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AIR QUALITY MONITORING SYSTEM

PHASE - 1 Synopsis
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PHASE-1

Project Synopsis

Air Quality Monitoring System

Rapid urbanization and increased industrial activities have significantly contributed to the deterioration of air quality, posing serious risks to human health and the environment. Poor indoor air quality can lead to respiratory problems, reduced productivity, and long-term health complications. To address this issue, this project proposes an IoT-based Air Quality Monitoring System that enables continuous, real-time monitoring of critical air quality parameters using low-cost and energy-efficient sensing devices.

The system is built around the ESP32 microcontroller, which acts as the central processing and communication unit. It integrates the ENS160 digital air quality sensor to measure Air Quality Index (AQI), Total Volatile Organic Compounds (TVOC), and equivalent Carbon Dioxide (eCO2), and the SHT40 sensor to accurately measure temperature and relative humidity. Temperature and humidity data are used to compensate gas sensor readings, thereby enhancing the accuracy and stability of air quality measurements under varying environmental conditions.

The ESP32 connects to a wireless network and hosts an embedded RESTful web server, allowing sensor data to be accessed remotely in JSON format. A web-based dashboard is used to visualize real-time and historical air quality data, enabling users to assess pollution levels and take preventive actions when necessary. The system architecture supports scalability through multiple sensor nodes, each identified by a unique device ID and location tag, making it suitable for distributed monitoring across large indoor spaces.

The proposed solution is cost-effective, scalable, and easy to deploy, making it suitable for applications such as smart homes, offices, educational institutions, and healthcare facilities. This system demonstrates the effective use of IoT technologies to improve environmental awareness and promote healthier living conditions.

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Abstract

Rapid urbanization and increased industrial activities have significantly contributed to the deterioration of air quality, posing serious risks to human health and the environment. Poor indoor air quality can lead to respiratory problems, reduced productivity, and long-term health complications. To address this issue, this project proposes an IoT-based Air Quality Monitoring System that enables continuous, real-time monitoring of critical air quality parameters using low-cost and energy-efficient sensing devices. The system is built around the ESP32 microcontroller, which acts as the central processing and communication unit. It integrates the ENS160 digital air quality sensor to measure Air Quality Index (AQI), Total Volatile Organic Compounds (TVOC), and equivalent Carbon Dioxide (eCO2), and the SHT40 sensor to accurately measure temperature and relative humidity. Temperature and humidity data are used to compensate gas sensor readings, thereby enhancing the accuracy and stability of air quality measurements under varying environmental conditions. The ESP32 connects to a wireless network and hosts an embedded RESTful web server, allowing sensor data to be accessed remotely in JSON format. A web-based dashboard is used to visualize real-time and historical air quality data, enabling users to assess pollution levels and take preventive actions when necessary. The system architecture supports scalability through multiple sensor nodes, each identified by a unique device ID and location tag, making it suitable for distributed monitoring across large indoor spaces. The proposed solution is cost-effective, scalable, and easy to deploy, making it suitable for applications such as smart homes, offices, educational institutions, and healthcare facilities. This system demonstrates the effective use of IoT technologies to improve environmental awareness and promote healthier living conditions.

1. Introduction

Air quality monitoring has become increasingly important due to rising pollution levels and their adverse effects on human health and the environment. Poor indoor air quality can lead to serious health issues such as respiratory problems, allergies, and reduced comfort. With advancements in embedded systems and the Internet of Things (IoT), it is now possible to develop compact, low-cost, and real time air quality monitoring solutions. This project presents an IoT-based Air Quality Monitoring System that continuously measures and displays air quality parameters using sensor-based technology and wireless communication.

1.1 Background and Motivation

Air pollution has emerged as one of the most critical environmental challenges affecting human health and quality of life. In recent years, increased urbanization, industrial activities, and the extensive use of household chemicals have significantly degraded air quality, particularly in indoor environments. Since people spend a majority of their time indoors, exposure to pollutants such as volatile organic compounds (VOCs), carbon dioxide, and particulate contaminants can lead to respiratory disorders, headaches, fatigue, and long-term health issues. Continuous monitoring of indoor air quality is therefore essential to identify pollution sources and maintain a healthy living and working environment. Despite the importance of air quality monitoring, conventional monitoring systems are often expensive, bulky, and limited to centralized outdoor locations. These systems do not provide real-time, localized information required for effective indoor monitoring. With advancements in sensor technology and the Internet of Things (IoT), it has become possible to design compact, low-cost, and energy-efficient monitoring systems capable of real-time data collection and remote access. The motivation behind this project is to leverage IoT technology to develop a scalable and user-friendly air quality monitoring system that provides accurate environmental data through a wireless dashboard, thereby increasing awareness and enabling timely preventive actions to improve indoor air quality.

