"IOT-BASED INDOOR AIR QUALITY MONITORING SYSTEM "

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ABSTRACT

Indoor air quality (IAQ) significantly impacts health, safety, and productivity in enclosed spaces. Rising air pollution and its associated health risks highlight the need for affordable, continuous IAQ monitoring. This work proposes a low-cost, real-time IAQ monitoring system using a NodeMCU (ESP8266) microcontroller integrated with sensors to measure temperature, humidity, VOCs, and particulate matter. Data is transmitted to the ThingSpeak cloud platform and visualized through a Flutter-based mobile application, which also computes a user-friendly IAQ index. Firebase is utilized for secure authentication and historical data storage, enabling both real-time insights and trend analysis. The system leverages IoT, cloud, and mobile technologies to enable remote monitoring and alerts when pollutant levels exceed safe thresholds—offering a scalable, user-centric solution for healthier indoor environments.

Keywords: Indoor Air Quality, IoT Monitoring, VOCs, Particulate Matter, Cloud Storage, ThingSpeak, Mobile App, NodeMCU

1. INTRODUCTION

Air conditions keep worsening year by year with the expansion of civilization and mounting dirty emissions from industries and cars. While air is a necessary resource for living, most people do not care about the gravity of air pollution or only now realize the issue. Of the different kinds of polluting substances like water, land, thermal, and noise, air pollution is the worst and most perilous, leading to climate change and fatal diseases. Air pollution is an enormous issue and not limited to inhabitants of smog-filled cities, in such ways as global warming and destruction of the ozone layer, it can harm us all.

Based on the World Health Organization (WHO), 90 percent of the population currently inhales tainted air, and air pollution is the cause of death for 7 million people every year. Pollution's health impacts are extremely harsh that leads to stroke, lung cancer, and heart disease. Air quality monitoring and management are thus prime topics of concern. The impact of dirty air must be prevented and one of the options is by employing a system to control the indoor air quality.

To address this issue, our project proposes to create a real-time IAQ monitoring system based on temperature, humidity, VOC, and PM sensors. The suggested system can identify the air's quality level. The data will be uploaded to the ThingSpeak cloud platform, accessed through API keys, and presented in a Flutter-based Android app. Firebase will also store past IAQ data and handle user authentication. This system will help industries like Arklite monitor environmental conditions, ensuring a safer and more productive workspace.

Ensuring good indoor air quality (IAQ) is crucial for maintaining a safe and healthy environment, particularly in industrial settings where air pollutants like VOCs, particulate matter, and humidity variations can pose serious health risks. Current monitoring technologies are typically antiquated, have no real-time analysis, and need manual intervention, so detecting and reacting to air quality changes in a timely manner is problematic.

To overcome these limitations, this project aims to develop a real-time IAQ monitoring system with continuous monitoring of air quality parameters utilizing temperature, humidity, VOC, and PM sensors. The sensor readings will be transferred to the ThingSpeak cloud, accessed through API keys, and represented using a Flutter-based Android app.

In addition, Firebase will save past IAQ data and handle user authentication, allowing industries such as Arklite to track air quality trends and make better decisions for a healthier working environment.

2. SYSTEM REQUISITES

The planned Indoor Air Quality (IAQ) monitoring system is to be cost-effective, scalable, and able to supply real-time information on different environmental parameters. In order to meet the requirements of precise sensing, wireless data transfer, mobile access, and storing historical data, certain hardware and software requirements are outlined. They are classified below.

