MERU UNIVERSITY OF SCIENCE TECHNOLOGY

SCHOOL OF ENGINEERING AND ARCHITECTURE (SEA)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Title: IoT – Based Air Quality Monitoring System

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A proposal submitted in partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in Electrical and Electronics Engineering in the Department of Electrical and Electronics Engineering at Meru University of Science and Technology.

Date:23/12/2025

DECLARATION

I hereby declare that this project proposal is my original work except as cited in the references and has not been presented for the award of a degree in any other University.

Sign: ....Date: ....

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This proposal has been submitted for examination with my approval as the University supervisor.

Sign: .... Date……...................................

Supervisor: ……………………………………………………......................................

Dedication

I dedicate this project proposal to my family, whose unwavering support, encouragement, and belief in my academic journey have continually inspired me. Their patience and motivation have been my greatest source of strength throughout this pursuit.

Acknowledgement

I wish to sincerely acknowledge the invaluable guidance and support provided by my supervisor, **Eng. Job Kerosi**, whose expertise and mentorship played a significant role in shaping this project idea. I also extend my appreciation to the Department of Electrical Engineering at Meru University of Science and Technology for providing the academic foundation and resources necessary for the development of this proposal. Lastly, I am grateful to my colleagues and friends for their constructive insights and encouragement, which contributed to the refinement and clarity of this work.

Abstract

Air quality degradation and hazardous gas emissions represent critical challenges to public health, safety, and environmental sustainability. Urbanization and industrialization have intensified the release of pollutants, including carbon monoxide, methane, nitrogen oxides, and particulate matter (PM2.5 and PM10), while domestic environments remain vulnerable to leaks of liquefied petroleum gas (LPG) and other combustible gases. These pollutants are linked to respiratory illnesses, cardiovascular diseases, climate change, and fire outbreaks. However, existing monitoring approaches are often centralized, costly, and inaccessible to individuals for real-time decision-making. This project proposes EcoSphere Monitor, an IoT-based air quality monitoring system designed to provide real-time data acquisition, cloud-based storage, and predictive analytics. The system integrates low-cost MQ gas sensors, particulate matter sensors, and environmental sensors with an ESP32 microcontroller for data collection and analysis. Data are transmitted to Firebase for secure storage, visualization, and alert dissemination through a web application. Furthermore, predictive models are employed to forecast pollution levels, detect anomalies, and assess potential fire hazards. The proposed system contributes to environmental health research by offering a scalable and affordable solution for continuous monitoring, early warning, and risk mitigation in urban, domestic, agricultural, and healthcare settings.

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Air quality degradation has become a pressing environmental and public health concern globally. Rapid urbanization, increased industrial activities, transportation, and population growth have significantly elevated the release of harmful pollutants such as particulate matter (PM2.5 and PM10), carbon monoxide, methane, nitrogen oxides, and volatile organic compounds. These pollutants are directly associated with respiratory illnesses, cardiovascular diseases, allergies, and climate impacts. In addition to outdoor pollution, domestic environments face risks of hazardous gas leaks such as liquefied petroleum gas (LPG) and methane, which can lead to poisoning, fire outbreaks, and explosions.

Although government-operated monitoring stations exist in major cities, current air quality monitoring approaches remain centralized, expensive, and inaccessible to individuals at the household level. This creates a gap in real-time localized monitoring that can help mitigate risks promptly.

Recent advancements in Internet of Things (IoT), cloud computing, and machine learning present a promising opportunity to develop affordable and scalable monitoring systems. The proposed EcoSphere Monitor integrates low-cost sensors with cloud-based storage and real-time data visualization to deliver accessible environmental insights. By leveraging MQ-series gas sensors, particulate matter sensors, and ESP32 microcontrollers, the system offers continuous surveillance of air pollutants and hazardous gases. The integration of predictive analytics further enhances the capability to detect anomalies and forecast pollution trends.

The EcoSphere Monitor, therefore, represents a timely initiative toward improving environmental health, public safety, and awareness by bridging the gap between centralized air quality monitoring and household-level accessibility.