1.2 Literature Survey

Several air quality monitoring systems have been developed using conventional gas sensors such as the MQ-series in combination with microcontrollers like Arduino and Raspberry Pi. These systems are capable of detecting basic air pollutants and are widely used due to their low initial cost and simple implementation. However, they often face significant limitations, including low measurement accuracy, high power consumption, sensitivity to environmental conditions, and the requirement for frequent manual calibration. These drawbacks reduce their reliability for long-term and real-time indoor air quality monitoring applications.

Recent research has focused on the use of digital air quality sensors integrated with IoT-enabled

microcontrollers to overcome these limitations. Digital sensors provide improved accuracy, factory calibration, and stable performance under varying environmental conditions. Additionally, IoT-based systems enable wireless data transmission and integration with cloud-based or web-based dashboards for real-time visualization and remote access. These advancements demonstrate the effectiveness of IoT technologies in developing scalable, reliable, and user-friendly air quality monitoring solutions suitable for modern smart environments.

1.3 Problem Statement

Although significant progress has been made in IoT-based environmental sensing technologies, many existing air quality monitoring systems still lack the ability to provide consistent, accurate, and context-aware indoor air quality information. Several available solutions depend on low-cost analog sensors that are highly sensitive to environmental variations and require frequent recalibration. Others offer continuous data reporting without addressing factors such as temperature and humidity effects, which can compromise the reliability of gas sensor measurements. These limitations highlight a gap in developing monitoring systems that effectively combine affordability, accuracy, and long-term stability.

This project addresses the need for a reliable and scalable air quality monitoring solution that integrates digital air quality sensing with environmental compensation and real-time data accessibility. The objective is to design an IoT-based framework capable of delivering precise air quality parameters while remaining non-intrusive and easy to deploy in indoor environments. The system also evaluates the feasibility of multi-node deployment for continuous monitoring, making it suitable for practical implementation in real-world applications such as homes, offices, and educational institutions.

1.4 Objectives

1. To continuously monitor indoor air quality conditions in real time.
2. To detect and display air quality parameters such as AQI, TVOC, and eCO_2.
3. To measure ambient temperature and humidity affecting indoor air quality.
4. To provide accurate air quality readings by compensating gas sensor data using environmental parameters.
5. To display real-time sensor data on a dashboard for easy monitoring and analysis.
6. To enable remote access to air quality information through a wireless network.
7. To support monitoring across different locations using multiple sensor nodes.
8. To increase awareness of indoor air pollution and support timely corrective actions.

2. Proposed Project Details

2.1 System Overview

The proposed system is an IoT-based Air Quality Monitoring System designed to continuously observe indoor environmental conditions and present real-time air quality information through a digital dashboard. The system uses sensor nodes built around the ESP32 microcontroller to collect air quality parameters such as Air Quality Index (AQI), Total Volatile Organic Compounds (TVOC), equivalent Carbon Dioxide (eCO_2), temperature, and humidity. The collected data is processed locally and transmitted wirelessly over WiFi for remote access and visualization.

Each monitoring node is uniquely identified by a device ID and location tag, enabling deployment across multiple indoor locations. The system operates in real time and provides users with an intuitive interface to assess air quality conditions and take preventive actions when required. The proposed solution is cost-effective, scalable, and suitable for applications such as homes, offices, classrooms, and laboratories. Additionally, the system supports continuous monitoring with minimal power consumption, making it suitable for long-term deployment. The modular design allows easy integration of additional sensors or features in future enhancements.

2.2 Proposed System / Methodology

The methodology followed in this project consists of four primary stages:

1. Data Collection

- The ENS160 air quality sensor is used to measure critical air quality parameters such as Air Quality Index (AQI), Total Volatile Organic Compounds (TVOC), and equivalent Carbon Dioxide (eCO_2).
- The SHT40 sensor continuously monitors ambient temperature and relative humidity, which influence air quality conditions.

2. Data Processing

- Temperature and humidity values obtained from the SHT40 sensor are applied to compensate the ENS160 sensor readings, improving accuracy and stability.
- The ESP32 microcontroller processes the compensated sensor data and organizes it into a structured format suitable for transmission.

3. Data Transmission

- The processed sensor data is transmitted wirelessly over WiFi using the HTTP protocol.
- Data is shared in JSON format through REST API endpoints hosted on the ESP32, allowing easy access by external applications.

4. Data Visualization

- A web-based dashboard periodically fetches data from the ESP32.

