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Implementation of an Internet of Things (IoT)-Based Air Quality Monitoring System for Enhancing Indoor Environments

Abdi Enal Wahyudi [1,a]; Sri Kurniyan Sari [1,b]; Firman Aziz [2,c*]; Jeffry [3,d]
[1] *Universitas Indonesia Timur, Rappocini Raya Street No.171-173, Makassar 90222, Indonesia*
[2] *Universitas Pancasakti, Andi Mangerangi Street 73, Makassar 90121, Indonesia*
[3] *Institut Teknologi Bacharuddin Jusuf Habibie, Jl. Balaikota No.1, Parepare 91122, Indonesia*
[a] *wahyudienal1827@gmail.com; [b] srikurniyans@gmail.com; [c] firman.aziz@unpacti.ac.id; [d] jeffry@ith.ac.id*
** Corresponding author*

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Abstract

This research investigates the development and implementation of an IoT-based air quality monitoring system designed to improve indoor environmental conditions. The primary objective of this study is to develop a comprehensive system that continuously monitors air quality parameters, including smoke, LPG gas, carbon monoxide (CO), temperature, and humidity. The system integrates real-time data collection from various sensors, which is then processed and transmitted to a cloud platform for secure storage and detailed analysis. The user-friendly interface of the software allows for intuitive monitoring and reporting, while built-in notification and alert features ensure timely responses to significant air quality changes. Testing results demonstrate that the system operates with high reliability, providing accurate data and stable performance. The findings confirm that the system effectively addresses indoor air quality concerns and offers valuable insights for maintaining a healthy and safe environment. This research contributes to the field by showcasing a practical application of IoT technology in environmental monitoring.

Keywords*—IoT, air quality monitoring, Real-time data collection, Sensor integration*

1. Introduction

Indoor air quality has become a critical concern in recent years due to the significant amount of time people spend indoors, whether at home, in offices, or in other enclosed environments (Mannan, M, 2021; Vardoulakis et al., 2020). Poor indoor air quality can lead to various health issues, ranging from respiratory problems to more severe chronic conditions (Tran & Park, D, 2020). Common pollutants such as particulate matter (PM2.5 and PM10), volatile organic compounds (VOCs), carbon dioxide (CO2), and other harmful gases can accumulate indoors, often at levels much higher than those found outdoor (Kumar et al., 2024). This scenario underscores the importance of continuous monitoring and management of indoor air quality to ensure a healthy living and working environment (Antony et al., 2024).

The rapid advancement of Internet of Things (IoT) technology offers a promising solution for real-time air quality monitoring and control (Saini et al., 2020). IoT devices can integrate multiple sensors to detect various pollutants, temperature, humidity, and other environmental factors (Jo et al., 2020). These devices can transmit data continuously to cloud-based platforms, where it can be analyzed and visualized to provide insights into air quality conditions (Yasin et al., 2022). The accessibility and affordability of IoT technologies make them an attractive option for widespread deployment in both residential and commercial settings (Korneeva & Olinder, N, 2021).

The study conducted by (Sadali et al., 2022) utilized the Wemos D1 to connect an MQ-135 sensor with an Internet of Things (IoT) platform for remote air quality monitoring. Research on early air monitoring was also carried out by (Octaviano et al., 2022) using an MQ-02 gas sensor to measure carbon monoxide levels (Maharani, SH, 2020). The findings indicated that this early detection device could monitor air pollution in real-time. Furthermore, the study by (Salasa, MG, 2021) employed a TGS-2442 gas sensor to monitor air quality, providing notifications on mobile phones when outdoor pollution was detected.

The research by (Prakoso et al., 2022) implemented the Wemos D1 Mini and Android for IoT-based air quality monitoring. The results showed that the system could measure indoor CO gas levels ranging from 7 ppm to 38 ppm. Meanwhile, (Ratri et al., 2022) used the ESP32 microcontroller as a server with IoT technology to monitor weather conditions and transmit data in real-time. (Utami et al., 2022) employed the MQ-7 sensor to detect cigarette smoke indoors and the DHT11 sensor to monitor temperature and humidity, with the monitoring results displayed on a mobile application.

Air pollution level monitoring was also researched by (FIKRI, 2023) using an IoT system and an MQ-7 sensor, tested over three months on a campus environment. This study aligns with the research by (Sadali et al., 2022), which focused on monitoring air quality on highways using the MQ-135 sensor and an IoT platform. Additionally, (Mashuri & Upgris, 2022) used a combination of MQ-6, MQ-7, MQ-135, and DHT-11 sensors in their study to monitor air quality in Semarang City with IoT, supporting decision-making processes.