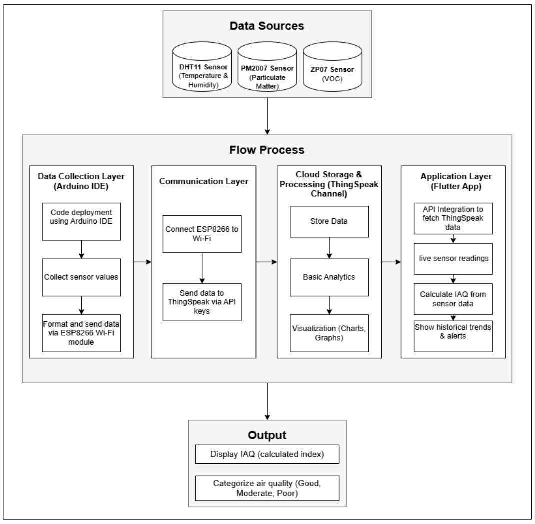

Fig 2.1 Block Diagram

2.1 Hardware Requirements

2.1.1 NodeMCU ESP8266 Microcontroller

The NodeMCU ESP8266 is the system controller of the IAQ monitoring system. It communicates with all environmental sensors and analyzes data obtained. Among the most notable characteristics of the ESP8266 is the fact that it comes with an inbuilt Wi-Fi module, making it possible to have wireless connection to cloud services without the need for extra hardware. This wireless functionality enables the microcontroller to interface with a nearby Wi-Fi network and send live sensor readings to the ThingSpeak cloud platform over HTTP or MQTT protocols. In addition to adding portability and ease of installation to the system, the wireless communication also enables remote access to air quality data via mobile applications. The small form factor, low power usage, and affordability make NodeMCU a perfect candidate for IoT-based environmental monitoring solutions.

2.1.2 DHT11 Temperature and Humidity Sensor

This sensor tracks the indoor environment by sensing ambient temperature and relative humidity. These are important parameters since high levels of temperature and humidity can influence comfort, productivity, and health, and they tend to interact with pollutants to enhance their effect.

2.1.3 ZP07 V4.0 (VOC Sensor)

Able to detect a broad array of gases such as ammonia, benzene, and smoke, this sensor finds application in VOC monitoring. Volatile Organic Compounds (VOCs) are often emitted by domestic products and are notorious for causing irritation, headaches, and long-term health impacts.

2.1.4 PM2007 (PM Sensor)

This laser sensor is utilized to detect the concentration of PM2.5 and PM10. PM exposure has been associated with respiratory diseases, asthma, and cardiovascular diseases. Real-time monitoring of PM enables immediate action against unsafe levels of air quality indoors.

2.1.5 Power Supply (5V)

The device needs a stable power source, which can be supplied via a USB adapter, battery pack, or power bank. In the case of permanent installations, a surge protector adapter is advised.

2.1.6 Breadboard, Resistors, Jumper Wires

All these elements are necessary for creating a prototype circuit. The modularity of breadboards accommodates quick prototyping, and the resistors maintain proper current regulation and jumper wires offer convenient interconnections.

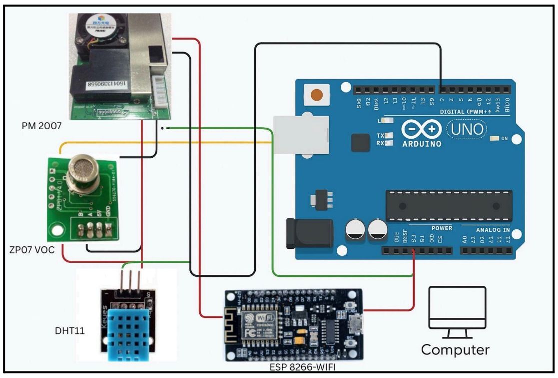

Fig 2.2 Schematic Diagram

2.2 SYSTEM SOFTWARE

2.2.1 Arduino IDE

Utilized in programming the NodeMCU, the Arduino IDE is capable of C/C++ programming and offers libraries for sensor integration and cloud connectivity. It is easy to use and well-supported within the maker and research communities.

2.2.2 ThingSpeak Cloud Platform

An IoT analytics cloud platform that stores and displays sensor data in real-time. It supports RESTful APIs which makes it appropriate for low-latency applications. It also allows easy mathematical processing and threshold-based alerts.