- The dashboard displays real-time air quality and environmental parameters in a clear and user-friendly manner, enabling continuous monitoring.

2.3 System Architecture

The system architecture of the proposed Air Quality Monitoring System follows a layered IoT model that integrates sensing hardware, embedded firmware, wireless communication, and a web-based dashboard developed using React.js. The architecture ensures real-time data acquisition, processing, transmission, and visualization.

1. Sensing Layer

- Consists of ENS160 and SHT40 sensors connected to the ESP32.

- ENS160 measures air quality parameters such as AQI, TVOC, and eCO_2.

- SHT40 measures ambient temperature and humidity.

- Sensors communicate with the ESP32 using the I^2C protocol.

2. Device / Embedded Layer

- ESP32 acts as the main embedded controller.

- Arduino firmware handles sensor initialization, data acquisition, and processing.

- Temperature and humidity values are used to compensate air quality readings.

- The ESP32 formats the sensor data into JSON.

- A RESTful web server is hosted on the ESP32 to expose sensor data endpoints.

3. Communication Layer

- ESP32 connects to a local WiFi network.

- Sensor data is transmitted using HTTP protocol.

- REST API endpoints (e.g., /data) allow external clients to request real-time data.

- CORS headers enable cross-origin communication with the React.js dashboard.

4. Application Layer

- A web-based dashboard is developed using React.js.

- The dashboard periodically fetches sensor data from the ESP32 REST API.

- Real-time values of AQI, TVOC, eCO_2, temperature, and humidity are displayed.

- The interface provides a clear and intuitive visualization of air quality conditions.

- Supports monitoring of multiple ESP32 nodes using device ID and location information.

5. User Interaction Layer

- Users access the dashboard through a web browser.

- Real-time monitoring enables users to assess air quality conditions remotely.

- The system helps users take preventive actions when poor air quality is detected.

2.4 Implementation Details

The implementation of the proposed Air Quality Monitoring System involves programming the ESP32 microcontroller using the Arduino IDE. The firmware integrates the required libraries for the ENS160 air quality sensor and the SHT40 temperature and humidity sensor to enable accurate data acquisition. Sensor readings are collected at fixed time intervals, and temperature and humidity values are used to compensate the air quality measurements, improving accuracy and stability. The processed sensor data is then organized into a structured JSON format that includes air quality parameters along with device identification details.

An asynchronous web server is implemented on the ESP32 to enable real-time data access. REST API endpoints are created to provide sensor readings and system health information, while Cross-Origin Resource Sharing (CORS) headers allow seamless communication with the React.js-based dashboard. The dashboard fetches and displays real-time air quality data in a user-friendly interface, supporting monitoring across multiple sensor nodes. The system is tested using serial monitoring and dashboard validation under different indoor conditions to ensure reliable and consistent performance.

2.5 Devices and Technology Stack

The implementation of the proposed IoT-based Air Quality Monitoring System focuses on integrating sensor hardware, embedded firmware, and a web-based dashboard for real-time monitoring. It describes the system architecture, data acquisition methodology, and communication approach used to transmit air quality data wirelessly. The section also highlights the devices and technology stack adopted to develop a scalable and reliable monitoring solution.

Hardware Devices

- **ESP32 Microcontroller:** Acts as the central processing and communication unit, handling sensor data acquisition, processing, and wireless transmission.
- **ENS160 Air Quality Sensor:** Measures air quality parameters such as Air Quality Index (AQI), Total Volatile Organic Compounds (TVOC), and equivalent Carbon Dioxide (eCO_2).
- **SHT40 Temperature and Humidity Sensor:** Provides accurate ambient temperature and relative humidity measurements used for environmental monitoring and sensor compensation.
- **Power Supply Unit:** Supplies stable power to the ESP32 and connected sensors for continuous operation.

Software Technologies

- **Arduino IDE:** Used for writing, compiling, and uploading firmware to the ESP32.
- **Arduino Framework:** Utilized for sensor interfacing, data processing, and system control.
- **Sensor Libraries:** Libraries for ENS160 and SHT40 enable reliable sensor initialization and data acquisition.

Communication and Networking

- **WiFi Communication:** Enables wireless data transmission between the ESP32 and the dashboard.

- **HTTP Protocol:** Used for data communication through RESTful API endpoints.

- **REST API:** Provides structured access to real-time sensor data.

**Frontend and Data Visualization**

- **React.js:** Used to develop the web-based dashboard for real-time data visualization.

- **JSON Data Format:** Ensures structured and lightweight data exchange between the ESP32 and the dashboard.

