.

Here is your **IEEE-standard "Subsystem Connections" section**, written in formal academic style:

XII. SUBSYSTEM CONNECTIONS

The Air Quality Monitoring System is composed of multiple interconnected subsystems that work together to ensure efficient data acquisition, processing, and output. Proper interfacing between these subsystems is essential for accurate and reliable system performance.

A. Sensor-to-Microcontroller Interface

The MQ-series gas sensor is connected to the analog input pin of the ESP32 microcontroller [2][9], allowing the sensor's analog voltage output to be converted into digital values using the built-in Analog-to-Digital Converter (ADC). The DHT11 temperature and humidity sensor is interfaced through a digital GPIO pin, utilizing a single-wire communication protocol for data transmission.

B. Microcontroller-to-Display Interface

The processed data from the ESP32 is transmitted to the display module (LCD or OLED) for real-time visualisation. Depending on the type of display used, communication is established using protocols such as I2C or SPI, ensuring efficient data transfer with minimal wiring.

C. Microcontroller-to-Alert System Connection

The alert components, including LEDs and buzzers, are connected to the digital output pins of the ESP32. The microcontroller controls these components based on predefined threshold conditions. When pollutant levels exceed safe limits, the corresponding output pins are activated to trigger visual or audible alerts.

D. Power Supply Connections

All subsystems are powered through a regulated power supply. The ESP32 and sensors typically operate at 3.3V or 5V, depending on their specifications. Proper voltage regulation and grounding are maintained to ensure stable operation and to prevent damage to components.

E. Communication Interface: The ESP32's built-in Wi-Fi module enables wireless communication [2][9] with external devices or cloud platforms. This allows the system to transmit data for remote monitoring and analysis. Communication protocols such as HTTP or MQTT [2][9] can be used for efficient data exchange.

F. Overall Integration

All subsystems are integrated on a breadboard during the prototyping stage, ensuring flexible connections and ease of modification. The coordinated interaction between sensors, processing unit, display, and communication modules ensures seamless operation of the system.

G. Connection Reliability Considerations

To ensure reliable subsystem connections, proper wiring practices, secure connections, and noise reduction techniques are implemented.

XIII. CONCLUSION

In this paper, an IoT-based Air Quality Monitoring System [2][6][7] has been designed and implemented to measure key environmental parameters such as gas concentration, temperature, and humidity. The system utilizes MQ-series gas sensors [3] and a DHT11 sensor [4] interfaced with an ESP32 microcontroller [2][9] to enable real-time data acquisition, processing, and wireless communication [2][9].

The developed prototype successfully demonstrates the ability to monitor air quality conditions and provide immediate feedback through a display and alert mechanism when pollutant levels exceed predefined thresholds. The experimental results indicate that the system is reliable, responsive, and suitable for basic air quality assessment in indoor and small-scale outdoor environments.

The proposed system offers a cost-effective and scalable solution for continuous environmental monitoring. It can be deployed in residential areas, educational institutions, and workplaces to increase awareness about air pollution and promote preventive measures. Although certain limitations exist in terms of sensor accuracy and scalability, the system provides a strong foundation for further development.

Future enhancements, including the integration of advanced sensors, cloud-based data analytics, and intelligent prediction techniques, can significantly improve the performance and applicability of the system. Overall, the project highlights the potential of IoT-based solutions in addressing environmental challenges and contributing to sustainable development.

XIV. REFERENCES

1. Arduino, “Arduino Official Website.” [Online]. Available: https://www.arduino.cc
2. Espressif Systems, “ESP32 Technical Reference Manual.” [Online]. Available: https://www.espressif.com
3. Hanwei Electronics, “MQ Gas Sensor Datasheet,” 2018.
4. Aosong Electronics, “DHT11 Temperature and Humidity Sensor Datasheet,” 2016.
5. Plantower, “PMS5003 Particulate Matter Sensor Manual,” 2017.
6. S. Kumar, A. Jasuja, “Air Quality Monitoring System Based on IoT Using Raspberry Pi,” International Journal of Engineering Research & Technology (IJERT), vol. 9, no. 5, pp. 123–126, 2020.
7. P. Rai, K. Kumar, “Design and Implementation of Smart Air Pollution Monitoring System,” IEEE Xplore, 2019.

8. S. Monk, Arduino Projects for Beginners, New York, NY, USA: McGraw-Hill, 2019.
9. A. Kurniawan, Internet of Things with ESP32, Birmingham, U.K.: Packt Publishing, 2020.
10. World Health Organization (WHO), "Air Pollution and Health," 2021. [Online]. Available: https://www.who.int