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Next-Generation IoT-Based Air & Noise Pollution Monitoring System Using ESP32-S3

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Abstract

Air and noise pollution have become serious environmental problems in modern urban areas due to rapid industrialization, increasing traffic, and population growth. Continuous monitoring of pollution levels is important to protect public health and maintain environmental safety. Traditional pollution monitoring systems are expensive and limited in coverage, which makes real- time monitoring difficult in many locations. To address this issue, this project proposes a low-cost Internet of Things (IoT) based air and noise pollution monitoring system using the ESP32-S3 microcontroller. The proposed system uses the MQ-135 gas sensor to detect harmful gases in the air and a sound sensor to measure environmental noise levels. The ESP32-S3 microcontroller collects sensor data, processes it, and calculates pollution levels. When pollution exceeds predefined safety limits, the system activates a buzzer to provide an immediate alert. The collected data is transmitted to a cloud platform using Wi-Fi connectivity and stored in a Firebase database for real-time monitoring and historical analysis. A mobile application developed using Flutter allows users to view real-time air quality and noise levels remotely. The system provides a cost-effective, scalable, and efficient solution for environmental monitoring. The proposed system can support smart city applications by enabling continuous pollution monitoring and increasing public awareness about environmental conditions.

Keywords: IoT, ESP32-S3, air quality monitoring, noise pollution, MQ-135 sensor, cloud monitoring, smart cities

INTRODUCTION

Environmental pollution has become one of the most serious challenges faced by modern cities. Rapid industrialization, increasing population, urban development, and the growing number of vehicles have significantly increased the levels of air and noise pollution. These pollutants not only degrade environmental quality but also have a direct impact on human health and overall quality of life. Air pollution is mainly caused by harmful gases, particulate matter, and chemical pollutants released from vehicles, factories, and other human activities. Continuous exposure to polluted air can lead to respiratory diseases, cardiovascular problems, allergies, and other serious health issues. Similarly, excessive noise generated from traffic, construction sites, and industrial operations can cause stress, sleep disturbances, hearing impairment, and psychological discomfort. Therefore, monitoring environmental conditions in real time has become essential for maintaining a healthy and sustainable environment. Traditional pollution monitoring systems used by environmental agencies generally rely on large and expensive monitoring stations. These systems provide accurate measurements but are limited in number due to their high installation and maintenance cost. As a result, only a few monitoring stations are installed in major areas of a city, which makes it difficult to obtain detailed pollution information across different locations. Moreover,

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these traditional systems often provide data with some delay, which reduces their effectiveness in providing immediate alerts or warnings to the public. Because of these limitations, there is a growing need for low-cost, scalable, and real-time monitoring systems that can be deployed in multiple locations and provide continuous environmental data.

MOTIVATION

The motivation for this project comes from the growing concerns about the environment and health due to air and noise pollution, especially in crowded urban and industrial areas. Rapid urban growth and vehicle emissions have caused sharp rises in particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO), and volatile organic compounds (VOCs). At the same time, continuous exposure to urban noise from heavy traffic, construction, and industrial machines often exceeds safe levels set by the WHO and national standards. Despite the seriousness of these issues, real-time and localized monitoring data is still hard to find because traditional monitoring systems are expensive and not widely available.

OBJECTIVE

- To design and develop an automated greenhouse system that monitors and controls soil moisture, temperature, humidity, pH, and light using IoT sensors in real time.
- To provide remote monitoring and control of greenhouse conditions through an IoT dashboard (Thing Speak/Blynk/Firebase).
- To design and develop an automated greenhouse system that monitors and controls soil moisture, temperature, humidity, pH, and light using IoT sensors in real time.
- To implement automatic irrigation, lighting, and ventilation control using a Raspberry Pi to ensure optimal environmental conditions for plant growth.
- To integrate a CNN-based model for early detection of plant leaf diseases, enabling timely diagnosis and preventive action.
- To provide remote monitoring and control of greenhouse conditions through an IoT dashboard (Thing Speak/Blynk/Firebase).
- To design and develop an IoT-based system for monitoring air and sound pollution in real time.
- To measure harmful gases (NH_3, CO_2, benzene, smoke) using the MQ-135 sensor and monitor ambient noise levels using a noise sensor.
- To process and display pollution data through an Arduino microcontroller and LCD screen for user visibility.
- To trigger instant alerts (via buzzer) when air or noise pollution exceeds safe thresholds.
- To provide a low-cost, scalable, and portable solution suitable for urban, residential, and industrial applications.
- To lay the foundation for integration with cloud platforms and mobile applications in smart city environments.

