Sensor-Based Monitoring System to Ascertain the Temperature, Humidity and Air Quality of an Environment

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ABSTRACT

Air pollution has become one of the major environmental challenges affecting human health, climate conditions, and overall quality of life. Traditional methods of monitoring air quality are often expensive, less accessible, and unable to provide real-time predictions for preventive actions. This paper focuses on the designing an Air Quality Monitoring System capable of monitoring environmental air conditions to ascertain the temperature, humidity and air quality of an environment the system is designed to collect air quality parameters such as temperature, humidity, smoke concentration, and harmful gas levels using sensors connected to a microcontroller. The collected data is processed and analysed to determine the quality of air within a particular environment. In addition, the system aims to provide users with real-time monitoring, accurate data analysis, and timely alerts whenever air pollution levels exceed acceptable standards. The implementation of this work demonstrates that an affordable and intelligent air quality monitoring system can contribute significantly to environmental safety and public health management.

Keywords: Air Pollutants, Monitoring System, Calibration, Machine Learning, Data Visualization

INTRODUCTION

Air pollution is widely recognized as one of the most serious environmental challenges facing the world today. The rapid growth of urban centres, increased industrial activities, widespread use of fossil fuels, and the rising number of automobiles have significantly contributed to the degradation of air quality in many regions. In developing countries, the problem is further intensified by the use of diesel generators, open burning of waste, poor urban planning, and lack of strict environmental regulations. Exposure to polluted air has been linked to numerous health conditions, including asthma, chronic obstructive pulmonary disease, cardiovascular diseases, lung cancer, and premature mortality. Adebayo (2020)

Traditionally, air quality monitoring has been carried out using large-scale monitoring stations operated by government agencies and research institutions. Although these stations provide accurate and reliable measurements, they are often expensive to deploy and maintain, and their coverage is usually limited to a few locations. As a result, many communities and individuals do not have access to localized air quality information that directly affects their daily activities and health. Okafor and Eze (2020)

In recent years, advancements in computer science, embedded systems, and the Internet of Things (IoT) have enabled the development of low-cost, distributed, and intelligent environmental monitoring systems. These systems utilize sensors, microcontrollers, wireless communication, and cloud platforms to collect, process, and transmit environmental data in real time. Furthermore, the integration of data analytics and machine learning techniques makes it possible to analyse historical data.

This article focuses on the designing an air quality monitoring system that combines sensor-based data acquisition, and real-time data processing. By leveraging computer science techniques such as data processing, machine learning algorithms, and software development, the system aims to provide an intelligent and cost-effective solution for monitoring air pollution levels.

Air pollution has become a major concern in urban and semi-urban areas due to increased industrialization, transportation, and domestic energy consumption. Many existing air quality monitoring systems are centralized and provide data for large geographical regions rather than specific local environments. Consequently, individuals, schools, hospitals, and small communities lack access to localized and real-time air quality information that could help them make informed decisions.

In addition, most conventional monitoring systems focus mainly on measuring current pollutant levels without offering predictive insights into future air quality trends. This reactive approach limits the ability of authorities and individuals to implement preventive measures before pollution reaches hazardous levels. There is also a lack of affordable and user-friendly monitoring solutions that can be easily deployed in resource-constrained environments.

Therefore, there is a need for a low-cost, intelligent, and scalable system that can monitor air quality parameters in real time pollution levels using computational techniques. Such a system would contribute to improved environmental awareness, better public health protection, and enhanced decision-making processes.

LITERATURE REVIEW

The conceptual framework for this study is built around the relationship between environmental pollutants, monitoring technologies, control mechanisms, and user interaction systems. The framework assumes that air pollutants originate from various anthropogenic and natural sources, and that these pollutants can be detected using electronic sensors. The detected data are processed by embedded systems, analysed for decision-making, and used to trigger control actions such as alarms, ventilation, or purification. The framework also considers prediction models that use historical data to forecast future air quality conditions. . Li and Wang (2021)