2.2.3 Flutter Framework

Flutter is employed to build a cross-platform mobile app for Android and iOS. The application gets data from ThingSpeak via API calls and displays it on a user interface dashboard. Flutter supports contemporary, responsive UI design that improves the user experience.

2.2.4 Firebase (Authentication and Realtime Database)

Firebase Authentication provides secure access to app functionality, enabling users to sign in with email or third-party accounts. Firebase Database can be optionally utilized for storing historical data locally within the app for offline analysis or backup.

2.2.5 Internet Access (Wi-Fi Connection)

Stable internet connectivity is required for the NodeMCU to send data to the ThingSpeak cloud and for the mobile application to retrieve real-time updates. A persistent connection is required for alert features to function properly.

3. LITERATURE REVIEW

[1] M. N. M. Aashiq et al. (2023) designed an IoT-based handheld environmental and air quality monitoring station capable of measuring temperature, humidity, particulate matter (PM), and several gases including CO and NO_2. The device integrates multiple sensors (DHT11, MQ-series gas sensors, PM sensor) with a microcontroller and uses Wi-Fi for real-time data transmission to a cloud platform. The system allows remote access to environmental readings through a web interface. Notably, the study emphasizes the portability and low-cost aspect of the device, making it suitable for field studies and real-time environmental monitoring in underserved regions. Performance evaluations indicated good accuracy, and the modular design ensures scalability and future upgrades. *(Acta IMEKO, vol. 12, no. 3, pp. 1–8, Sep. 2023)*

[2] W.-T. Sung and S.-J. Hsiao (2021) built an indoor air quality monitoring system based on IoT architecture with the aim of enhancing building safety and comfort. Their design uses wireless sensor networks to collect real-time environmental parameters such as CO_2 levels, temperature, and humidity. The collected data is processed and sent to a cloud-based control center, enabling real-time visualization and control. One of the key contributions of this paper is the integration of data fusion techniques and fuzzy logic to make smart decisions based on sensor readings, e.g., activating exhaust fans or issuing air quality alerts. The system was tested in classrooms and labs, proving its robustness and accuracy. *(Journal of Wireless Communications and Networking, vol. 2021, no. 153)* body of research on using machine learning in healthcare for disease diagnosis and underscores the potential of these algorithms in enhancing CKD management.

[3] H. Othman, R. Azari, and T. Guimarães (2024) proposed a low-cost, IoT-enabled indoor air quality monitoring solution targeting budget-limited institutions. Their prototype employs the NodeMCU (ESP8266) and sensors such as MQ-135 and SDS011 for tracking VOCs and PM2.5/10 respectively. Data is collected and visualized on a cloud dashboard (via ThingSpeak), offering historical trend analysis and real-time updates. The system supports SMS and email alerts when AQI crosses predefined safe limits. The authors focused on cost-efficiency and replicability, stating that the total hardware cost was under $50. Their pilot deployment in a small office setting demonstrated effective early detection of poor air quality and user-friendly interfacing. *(Technology | Architecture + Design, vol. 8, no. 2, pp. 250–270, 2024)*

[4] J. M. S. Waworundeng and W. H. Limbong (2020) presented AirQMon, a smart indoor air quality system integrating a microcontroller (Arduino Mega 2560), a set of environmental sensors, and an Android application. Their system measures CO_2, temperature, and humidity, and utilizes Firebase to store and retrieve real-time data. The Android app was designed with user-centric dashboards to provide real-time feedback and alerts. Their focus was on building a fully offline-capable prototype with Bluetooth fallback when Wi-Fi was unavailable. This makes AirQMon

particularly effective in environments with intermittent internet access. Their field tests in classrooms and homes showed responsive monitoring and reliable app performance. *(Cogito Smart Journal, vol. 6, no. 2, pp. 251–261, Dec. 2020)*