SCOPE

This project includes developing a complete IoT-based environmental monitoring system that consists of hardware sensors, firmware, cloud infrastructure, and a mobile user interface. The hardware unit features the ESP32-S3 microcontroller and has an MQ-135 gas sensor for detecting air pollutants like carbon dioxide, ammonia, and nitrogen oxides. It also includes a sound sensor (INMP441 or LM393) to measure ambient noise levels.The firmware manages the real-time collection of data, calculates environmental indicators like the Air Quality Index (AQI) and Equivalent Continuous Noise Level (Leq), and transmits data securely to the cloud.The cloud platform (Firebase) takes care of data storage, sends alerts when pollution levels exceed set limits, and provides access to historical and analytical data.Users engage with a Flutter-based mobile application that shows live readings, visual graphs,and notifications. Administrators and technicians have additional access for system configuration, calibration, and remote firmware updates. Overall, the project scope covers everything from hardware-level sensing to cloud-based visualization and management, ensuring a complete and scalable solution for real-time monitoring.

LITERATURE REVIEW

Environmental pollution monitoring has become an important research area in recent years due to the increasing impact of pollution on human health and the environment. Researchers around the world have proposed various technologies and systems to monitor air quality and environmental noise using sensors, wireless networks, and cloud platforms. The development of Internet of Things (IoT) technology has significantly improved the ability to collect and analyze environmental data in real time. One of the early approaches to environmental monitoring involved the use of sensor networks connected to centralized monitoring stations. These systems used different types of sensors to measure environmental parameters such as air quality, temperature, humidity, and gas concentration. However, these systems were often expensive and difficult to deploy on a large scale. To overcome these limitations, researchers began exploring low-cost sensor-based solutions that could provide continuous monitoring of environmental conditions. Studies have shown that integrating multiple sensors with communication technologies can improve the effectiveness of environmental monitoring systems [1–6].

With the advancement of wireless communication and embedded systems, IoT-based monitoring solutions have gained significant attention. IoT devices allow sensors to collect data from the environment and transmit it to cloud platforms for storage and analysis. Many researchers have proposed air pollution monitoring systems using low-cost gas sensors and microcontrollers. These systems enable real-time monitoring of harmful gases such as carbon monoxide, nitrogen dioxide, and volatile organic compounds. The use of IoT technology also allows users to access environmental data remotely through web applications or mobile devices, which improves public awareness and supports better environmental management [7].

Another important area of research is the use of wearable or portable sensing devices for environmental monitoring. These systems allow individuals to measure pollution levels in their immediate surroundings. Wearable environmental sensors can continuously monitor air quality and transmit the collected data to smartphones or cloud servers. Such systems are useful for personal exposure monitoring and health studies, as they help researchers understand how pollution affects individuals in different environments [8].

In addition to air pollution monitoring, several studies have focused on detecting chemical pollutants and toxic gases using advanced sensing technologies. Hybrid chemical sensors and wireless sensing platforms have been developed to detect volatile organic compounds and other hazardous substances in the environment. These technologies provide more accurate measurements and enable early detection of pollution sources. Integrating these sensors with IoT networks helps improve environmental monitoring by providing continuous data collection and real-time alerts [9].

Recent research has also explored the use of wireless sensor networks and IoT platforms to develop large-scale environmental monitoring systems. These systems combine multiple sensing nodes placed at different locations to collect pollution data across a wide area. The collected data is transmitted to centralized servers where it can be analyzed to identify pollution patterns and trends. Such systems are particularly useful for smart city applications, where environmental monitoring plays an important role in urban planning and public health protection [10].