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1.2 Problem Statement

Urban and domestic environments continue to experience rising levels of air pollution due to industrial emissions, vehicular exhaust, and dust particles. These pollutants pose serious health risks and negatively impact the quality of life. Similarly, households and small businesses remain vulnerable to hazardous gas leaks, which may result in fire hazards, explosions, and poisoning.

Despite the availability of conventional monitoring systems, most are centralized, costly, and lack the capability for real-time and localized monitoring. This leaves individuals without the necessary tools to detect and respond to air quality threats in their surroundings. A solution that is affordable, scalable, real-time, and accessible is needed to address these challenges effectively.

1.3 Main Objective

To design a scalable IoT air quality monitor with real-time detection, prediction, and alerts.

1.4 Specific Objectives

a. To monitor air pollutants such as particulate matter (PM2.5, PM10) and harmful gases (CO, LPG) in real time.
b. To measure environmental parameters like temperature and humidity.
c. To enable remote monitoring through a cloud–connected web application.
d. To provide instant alerts when air quality exceeds safe thresholds.

1.5 Justification

Air quality monitoring solutions are often limited to government-operated or industrial-scale systems, making them inaccessible to households and small businesses. As a result, individuals remain exposed to invisible yet harmful pollutants and gas hazards. An affordable and scalable system like EcoSphere Monitor helps bridge this gap by:

- enhancing public safety through early detection and alerts,
- providing accessible real-time data for informed decision-making,
- reducing environmental health risks,
- aiding in community-level awareness and mitigation,
- integrating modern IoT and machine learning technologies for proactive monitoring.

The system thus offers a practical and research-driven solution to promote environmental health and public safety.

1.6 Scope of the Study

This project focuses on designing and implementing an IoT-based air quality monitoring system using low-cost gas sensors, particulate matter sensors, environmental sensors, and ESP32 microcontrollers. The scope includes real-time data collection, wireless transmission to a cloud platform (Firebase), web-based data visualization, and predictive modeling for anomaly detection and forecasting.

The project will cover:

- hardware integration,
- firmware development,
- cloud connectivity,

- web application interface,
- alert systems,
- and evaluation of system performance.

However, it does not cover nationwide monitoring or industrial certification standards. Instead, the focus remains on household, urban, agricultural, and healthcare environments where feasible and cost-effective deployment is needed.

CHAPTER 2: LITERATURE REVIEW

Air quality monitoring has increasingly become a central topic in environmental research due to the rising levels of pollutants associated with industrialization, urbanization, and population growth. Traditional monitoring networks, while accurate, are limited in accessibility and cost, thus driving the development of more scalable and affordable systems. Recent technological advancements in Internet of Things (IoT), low-cost sensors, cloud computing, and machine learning are enabling innovative approaches to air quality surveillance. This chapter reviews the evolution of monitoring systems, low-cost sensing technologies, regional monitoring initiatives, and the emerging role of predictive analytics in environmental safety.

2.1 Traditional Air Quality Monitoring Systems

Historically, large-scale and government-operated stations have formed the backbone of air quality surveillance in major cities. These fixed monitoring stations provide reliable and accurate pollutant measurements; however, they are geographically limited and expensive to deploy and maintain. For example, networks such as the London Air Quality Network operate multiple fixed stations to monitor particulate matter and gaseous pollutants across the city. While these systems are suitable for policy and research, their centralized nature restricts real-time, localized access for households and small businesses.

Although highly accurate, these systems often lack affordability and flexibility, creating a gap in environmental awareness at the individual level. Consequently, researchers and environmental agencies have sought alternative approaches that retain reliable sensing while lowering deployment costs.

2.2 Emergence of Low-Cost and Distributed Sensor Networks

The limitations of conventional monitoring systems have catalyzed a shift toward **distributed low-cost sensor networks**. Devices based on MQ-series gas sensors, particulate matter (PM2.5/PM10) sensors, and other inexpensive electronic components have demonstrated promising results for community-level air quality monitoring.

Global initiatives such as Clarity Movement have deployed low-cost sensors across more than 85 countries, indicating that distributed systems can offer scalable environmental sensing at relatively low costs. These deployments highlight the feasibility of crowd-sourced and community-integrated monitoring approaches.