In this study, the independent variables include pollutant concentrations (CO, CO_2, NO_2, SO_2, PM2.5, PM10, and VOCs), while the dependent variables include system response actions such as alarm activation, ventilation control, and data notification. The moderating variables include environmental factors such as temperature, humidity, and airflow patterns, which influence pollutant dispersion and sensor accuracy. Ahmed and Khan (2021)

A conceptual model for the proposed system consists of four main layers: the sensing layer, processing layer, communication layer, and application layer. The sensing layer consists of gas and particulate sensors that collect raw environmental data. The processing layer involves microcontrollers and embedded systems that convert analogue sensor signals into digital values and perform computations. The communication layer transmits processed data to displays, mobile devices, or cloud servers. The application layer provides visualization, alerts, and predictive analytics to end users.

The conceptual framework explains the key concepts, variables, and components involved in the design and implementation of an air quality monitoring and control system. It provides a general understanding of how air quality is monitored, how pollution is controlled, and how technological systems are designed to support environmental monitoring.

1. *Concept of Air Quality: Air quality refers to the condition of the air in a given environment, particularly in relation to the concentration of pollutants that can affect human health and the environment. According to the World Health Organization (WHO), air quality is determined by the levels of harmful substances such as particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds. Poor air quality is associated with respiratory diseases, cardiovascular diseases, and reduced life expectancy. In Nigeria, air quality is a major concern due to rapid urbanization, industrial activities, and widespread use of fossil fuel-powered generators.*
2. *Concept of Air Pollution: Air pollution is the presence of harmful substances in the air at concentrations that can cause adverse effects on humans, animals, plants, and the environment. Pollutants can be classified into primary pollutants, which are emitted directly from sources, and secondary pollutants, which are formed through chemical reactions in the atmosphere. Common*

sources of air pollution in Nigeria include vehicular emissions, industrial processes, burning of waste, and domestic cooking using biomass fuels.

3. *Air Quality Monitoring Systems: An air quality monitoring system is a technological solution used to measure, record, and analyze the concentration of air pollutants in a given environment. Such systems typically consist of sensors, data acquisition modules, processing units, communication modules, and user interfaces. Monitoring systems can be stationary or mobile and can be deployed indoors or outdoors. The primary purpose of monitoring is to provide real-time data that can be used for environmental management and decision-making.*
4. *Air Quality Control Systems: Air quality control systems are designed to reduce the concentration of pollutants in the air through various mechanisms such as ventilation, filtration, and purification. In automated systems, control actions are triggered when pollutant levels exceed predefined thresholds. Control mechanisms may include activating fans, opening windows, triggering alarms, or sending alerts to users.*
5. *Sensors and Data Acquisition: Sensors are electronic devices that detect and measure physical parameters such as gas concentration, temperature, humidity, and particulate matter. In air quality monitoring, gas sensors such as MQ-2, MQ-7, MQ-9, and MQ-135 are commonly used to detect gases like carbon monoxide, methane, and ammonia. Particulate matter sensors such as PMS5003 and SDS011 are used to measure PM2.5 and PM10 concentrations. Data acquisition involves collecting sensor readings and converting them into digital data for processing.*
6. *Microcontroller and Embedded Systems: Microcontrollers such as Arduino, ESP32, and Raspberry Pi are widely used in environmental monitoring systems. They serve as the processing unit that reads sensor data, performs computations, and controls actuators. Embedded systems are designed to operate continuously with minimal human intervention.*
7. *Communication and Notification Systems: Communication modules such as Wi-Fi, GSM, and Bluetooth are used to transmit air quality data to remote servers or mobile devices. Notification systems include LCD displays, mobile applications, SMS alerts, and alarms that inform users about air quality status. These systems enhance user awareness and enable timely response to pollution events.*

SYSTEM THEORY

Systems theory views a system as a set of interconnected components that work together to achieve a common goal. An air quality monitoring and control system can be considered a complex system comprising sensors, microcontrollers, communication modules, power supply units, actuators, and user interfaces. Systems theory emphasizes the interaction between these components and the importance of integration and coordination in system design.