Although many IoT-based air quality monitoring systems have been developed, most of them focus only on air pollution and do not consider noise pollution as part of environmental monitoring. Noise pollution is also a major concern in urban areas, and monitoring sound levels along with air quality can provide a more complete understanding of environmental conditions. Therefore, integrating both air and noise sensors into a single IoT-based system can help improve environmental monitoring and provide better information for decision-making. The proposed system in this project builds upon these existing studies by integrating air quality monitoring and noise level detection using the ESP32-S3 microcontroller. The system uses IoT technology to collect environmental data, process it locally, and transmit it to a cloud platform for real-time monitoring and analysis. By combining multiple sensors, cloud connectivity, and mobile applications, the proposed system aims to provide an efficient and cost-effective solution for environmental pollution monitoring (Figure 1).

METHODOLOGY

Framework and Basic Architecture

The diagram shows an IoT-based Air Quality Monitoring System that uses the ESP32-S3 as the field node.

- *Field Node (Edge):* This node collects air quality data with sensors (MQ-135, INMP441,
- SHTC3) and controls actuators (buzzer, relay). BLE is used for device setup.
- *Communication:* Data is sent via Wi-Fi using MQTT/TLS or HTTPS to the cloud.
- *Cloud (Firebase):* This component stores data in Realtime DB or Firestore, processes data
- through Cloud Functions, and sends notifications using Firebase Cloud Messaging (FCM).
- *Admin Dashboard (Web):* This dashboard allows users to configure settings, set thresholds, and send control commands.
- *Mobile App (Flutter):* This app shows real-time air quality data and notifications synced from

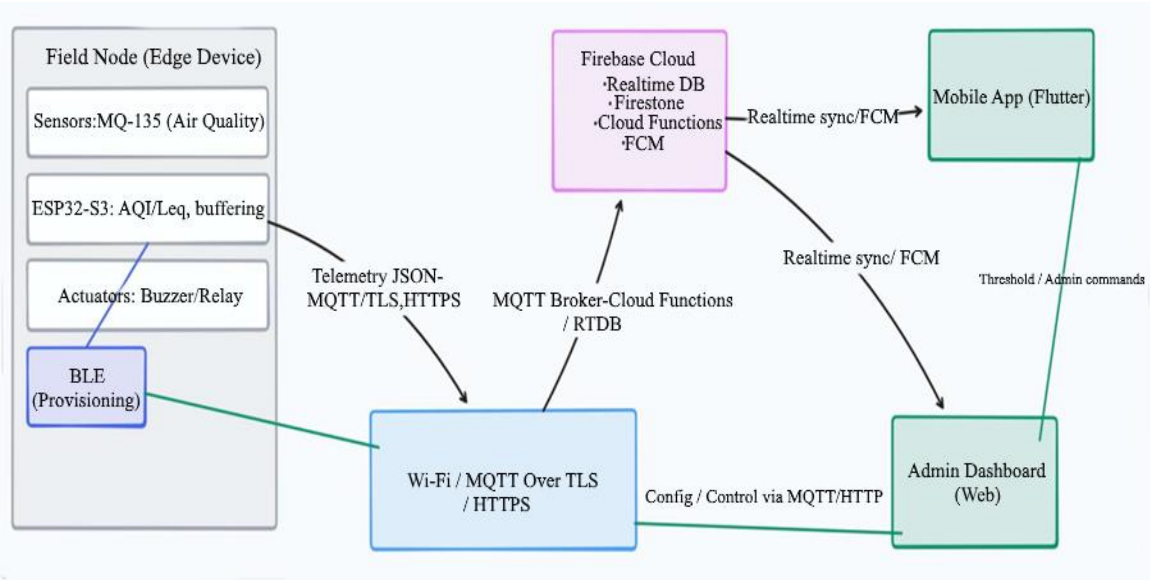

Figure 1. System architecture.

Core Technologies

Sensor Network

- *Noise Sensor:* A noise sensor is an electronic device that detects sound intensity (noise level) in the environment and converts it into an electrical signal. It helps systems understand how loud or quiet the surroundings are.
- *Gas sensor:* A gas sensor is a device that detects the presence and concentration of gases (like LPG, methane, CO_2, smoke, etc.) in the air and converts it into an electrical signal.