In urban environments, PM sensors and MQ-series sensors have shown significant utility in detecting common pollutants, including carbon monoxide, nitrogen oxides, and volatile organic compounds. Although issues such as sensor drift and calibration inaccuracies persist, pre-processing techniques and cloud-based calibration models are continuously improving data quality.

Thus, the literature suggests that low-cost sensors can effectively complement traditional networks by expanding spatial coverage and enabling household-level monitoring.

2.3 Regional Studies and Local Initiatives

In developing regions, particularly Africa, air pollution monitoring research has grown rapidly due to heightened exposure to traffic emissions, industrial sources, and domestic fuel combustion. In Kenya, localized sensor deployments have demonstrated the practicality of low-cost monitoring methods. Initiatives in cities such as Kisumu and Dandora illustrate how particulate sensors can reveal pollution hotspots, especially in densely populated urban settings.

Moreover, Kenyan institutions such as the Kenya Meteorological Department and SEI Africa have engaged in air quality research for climate and public health applications. However, these studies have largely remained academic or region-specific, and widespread household adoption remains limited. This reinforces the need for affordable, accessible, scalable monitoring systems like EcoSphere Monitor.

2.4 IoT-Based Monitoring and Real-Time Analytics

Recent advancements in IoT technology have revolutionized environmental monitoring by enabling continuous sensing, wireless communication, and remote access. Microcontrollers like ESP32 facilitate real-time data acquisition and wireless transmission, reducing the need for manual data collection. Cloud computing solutions such as Firebase offer platforms for secure storage, visualization, and user notifications.

IoT-based monitoring systems address challenges of cost and accessibility while enabling timely responses to hazardous gas levels and pollution spikes. As such, they represent a significant evolution toward democratizing environmental data.

2.5 Machine Learning and Predictive Modeling in Air Quality

Modern monitoring systems increasingly integrate **machine learning (ML)** to enhance data interpretation and predictive capabilities. Regression models, Support Vector Machines (SVM), Random Forest, and deep learning techniques such as Long Short-Term Memory (LSTM) networks have been applied to forecast short-term pollution trends with promising accuracy.

Similarly, anomaly detection models such as Isolation Forests enable early identification of unusual patterns, including gas leaks or unexpected pollutant spikes. These predictive analytics transform monitoring from passive observation to proactive environmental management.

The literature consistently supports the integration of IoT and ML as a means to:

- detect hazardous events,
- anticipate pollution episodes,
- and improve situational awareness.

This combination positions systems like EcoSphere Monitor as crucial tools in both preventive and responsive environmental safety.

2.6 Summary of Literature Gaps

Despite extensive research on both centralized monitoring and low-cost sensor deployments, gaps remain:

- limited accessibility of monitoring solutions for households,
- lack of real-time alerts for gas leaks and pollution hazards,
- insufficient integration of predictive analytics at the community scale,
- and the need for scalable, low-cost architectures.

EcoSphere Monitor addresses these gaps by combining:

- low-cost sensors,
- IoT communication,
- cloud storage,

- and machine learning forecasting

to deliver an affordable and practical system tailored for both domestic and urban environments.

CHAPTER 3: METHODOLOGY

This chapter describes the methodology used in the design and implementation of the EcoSphere Monitor system. The approach follows a systematic framework consisting of hardware integration, data acquisition, cloud connectivity, predictive analytics, and visualization. The methodology ensures that the proposed system delivers real-time monitoring, alerts, and environmental data insights using low-cost IoT components and machine learning techniques.

3.1 Research Design

The project adopts an experimental and design-based research methodology. An IoT-driven prototype is developed to demonstrate real-time detection of pollutants and hazardous gases. The system integrates sensors with an ESP32 microcontroller to collect air quality data, which is transmitted to a cloud database for storage and visualization. Predictive analytics and anomaly detection models are incorporated to enhance system intelligence.

The research design emphasizes:

- low-cost implementation,
- scalability,
- real-time communication,
- and end-user accessibility.

3.2 System Development Approach

The methodology consists of four major development phases:

Phase 1: Sensor Integration

This phase involves selecting and interfacing appropriate sensing components with the ESP32 microcontroller.