1. *Control Systems Theory: Control systems theory explains how systems regulate their behaviour to maintain desired conditions. In air quality control, feedback mechanisms are used to monitor pollutant levels and trigger control actions when thresholds are exceeded. Control systems can be open-loop or closed loop, with closed-loop systems providing automatic feedback and adjustment. This theory forms the basis for the automated control component of the proposed system.*
2. *Internet of Things (IoT) Theory: IoT theory explains how physical devices are interconnected through the internet to collect and exchange data. IoT-based air quality monitoring systems use sensors and microcontrollers connected to cloud platforms for data storage, analysis, and visualization. IoT technology enhances accessibility, scalability, and real-time monitoring capabilities.*
3. *Human Health Risk Theory: Human health risk theory explains the relationship between exposure to environmental pollutants and health outcomes. According to this theory, prolonged exposure to polluted air increases the risk of respiratory and cardiovascular diseases. This theory justifies the importance of monitoring and controlling air quality to protect public health.*

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DISCUSSIONS ON AIR QUALITY MONITORING SYSTEM

In recent years, there has been a significant shift from traditional air quality monitoring systems to intelligent, IoT-based real-time monitoring frameworks. According to the World Health

Organization (WHO, 2022), air pollution remains one of the leading environmental health risks globally, contributing to millions of premature deaths annually. This has increased global investment in smart monitoring and predictive systems.

1. A study by Zhang et al. (2021) developed a cloud-based IoT air quality monitoring system using low-cost sensors integrated with wireless communication modules. The system allowed real-time monitoring and remote data access via mobile applications. Their results showed improved responsiveness compared to traditional monitoring stations.
2. Similarly, Kumar and Singh (2022) designed a smart air quality monitoring system using ESP32 and multiple gas sensors, transmitting real-time data to cloud platforms. Their system incorporated threshold-based alert notifications, demonstrating the effectiveness of microcontroller-based air monitoring in urban environments.
3. In 2023, Li et al. proposed a machine learning-based air pollution prediction model that utilized Long Short-Term Memory (LSTM) networks for forecasting PM2.5 levels. Their findings showed that predictive modeling significantly enhances proactive environmental management.
4. Another recent study by Al-Mutairi et al. (2023) implemented an IoT-enabled environmental monitoring system integrated with Telegram and mobile notifications. Their research demonstrated how instant messaging platforms can improve real-time alert dissemination in smart cities.
5. Furthermore, according to the World Air Quality Report (IQAir, 2024), over 90% of the global population lives in areas exceeding recommended air quality guidelines. This highlights the urgent need for affordable and scalable air monitoring systems, especially in developing countries.

   These developments show that modern air quality systems are no longer limited to data collection but now incorporate intelligent prediction, automation, and remote accessibility.

6. Indoor air quality has gained significant research attention due to its impact on human health. Chen and Li (2020) designed an automated ventilation system that activates exhaust fans when indoor pollutant levels exceed safe thresholds. The system significantly reduced indoor pollutant concentrations and improved occupant comfort.

7. Zhang et al. (2020) developed a smart home air quality monitoring system that integrates gas sensors, particulate sensors, and temperature-humidity sensors. Their system provided real-time indoor air quality index (IAQI) values and recommendations for occupants.

8. Air quality control systems aim to reduce pollutant concentrations through filtration, ventilation, and purification. Johnson and Miller (2019) developed an automated air purification system using HEPA filters and UV sterilization. The system reduced particulate matter and microbial contaminants in hospital environments.

9. Patel and Sharma (2020) implemented a ventilation control system for industrial workplaces. Their system automatically adjusted airflow rates based on pollutant concentration levels, reducing worker exposure to harmful gases.

10. In Nigeria, air pollution is a major environmental challenge due to rapid urbanization, industrial activities, and energy challenges. Adeyemi, Johnson, and Akinwale (2019) conducted a comprehensive assessment of air pollution levels in Lagos and reported high concentrations of particulate matter and carbon monoxide in traffic-congested areas. The authors recommended the deployment of low-cost monitoring systems to support environmental policy enforcement.

11. Adebayo (2020) investigated indoor air quality in Nigerian universities and found that overcrowding and

inadequate ventilation contributed to high carbon dioxide concentrations. The study emphasized the need for automated ventilation and monitoring systems in educational institutions.