3. Project Screenshots

3.1 Hardware Prototype

The hardware prototype of the proposed Air Quality Monitoring System is developed to demonstrate real-time monitoring of indoor environmental conditions using compact and low-power components. The prototype consists of an ESP32 microcontroller integrated with an ENS160 air quality sensor and an SHT40 temperature and humidity sensor. All components are assembled on a breadboard to allow flexibility during development and testing. The sensors are interfaced with the ESP32 using the I²C communication protocol, ensuring efficient and reliable data exchange.

The ESP32 functions as the central control unit, responsible for acquiring sensor data, processing readings, and transmitting information wirelessly via WiFi. A stable power supply is provided to ensure uninterrupted operation of the system. The prototype is deployed in an indoor environment to measure air quality parameters such as AQI, TVOC, eCO_2, temperature, and humidity, which are displayed on a web-based dashboard. This prototype validates the practical implementation of the system and serves as a foundation for future enhancements and real-world deployment.
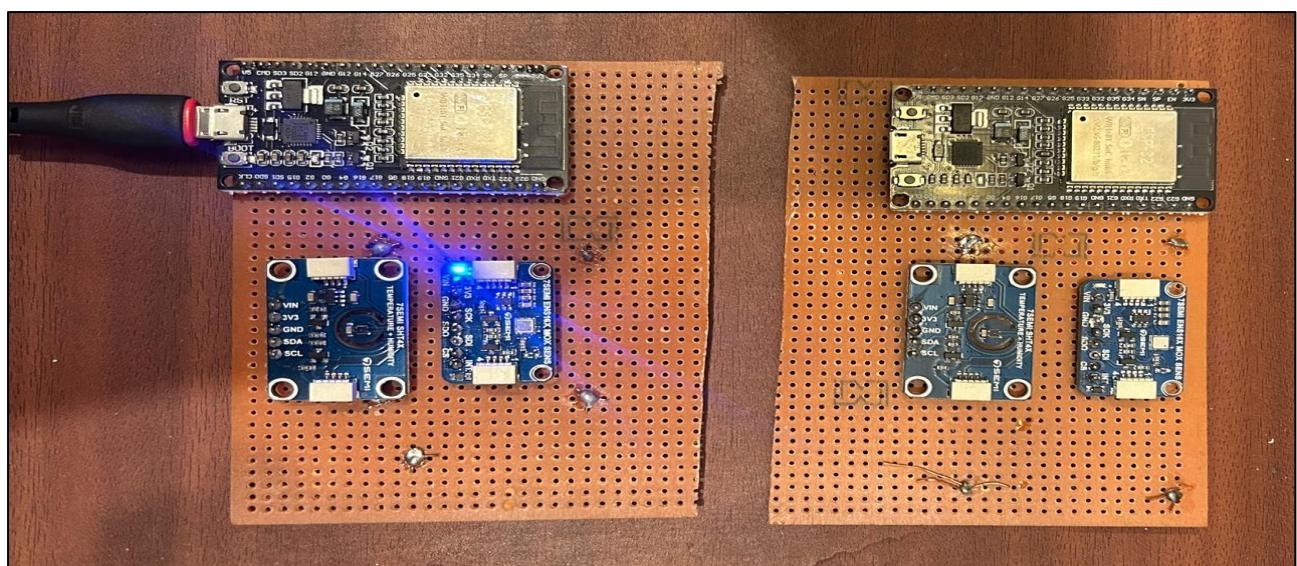
Figure 3: Hardware Prototype Images

3.2 Results and Observations

The developed IoT-based Air Quality Monitoring System was successfully implemented and tested in an indoor environment using multiple ESP32 sensor nodes deployed at different locations. The output is visualized through a React.js-based web dashboard, which receives real-time data from each controller. The dashboard continuously displays air quality parameters such as AQI, TVOC, eCO_2, temperature, and humidity, confirming reliable communication between the hardware nodes and the software interface.

One of the key results observed is the dashboard's ability to calculate and display average values of air quality parameters obtained from multiple controllers. The overall AQI and other summarized parameters shown at the top of the dashboard represent the mean of readings collected from different locations. This aggregation reduces the impact of localized fluctuations and provides a more accurate representation of the overall indoor air quality.