Key components include:

- MQ-series gas sensors (MQ-2, MQ-7, MQ-9, MQ-135)
- PM2.5 and PM10 particulate matter sensors
- DHT11 environmental sensor for temperature and humidity

Activities:

- wiring and assembling sensors on a stripboard/breadboard,
- testing detection ranges,
- calibrating sensor responses.

The purpose of this phase is to enable accurate measurement of gaseous pollutants and particulate matter.

Phase 2: Edge Processing and Data Acquisition

The ESP32 microcontroller is programmed to:

- capture sensor readings,
- filter noise,
- convert analog signals to digital values,
- and preprocess raw data.

Processing tasks include:

- normalization,
- threshold checks,
- timestamping,
- and packaging of readings.

Wireless communication via built-in Wi-Fi enables seamless transmission without additional networking modules.

The microcontroller acts as an intelligent edge device, reducing the cloud processing load.

Phase 3: Cloud Storage and Backend Integration

Firebase is used as the cloud backend due to its:

- real-time database functionality,
- secure data storage,
- and scalable architecture.

Core activities include:

- establishing a connection between ESP32 and Firebase,

- structuring cloud database fields for pollutants,
- implementing triggers for threshold-based alerts.

This allows remote access to sensor data, historical records, and system performance metrics.

Phase 4: Web Application and User Interface

A web application is developed to allow end-users to visualize and interact with data. Functionalities include:

- viewing real-time air quality indices,
- accessing historical pollutant trends,
- receiving notifications and warnings,
- interpreting visual charts.

The interface enhances usability by enabling monitoring from smartphones, PCs, or tablets.

3.3 Machine Learning and Data Analysis Methods

To improve system intelligence, predictive and analytical methods are employed.

Data Preprocessing

Involves:

- cleaning anomalous readings,
- calibration corrections,
- normalizing values,
- and managing missing data.

Exploratory Data Analysis

Used to:

- observe patterns and time-series trends,
- visualize pollution spikes,
- Identify seasonal or hourly variations.

Predictive Modeling

Methods include:

- Regression (Linear Regression, Random Forest)
- Deep Learning (LSTM)

Purpose:

- forecasting short-term pollutant levels,
- predicting hazardous events.

Classification and Anomaly Detection

Models include:

- Support Vector Machines,
- Isolation Forests.

Used to:

- detect gas leaks,
- flag abnormal pollution patterns,
- activate alerts.

Evaluation Metrics

System performance is validated using:

- RMSE and MAE (forecasting accuracy),
- confusion matrices (classification),
- and accuracy scores.

3.4 System Requirements

Hardware Requirements

- ESP32 microcontroller
- MQ-series gas sensors
- PM sensors
- DHT11
- LEDs/buzzer (alert interface)
- Breadboard/stripboard
- Jumper wires and enclosure

Software Requirements

- Firebase backend
- Web application framework
- Programming language (Arduino IDE / MicroPython)
- Machine learning libraries
- Data visualization tools

3.5 Prototype Testing

Testing is performed in two contexts:

1. **Controlled environment testing**
    - use simulated pollutant sources
    - validate sensor response and calibration
2. **Real-world deployment**
    - Monitor air quality in domestic or urban environments.
    - Evaluate performance under actual conditions.

Testing measures:

- accuracy of readings,
- latency of alerts,
- cloud update performance,
- and user interface usability.

3.6 Ethical and Safety Considerations

- safe handling of gas sources during testing,
- ensuring no exposure risks to people,
- data privacy for logged sensor information.

3.7 Methodology Summary

The methodology integrates IoT hardware, wireless data transmission, cloud computing, and machine learning. The phased structure ensures:

- effective data acquisition,
- scalable communication,
- intelligent analysis,
- and practical end-user functionality.

CHAPTER 4: EXPECTED OUTCOMES

The EcoSphere Monitor project is designed to deliver a practical, affordable, and scalable air quality monitoring system capable of real-time detection, analysis, and reporting of environmental pollutants. Upon completion, the system is expected to provide measurable improvements in environmental awareness, hazard prevention, and data accessibility. The following section outlines the anticipated outcomes of the proposed system.