12. Okafor and Eze (2020) developed a microcontroller-based gas leakage detection system for domestic applications. Their system used MQ sensors and buzzers to alert users of gas leaks. The study demonstrated the feasibility of low-cost sensor-based monitoring systems in Nigerian households.

13. In India, Sharma and Patel (2018) developed a low-cost air quality monitoring system using wireless sensor networks. Their system was deployed in urban communities to raise public awareness of air pollution. In Bangladesh, Rahman et al. (2020) implemented a mobile air quality monitoring system for urban slums and reported high levels of indoor pollution due to biomass cooking.

14. Machine learning techniques have been increasingly applied to air quality prediction. Zhang et al. (2020) used artificial neural networks to predict PM2.5 concentrations based on meteorological and historical data. Their model achieved high prediction accuracy compared to traditional statistical models.

15. Ahmed and Khan (2021) applied support vector machines and regression models to forecast air quality index values. The authors concluded that machine learning models can provide reliable short-term air quality predictions.

LIMITATIONS

Despite significant progress in air quality monitoring and control research, several limitations exist. Many monitoring systems are expensive and not suitable for developing countries. Some systems focus only on monitoring and do not include automated control mechanisms. Others rely heavily on internet connectivity, which may not be reliable in rural areas of Nigeria. Additionally, many studies do not consider local environmental conditions, sensor calibration challenges, and user-friendly interfaces.

Several researchers have developed low-cost air quality monitoring systems using sensor networks and microcontrollers. Kumar and Singh (2021) made a very good IoT-based air quality monitoring system using Arduino and gas sensors. Their system transmitted data to a cloud server and provided real-time visualization through a web interface. The study demonstrated that low-cost sensors can be used for environmental monitoring.

Smith, Brown, and Clark (2022) designed a portable air quality monitoring device to measure carbon monoxide and nitrogen dioxide levels in urban environments. Their results showed significant variations in pollutant levels across different locations, highlighting the need for distributed monitoring systems.

Gupta, Sharma, and Verma (2021) implemented an ESP32-based air quality monitoring system with MQTT communication protocol. The system provided real-time data and historical data analysis, demonstrating the effectiveness of IoT-based monitoring solutions.

RESEARCH GAP

From the reviewed literature, it is evident that most existing air quality monitoring systems focus on data collection and visualization without implementing automated control mechanisms. Additionally, many systems are designed for developed countries and are not tailored to the socioeconomic and environmental conditions of certain countries. There is also a lack of integrated systems that combine monitoring, control, and prediction in a single platform. Therefore, this paper tries to design a low-cost air quality monitoring and control system, integrating sensors, microcontroller-based processing, automated control, to improve environmental management and public health outcomes.

Air pollutants are substances present in the atmosphere that can cause adverse effects on human health and the environment. These pollutants can be classified into gaseous pollutants and particulate matter. Understanding these pollutants is essential in designing an effective air quality monitoring and control system.

Carbon monoxide is a colourless, odourless, and tasteless gas produced by incomplete combustion of carbon-containing fuels. Common sources include vehicle exhaust, generators, cooking stoves, and industrial processes. Exposure to high levels of carbon monoxide can cause headaches, dizziness, confusion, and even death in severe cases. According to WHO standards, the permissible concentration of CO in indoor environments should not exceed 9 ppm over an 8-hour period.

METHODOLOGY

The methodology consists of several phases, including problem identification, requirement analysis, system design, implementation, testing, evaluation, and documentation. Each phase is described in detail below.