[5] J. Jo, B. Jo, J. Kim, S. Kim, and W. Han (2020) developed Smart-Air, a scalable IoT-based indoor air quality monitoring platform. The platform collects data using a microcontroller with sensors for CO_2, PM, VOCs, temperature, and humidity. Data is sent to a cloud server via LTE, and visualized on a user dashboard accessible via mobile and web applications. What sets this system apart is the implementation of threshold-based alerts and an air quality scoring algorithm to help users interpret raw data easily. Their deployment across several buildings in Hanyang University showed system robustness, accuracy, and ease of maintenance. The study also discusses cloud architecture and RESTful API integration for third-party access. (Journal of Sensors, vol. 2020, pp. 1–14, Jan. 2020)

5. RESULTS AND DISCUSSION

5.1 Real-Time Monitoring

The app interface showed individual sensor readings and a computed IAQ Index, which enabled users to grasp the air quality quickly in a simplified manner (e.g., Good, Moderate, Poor). The system produced alerts when pollutant levels exceeded user-specified thresholds, allowing for prompt action.

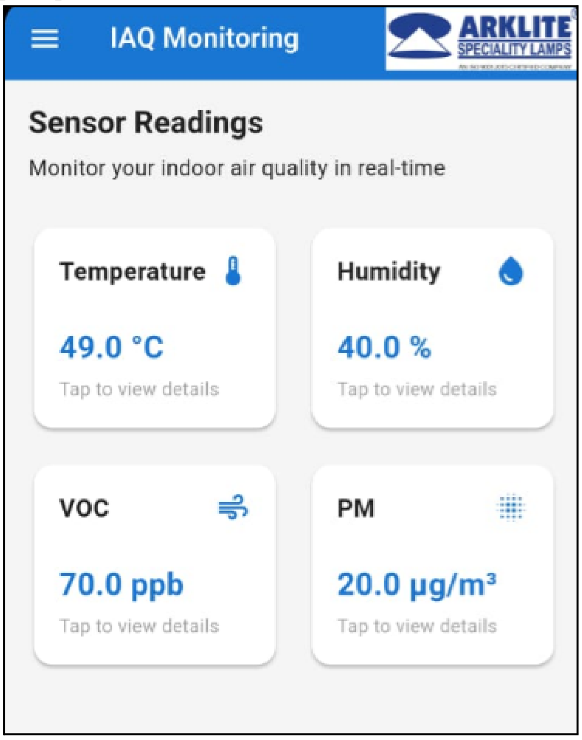

Fig 5.1 Sensors Reading

5.2 Categorization Logic

Air Quality Index (AQI) values are numeric representations of the quality of air based on concentrations of major pollutants like PM2.5, PM10, CO, NO_2, and others. However, to make this data more comprehensible to users, the AQI values are mapped to categorical labels. These categories indicate the level of health concern associated with different AQI ranges.The categorization in this system follows a tiered structure commonly adopted by environmental agencies. Each range represents a specific health impact:

0 – 50: *Good* – Air quality is considered satisfactory, and air pollution poses little or no risk.

51 – 100: *Moderate* – Air quality is acceptable; however, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.

101 – 150: *Unhealthy for Sensitive Groups* – Members of sensitive groups may experience health effects. The general public is not likely to be affected.

151 – 200: *Unhealthy* – Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.

201 – 300: *Very Unhealthy* – Health alert: everyone may experience more serious health effects.

301 and above: *Hazardous* – Health warnings of emergency conditions. The entire population is more likely to be affected.