4.1 Real-Time Monitoring of Air Pollutants

The system is expected to successfully monitor key pollutants such as particulate matter (PM2.5 and PM10), carbon monoxide, methane, and other hazardous gases. Continuous sensing through MQ-series gas sensors and PM sensors will enable immediate detection of fluctuations in pollutant levels. This real-time visibility will support individuals and households in understanding the quality of air in their immediate surroundings.

4.2 Detection of Hazardous Gas Leaks and Fire Risks

With integrated sensors like MQ-2, MQ-7, and MQ-135, the system is expected to detect combustible and toxic gases associated with fire outbreaks, poisoning, and explosions. By setting threshold values, the prototype should be capable of issuing warnings when gas concentrations exceed safety limits. This outcome minimizes risks and enables timely intervention, especially in kitchens, industries, laboratories, and fuel storage facilities.

4.3 Automated Alerts and User Notifications

Through Firebase integration and web application support, the system is expected to provide instant alerts to users via cloud-based notifications or interface warnings. These alerts will allow rapid response to hazardous environmental conditions, helping prevent accidents or prolonged exposure to pollution.

4.4 Data Visualization and Accessibility

The project is expected to deliver a user-friendly web application that displays real-time readings, historical trends, and pollution analysis. This ensures accessibility through mobile devices, laptops, and other internet-enabled platforms. The outcome democratizes environmental data by making it available to users who traditionally lack access to professional monitoring systems.

4.5 Predictive Analytics and Anomaly Detection

Machine learning models integrated into the system are expected to:

- forecast pollutant levels,
- detect abnormal pollution patterns,
- identify gas leak anomalies,
- and provide proactive insights.

This transforms the system from a purely reactive tool into a predictive decision-making platform.

4.6 Enhanced Awareness and Safety Practices

The project is expected to contribute significantly to public awareness by:

- educating users about pollutant risks,
- promoting safe practices,
- and encouraging environmental responsibility.

This outcome supports households, schools, healthcare facilities, and small industries in adopting safety-driven behavior.

4.7 Affordability and Scalability

By using low-cost sensing modules and open-source platforms, the system is expected to demonstrate that effective air quality monitoring can be achieved without high-cost equipment. The modular design ensures scalability for:

- household use,
- small businesses,
- urban communities,
- agricultural facilities,

- and healthcare environments.

4.8 Validation of IoT-Based Environmental Monitoring

Finally, the system is expected to validate that IoT-enabled monitoring can bridge the gap between centralized government monitoring systems and individual consumer needs. Success will confirm the feasibility of:

- decentralized sensing,
- cloud-based analytics,
- and low-cost environmental intelligence.

4.9 Summary

In summary, EcoSphere Monitor is expected to:

- enable real-time pollutant monitoring,
- detect hazardous gas leaks,
- provide timely alerts,
- support predictive analysis,
- improve environmental awareness,
- and offer a low-cost, scalable alternative to centralized monitoring systems.

Collectively, these outcomes position the system as an impactful solution to environmental health and safety challenges in both domestic and urban contexts.

Conclusion

The EcoSphere Monitor proposes an innovative, low-cost, and scalable approach to addressing the growing challenge of air pollution and hazardous gas leaks in domestic and urban environments. By integrating IoT sensing technologies, cloud-based data storage, and predictive analytics, the system offers a practical solution for real-time environmental monitoring and early warning alerts. Unlike traditional centralized monitoring stations, this project aims to make air quality data accessible, affordable, and actionable for households, small industries, and community settings.

The proposed system aligns with current technological trends and responds to an urgent health and safety need, particularly in regions where access to reliable monitoring infrastructure is limited or costly. Through its modular design and user-friendly interface, EcoSphere Monitor has the potential to enhance environmental awareness, reduce pollution-related risks, and contribute to public health and safety.

Overall, this proposal demonstrates the feasibility and significance of developing an IoT-based monitoring system that empowers individuals and communities with timely and accurate environmental insights. The project is therefore justified as both relevant and impactful, with measurable benefits in research, innovation, and real-world application.

REFERENCES