1. *Problem Identification: The first stage of the methodology involved identifying the problem of inadequate air quality monitoring and lack of predictive systems in many urban and semi-urban areas. Traditional monitoring stations are expensive and limited in coverage, making it difficult for individuals and authorities to access real-time localized air quality data. This research aims to address these limitations by developing a low-cost, intelligent air quality monitoring and prediction system.*
2. *Requirement Analysis: Requirement analysis involved identifying the functional and non-functional requirements of the proposed system. Functional requirements include real-time monitoring, data storage, prediction, and alert generation. Non-functional requirements include reliability, scalability, security, usability, and low power consumption.*
3. *System Design: The system design phase involved the creation of system architecture, hardware design, software design, data flow models, and algorithm design. Design tools such as block diagrams, flowcharts, and system models were used to represent the structure and operation of the system.*
4. *System Implementation: The implementation phase involved the integration of hardware components such as sensors and microcontrollers with software components such as data processing algorithms and machine learning models. Programming languages such as Python, C/C++, and web technologies were used in system development.*
5. *Testing and Validation: Testing was conducted to evaluate the functionality and performance of the system. Sensor readings were validated, communication links were tested, and prediction models were evaluated using performance metrics such as accuracy, mean squared error, and response time.*
6. *Evaluation and Documentation: The final phase involved evaluating the system against the defined requirements and documenting the results, limitations, and recommendations for future work. This ensures that the research can be replicated and improved upon by future researchers.*

a. *Input Parameters: The key input parameters in existing systems include:*

Particulate Matter (PM2.5 and PM10): Fine and coarse particles that affect respiratory health.

Carbon Monoxide (CO): A toxic gas produced by incomplete combustion.

Carbon Dioxide (CO_2): A greenhouse gas associated with climate change.

Nitrogen Dioxide (NO_2): A pollutant from vehicle emissions and industrial activities.

Sulfur Dioxide (SO_2): Produced from burning fossil fuels containing sulfur.

Volatile Organic Compounds (VOCs): Organic chemicals that evaporate easily and contribute

to air pollution.

Temperature and Humidity: Environmental parameters that influence pollutant dispersion.

Wind Speed and Direction: Meteorological parameters used in advanced models.

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b. *Input Design: In existing systems, sensors convert physical phenomena into electrical signals. These signals are processed by data acquisition units and transmitted to central servers. Input design includes analogto-digital conversion, signal conditioning, calibration, and data validation. Communication protocols such as HTTP, MQTT, and GSM are commonly used.*

c. *Sensor-Based Data Collection: The proposed system uses the following sensors:*

i. **Gas Sensors (MQ Series):** For detecting gases such as CO, CO_2, and VOCs.
ii. **Particulate Matter Sensors:** For measuring dust and smoke particles.
iii. Temperature and Humidity Sensors (DHT11/DHT22): For measuring environmental conditions.

These sensors generate analog or digital signals corresponding to pollutant concentrations and environmental parameters.

d. *Data Acquisition Process: The microcontroller reads sensor values at predefined intervals, performs basic preprocessing such as filtering and calibration, and stores the data temporarily before transmission.*

e. *Data Transmission: Data is transmitted wirelessly using Wi-Fi or GSM modules. Communication protocols such as MQTT or HTTP are used to send data to a cloud server.*

f. *Data Storage and Management: The cloud server stores sensor data in a database. Historical data is used for training machine learning models for air quality prediction. Data management includes indexing, backup, and retrieval mechanisms.*

ARCHITECTURE OF THE SYSTEM

The architecture of the air quality monitoring and prediction system is designed using a layered approach to ensure modularity, scalability, and flexibility.

a. *Sensor Layer: This layer consists of environmental sensors responsible for collecting raw data on air pollutants and environmental parameters. The sensors are deployed in different locations to provide spatially distributed data.*
b. *Data Acquisition Layer: The data acquisition layer includes microcontrollers such as Arduino or ESP32 that interface with sensors, perform preprocessing, and manage communication with other layers.*
c. *Communication Layer: This layer transmits data from sensor nodes to the cloud server using wireless technologies such as Wi-Fi, GSM, or LoRa. It ensures reliable and secure data transmission.*
d. *Processing and Prediction Layer: The processing layer includes cloud-based servers that perform data analytics and prediction. Machine learning algorithms such as linear regression, decision trees, random forest, and neural networks are used to predict future air quality levels.*
e. *Application Layer: The application layer provides user interfaces such as web dashboards and mobile applications that display real-time air quality data, historical trends, and predictions. It also generates alerts when pollutant levels exceed safe thresholds.*

SYSTEM DESIGN

The system design defines the architecture and operational framework of the system. The system is designed as an IoT-based monitoring platform capable of sensing environmental parameters, processing the data locally, and transmitting the information to users through a Telegram bot.