EVALUATION AND RESULTS

The mobile application interface of the proposed system is shown in Figure 2. This application is developed to provide real-time monitoring of environmental conditions such as air quality and noise levels. The dashboard displays the Air Quality Index (AQI) using a visual gauge, making it easy for users to understand pollution levels. It also shows individual gas readings such as CO_2, NH_3, alcohol, benzene, smoke, and VOC along with noise levels. The application is connected to the cloud database and updates sensor data continuously. This user-friendly interface allows users to monitor environmental parameters remotely and receive alerts when pollution levels exceed safe limits, thereby improving awareness and safety.

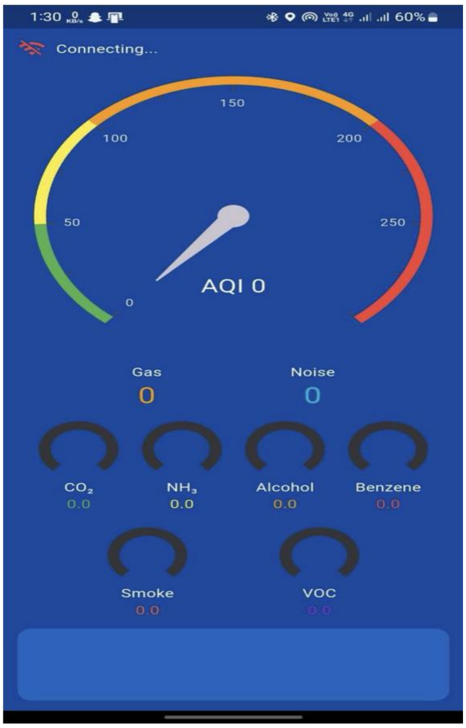

Figure 2. Mobile application interface.

The developed prototype of the IoT-based environmental monitoring system is shown in Figure 3. The system is built using an ESP32-S3 microcontroller mounted on a PCB board, which acts as the main unit for collecting, processing, and transmitting sensor data through Wi-Fi. An MQ-series gas sensor is used to detect harmful gases in the environment, while a buzzer provides immediate alerts when pollution levels exceed safe limits. The system is powered using two 9V batteries, ensuring stable operation of all components. All connections are properly soldered on a perforated board to maintain a compact and reliable design. Status LEDs on the microcontroller indicate power and system activity. The overall setup is portable, efficient, and suitable for real-time monitoring. This prototype demonstrates the practical working of the system and its ability to provide continuous environmental monitoring.


Figure 3. Air noise pollution monitoring device.

FUTURE SCOPE

The proposed IoT-based air and noise pollution monitoring system provides an effective solution for real-time environmental monitoring. However, there are several opportunities to improve and expand the system in the future. By integrating advanced technologies and additional features, the system can become more efficient, accurate, and suitable for large-scale environmental monitoring applications.

Integration of Advanced Pollution Sensors

In the current system, the MQ-135 gas sensor is used to detect harmful gases in the environment. In the future, more advanced sensors such as PM2.5 and PM10 particulate matter sensors can be added to measure fine dust particles present in the air. These particles are one of the major causes of respiratory diseases. Including particulate matter sensors will improve the accuracy and reliability of air quality monitoring.

GPS-Based Location Tracking

Future versions of the system can include a GPS module to record the geographical location of pollution data. By adding location information, the system can create pollution maps that show pollution levels in different areas. This will help authorities and researchers identify pollution hotspots and take appropriate actions to reduce pollution in affected areas.

Deployment of Large Sensor Networks

Currently, the system operates as a single monitoring node. In the future, multiple devices can be deployed in different locations across a city to form a wireless sensor network. These distributed monitoring nodes can collect environmental data from multiple areas simultaneously. Such a network can provide more detailed information about pollution patterns and support smart city environmental monitoring systems.

CONCLUSION

In this project, an IoT-based air and noise pollution monitoring system has been designed and implemented using the ESP32-S3 microcontroller. The main objective of the system is to provide a low-cost and efficient solution for monitoring environmental pollution in real time. With the increasing levels of air and noise pollution in urban areas, continuous monitoring of environmental conditions has become essential for protecting public health and maintaining environmental sustainability. The proposed system integrates sensors, wireless communication, cloud storage, and a mobile application to create a complete environmental monitoring solution. The MQ-135 gas sensor is used to detect harmful gases present in the air, while the sound sensor measures the level of environmental noise. The ESP32-S3 microcontroller collects data from these sensors, processes the information, and compares the readings with predefined safety limits.

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