Figure 1: Real-Time Air Quality Monitoring Dashboard
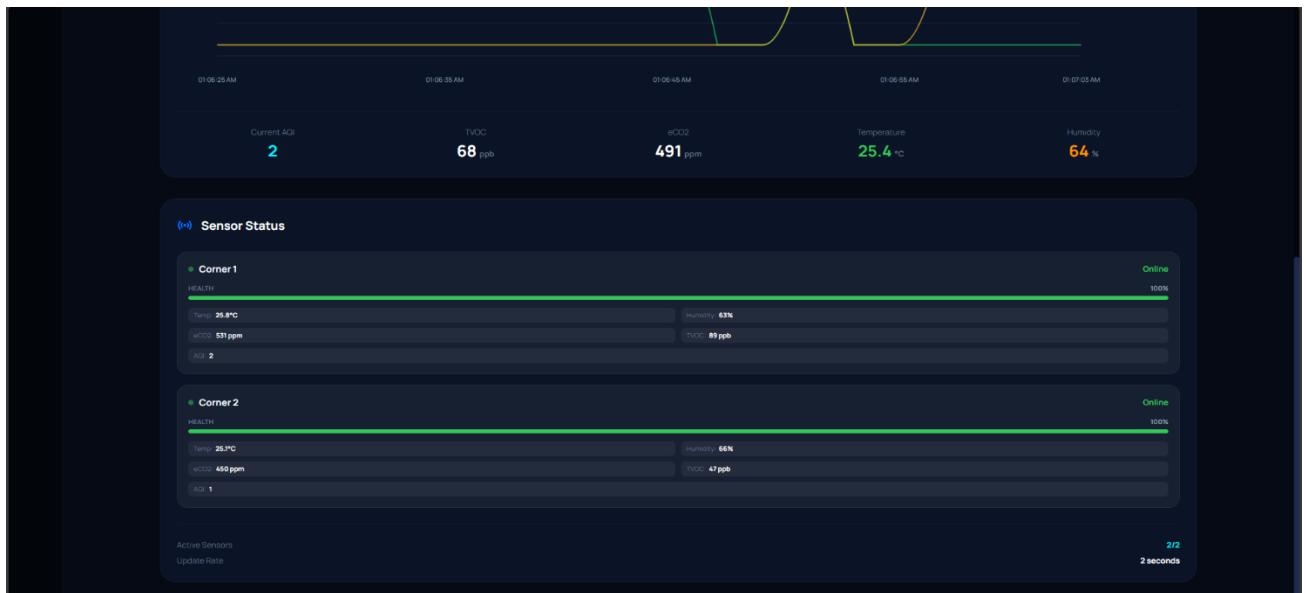
Figure 2: Sensor Status and Individual Node Readings from Multiple ESP32 Controllers

The real-time graphs displayed on the dashboard show consistent updates at regular intervals, demonstrating stable sensor performance and uninterrupted data transmission. Individual sensor status panels indicate that all controllers remain online with proper health indicators. Minor variations in temperature, humidity, TVOC, and eCO_2 were observed between different locations, highlighting the importance of multi-node deployment. Overall, the system performed reliably, validating the effectiveness of multi-sensor data averaging and real-time visualization for indoor air quality monitoring.

4. Conclusion

The IoT-based Air Quality Monitoring System presented in this project demonstrates an effective solution for continuous monitoring of indoor environmental conditions. The system integrates an ESP32 microcontroller with the ENS160 air quality sensor and the SHT40 temperature and humidity sensor to measure key air quality parameters such as AQI, TVOC, eCO_2, temperature, and humidity. The use of digital sensors and environmental compensation ensures reliable and accurate measurements under varying indoor conditions.

The implementation of a REST-based web server on the ESP32 enables real-time wireless transmission of sensor data. A web-based dashboard developed using React.js provides an intuitive interface for users to visualize air quality information remotely. The inclusion of device identification and location tagging allows the system to support multiple monitoring nodes, making it suitable for deployment across different indoor spaces.

The proposed system is cost-effective, scalable, and easy to deploy, making it suitable for applications such as homes, offices, classrooms, and laboratories. This project highlights the potential of IoT technologies in enhancing environmental monitoring and awareness, and it provides a strong foundation for future improvements and real-world deployment of smart air quality monitoring solutions.

Future Enhancement

In future, the proposed system can be enhanced by integrating cloud-based platforms for storing and analyzing historical air quality data. This would enable long-term monitoring, trend analysis, and advanced data visualization. Additional sensors such as particulate matter (PM2.5/PM10) and carbon monoxide sensors can also be incorporated to provide a more comprehensive evaluation of air quality conditions.

Another significant enhancement involves integrating an automatic air purification system with the monitoring unit. An air purifier can be connected to the system and configured to turn on automatically when air quality parameters such as AQI, TVOC, or eCO_2 exceed predefined threshold levels. This closed-loop control approach would allow the system not only to monitor air quality but also to actively improve it without manual intervention. Such an enhancement would make the system more intelligent and suitable for smart homes, offices, and healthcare environments

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