The system is divided into two major subsystems: hardware subsystem and software subsystem. The hardware subsystem is responsible for data acquisition, while the software subsystem performs data processing, decision making, and data transmission.

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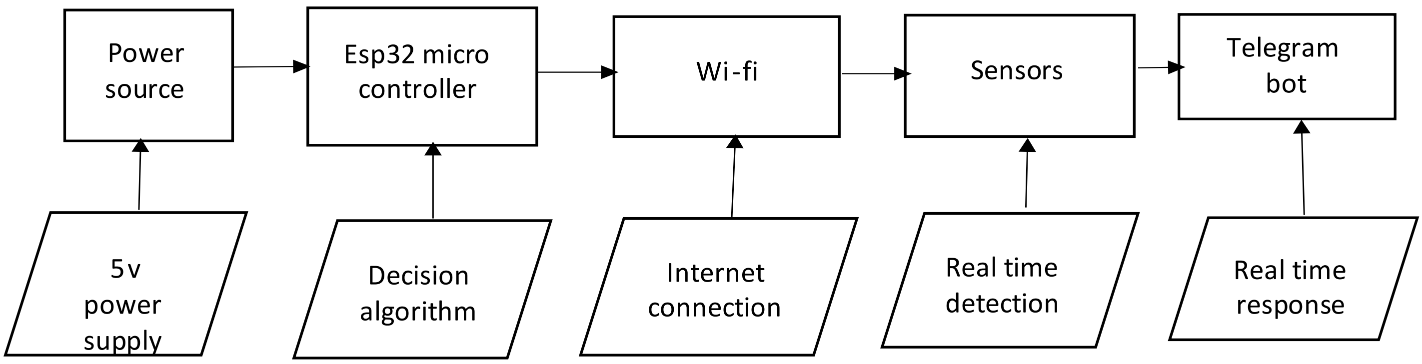

Figure1: Block Diagram of the Air Quality Monitoring System

The block diagram consists of the following components:

a. Module Description: The system is divided into several functional modules to simplify design and implementation.

1. Sensor Module: The sensor module consists of the MQ-135 gas sensor and the DHT11 temperature and humidity sensor. The MQ-135 sensor detects harmful gases such as carbon monoxide, carbon dioxide, ammonia, and smoke, while the DHT11 sensor measures ambient temperature and humidity. These sensors provide real-time environmental data to the processing module.
2. Processing Module: The processing module is implemented using the ESP32 microcontroller. The ESP32 reads data from the sensors, converts analog signals to digital values, processes the data using programmed algorithms, and determines air quality levels based on predefined thresholds.
3. Communication Module: The communication module uses the ESP32 built-in Wi-Fi capability to connect to the internet. This module sends processed data to a Telegram bot using HTTP requests and Telegram API services. It enables remote monitoring of air quality from any location.
4. User Interface Module: The user interface module is implemented using a Telegram bot. The bot displays air quality values, temperature, humidity, and system status messages. It can also send alert notifications when pollution levels exceed safe thresholds.
5. Control Module: The control module is responsible for triggering alerts and potential actuators such as fans or alarms. When air quality exceeds a predefined limit, the system sends warning messages via Telegram, indicating hazardous environmental conditions.

a. Base Design: The base design refers to the foundational hardware and software structure of the system.

1. *Hardware Base Design: The hardware base design includes the physical arrangement of the ESP32, MQ-135 sensor, DHT11 sensor, breadboard, and connecting wires. The ESP32 serves as the central controller, with sensors connected to its GPIO pins. Power is supplied through the USB port or an external power source.*

Table1: Hardware Component Connection Summary

Component	**ESP32 PIN**	**Function**
MQ-135	GPIO 34 (ADC)	Air Quality sensing
DHTII	GPIO4	Temperature and humidity sensing
VCC	3.3V/5V	Power supply
GND	GND	Ground reference

The circuit diagram shows the ESP32 connected to the MQ-135 sensor via an analog pin and the DHT11 sensor via a digital pin, with common ground and power connections. The ESP32 Wi-Fi module connects wirelessly to the internet for data transmission.