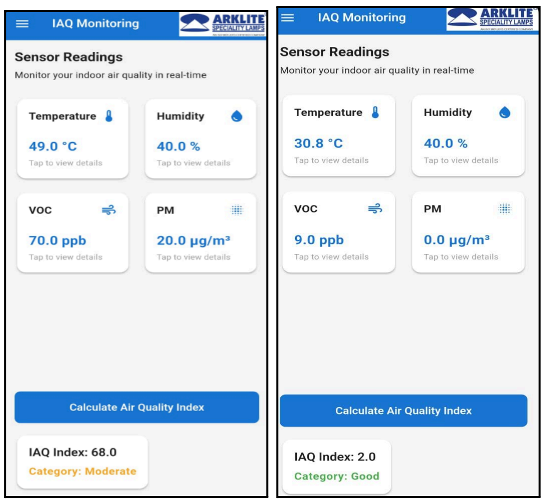

Fig 5.2 IAQ Calculation

5.2 Historical Data and Trend Analysis

To enable more in-depth analysis and greater user understanding, a historical graph function was added to the smartphone app. This graph portrays the fluctuation of indoor air parameters over time and allows users to monitor and understand trends easily. Through the analysis of peaks in pollutants like PM (Particulate Matter) or VOCs (Volatile Organic Compounds) on a daily or hourly basis, users have a better understanding of how certain factors affect indoor air. Second, the graph facilitates users to analyze the effect of ventilation measures or environmental adjustments on variables such as temperature and humidity. In the long run, it assists users in determining habitual patterns of indoor air quality for particular environments. This trend visualization enables users to make informed choices, for instance, maximizing air purifier use, opening windows at optimal periods, or making adjustments to HVAC system controls. It also provides correlations between air quality variations and factors such as room occupancy, time of day, or outdoor weather, so for proactive air quality management. it is important tool

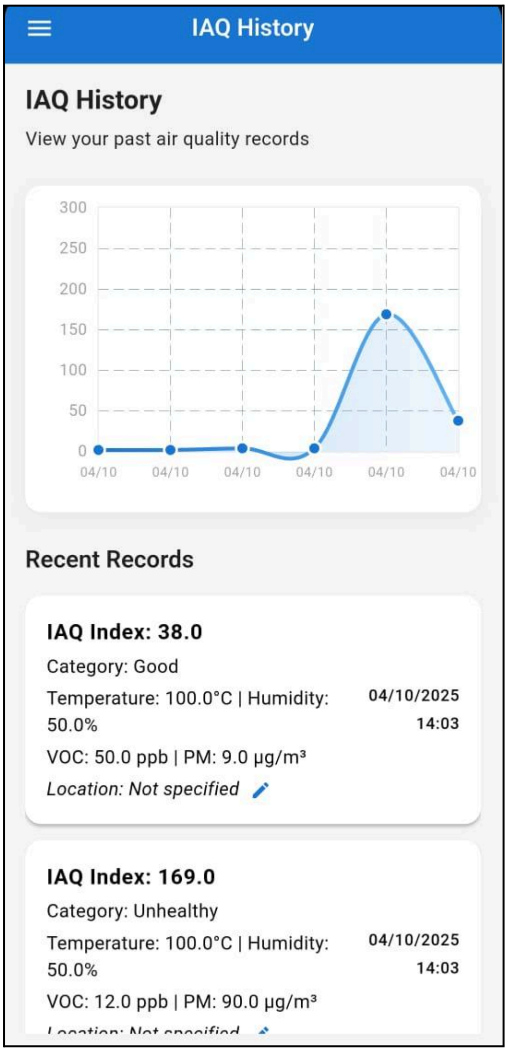

Fig 5.2 IAQ History

5.3 System Performance and Accuracy

The sensors used were evaluated for responsiveness and reliability. The results showed consistent performance with minimal lag in data updates. Calibration against standard air quality readings confirmed the accuracy of the sensors to an acceptable degree for real-time monitoring.

6. CONCLUSION

These readings are transmitted over the air to the ThingSpeak cloud platform for remote monitoring and data access via an intuitive Flutter-based mobile appThis paper presents the design and implementation of a low-cost, real-time Indoor Air Quality (IAQ) monitoring system based on IoT, cloud computing, and mobile technologies. Utilizing the NodeMCU ESP8266 microcontroller and a number of environmental sensors, the system is able to successfully monitor the key parameters such as temperature, humidity, VOCs, and particulate matter. Inclusion of Firebase for the purpose of authentication and the storage of historical data further makes the system more user-friendly and secure.

7. REFERENCES

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