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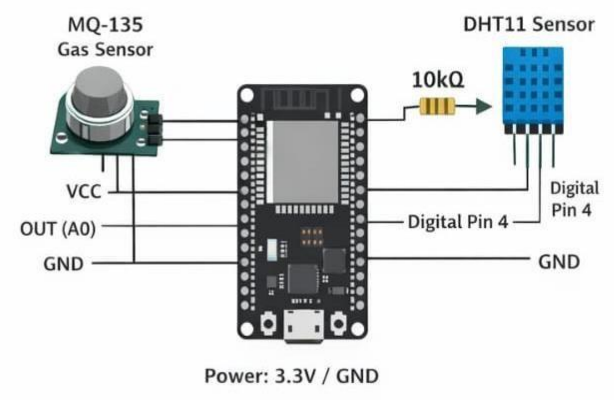

Figure 2: Circuit Diagram of the system

SYSTEM TESTING

System testing was conducted to verify functionality, accuracy, and reliability.

1. *Unit Testing: Each sensor was tested independently. The MQ-135 sensor was exposed to smoke and gas to observe variations in analog readings. The DHT11 sensor was tested in different temperature and humidity conditions.*

2. *Integration Testing: After individual testing, all components were integrated with the ESP32. The system was tested to ensure simultaneous sensor data acquisition and Telegram communication without system crashes.*

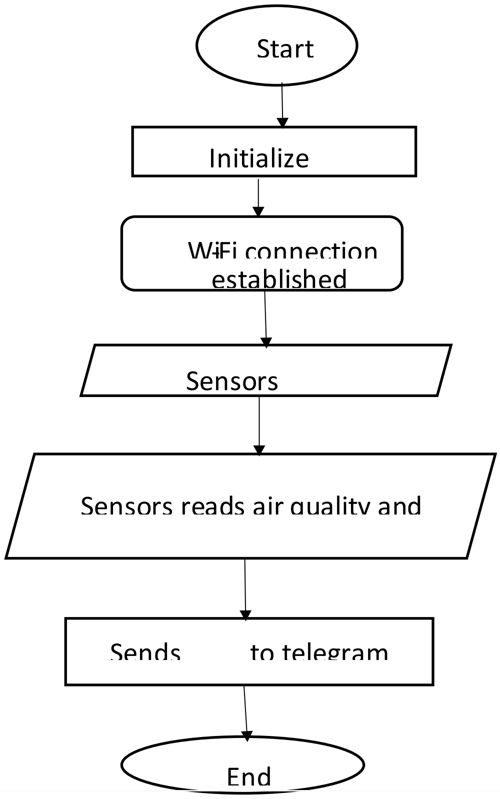

Figure 3.: System Flowchart

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RESULT

sensor, DHT11 sensor, and Telegram Bot, the system was tested under different environmental conditions to evaluate its performance. The system continuously monitored air quality, temperature, and humidity and transmitted the readings to the Telegram Bot through a Wi-Fi connection.

The experimental results showed that the system was able to acquire environmental data in real time and successfully send the information to the Telegram platform. The Telegram Bot served as a remote monitoring interface where users could view air quality conditions and receive status notifications. During testing, the system consistently transmitted sensor readings without communication failure, demonstrating the effectiveness of the IoT-based monitoring architecture.

The results obtained indicate that the developed system is capable of providing real-time environmental monitoring and can be used in homes, offices, schools, hospitals, and other indoor environments where air quality assessment is important.

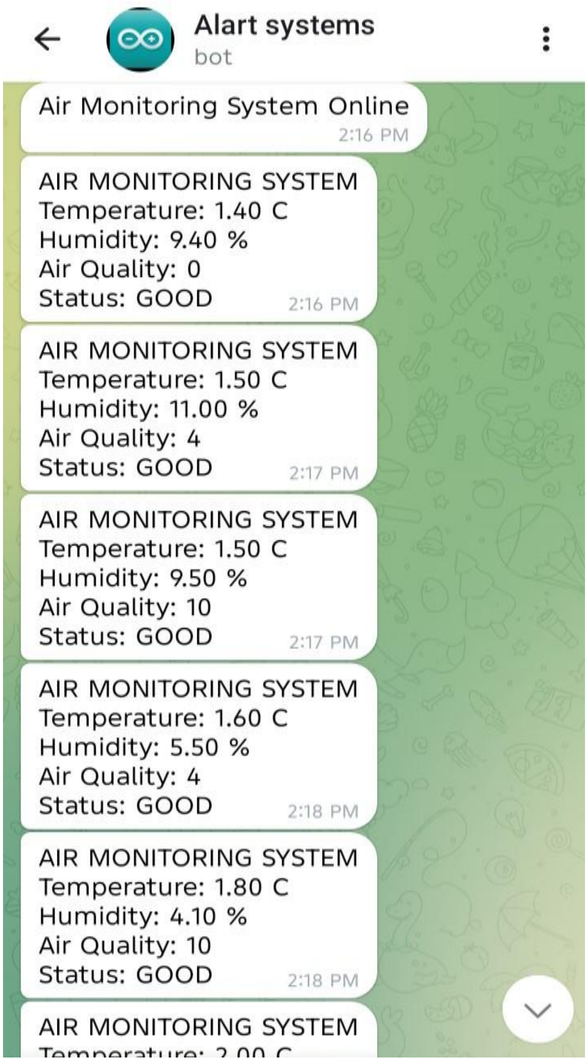

Figure 4: sample outputs

The above figure shows the real-time output generated by the system through the Telegram Bot interface.

The Telegram Bot output displayed the temperature, humidity, air quality value, and system status in real time. During the testing period, the system recorded temperature values ranging from approximately 1.4°C to 2.0°C, humidity values ranging from 4.1% to 11.0%, and air quality values between 0 and 10. Based on the programmed threshold values, the system classified the environmental condition as **GOOD**, indicating that no harmful concentration of pollutants was detected during the test period.

The successful transmission of sensor readings to the Telegram Bot confirms that the ESP32 WiFi communication module functioned correctly. The results also demonstrate that the developed system can effectively monitor environmental conditions and provide instant feedback to users through a mobile messaging platform.

The system can be enclosed in a protective casing and powered using rechargeable batteries or solar panels for outdoor deployment. Data collected by the Telegram bot can be archived for long-term environmental analysis and prediction.

CONCLUSION AND FUTURE WORK

This research successfully designed and implemented an air quality monitoring and control system based on IoT technology. The system demonstrated the capability to monitor environmental parameters, process sensor data, and provide real-time notifications using a Telegram bot. The results obtained from testing confirm that the system can detect changes in air quality and provide timely alerts to users.

The study has shown that low-cost microcontrollers such as the ESP32, combined with gas and environmental sensors, can be used to develop practical air quality monitoring solutions suitable for developing countries. The integration of wireless communication and cloud-based messaging platforms further enhances the usefulness of the system for smart city and environmental health applications.

Future Work: The following areas are suggested for future research and development:

1. Development of machine learning models for air quality prediction and trend analysis.
2. Integration of GPS modules to provide geolocation-based air quality mapping.
3. Deployment of multiple sensor nodes to create a distributed air quality monitoring network.
4. Development of a mobile application for real-time visualization and control.
5. Integration of automated control systems such as smart fans and air purifiers to improve indoor air quality.

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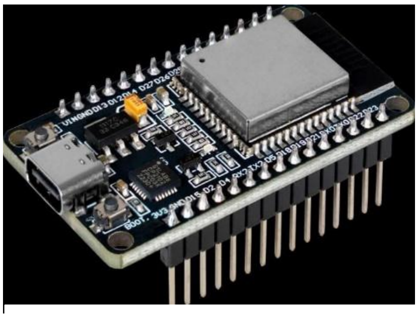
APPENDIX

DHT11

Mq-135 Gas Sensor



Jumper wire

ESP 32

BREADBOARD