This research focuses on the implementation of an IoT-based air quality monitoring system specifically designed for indoor environments. By leveraging IoT technologies, this study aims to develop a system that not only monitors air quality in real-time but also provides actionable feedback to improve indoor conditions. The ultimate goal is to enhance indoor air quality, thus contributing to better health outcomes and overall well-being for occupants.

2. Method

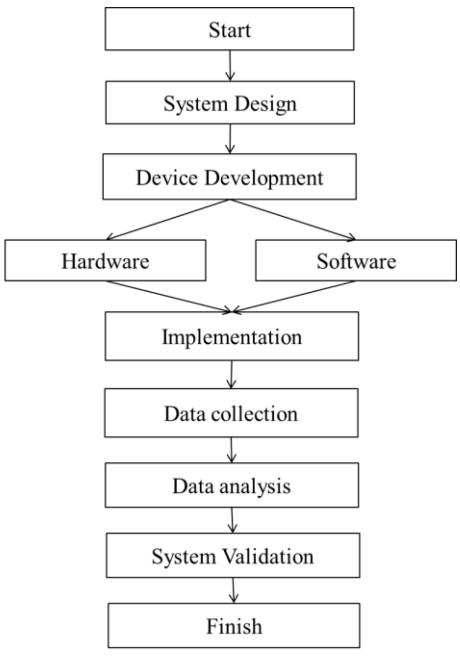

Figure 1. Figure Title.

2.1 System Design

The first phase involves designing the architecture of the air quality monitoring system. The system is designed to include multiple sensors for detecting various air quality parameters such as particulate matter (PM2.5 and PM10), carbon monoxide (CO), carbon dioxide (CO2), temperature, and humidity. The sensors are connected to a microcontroller, which processes the data and transmits it to a cloud platform via Wi-Fi.

Sensor Selection: The study uses specific sensors such as the MQ-135 for detecting CO2 and harmful gases, the PMS5003 for particulate matter, and the DHT11 for temperature and humidity. The choice of sensors is based on their accuracy, reliability, and compatibility with the microcontroller.

Microcontroller: An ESP8266 microcontroller is chosen due to its built-in Wi-Fi capability and compatibility with the selected sensors. The microcontroller is programmed to read data from the sensors and send it to the cloud platform.

Cloud Platform: The system uses a cloud platform, such as ThingSpeak or AWS IoT, for data storage and analysis. The platform provides tools for real-time data visualization and analysis, which are essential for monitoring air quality trends.

2.2 Hardware and Software Development

In this phase, the hardware is assembled by connecting the sensors to the microcontroller. The casing is designed to protect the sensors and microcontroller while allowing proper air circulation for accurate readings.

Firmware Development: The microcontroller is programmed using Arduino IDE. The firmware is responsible for reading sensor data, processing it, and transmitting it to the cloud. Error-handling mechanisms are implemented to ensure continuous data transmission.

Web Application: A web application is developed to allow users to monitor air quality data in real-time. The application connects to the cloud platform and displays key air quality metrics. Additionally, it provides alerts when certain thresholds are exceeded.

2.3 Implementation

The developed system is deployed in an indoor environment, such as a residential home or office space. The sensors are strategically placed in locations where air quality is most likely to vary, such as near windows, kitchens, or areas with high foot traffic.

2.4 Data Collection

Once the system is implemented, data is collected continuously over a period of three months. The system records air quality parameters every minute and transmits the data to the cloud platform, where it is stored for later analysis.

2.5 Data Analysis

The collected data is analyzed to identify patterns and trends in indoor air quality. Statistical methods, including time-series analysis, are employed to understand how air quality fluctuates over time and in response to specific events (e.g., cooking, opening windows).

Anomaly Detection: Machine learning algorithms are used to detect anomalies in the data, such as sudden spikes in pollutant levels. These anomalies can indicate potential sources of pollution or ventilation issues.

Impact Evaluation: The effectiveness of the system in improving indoor air quality is evaluated by comparing air quality data before and after the system's implementation.

2.6 System Validation

The system's accuracy and reliability are validated through comparison with standard air quality measurement devices. Calibration procedures are conducted periodically to ensure sensor accuracy.

3. Results And Discussion

The results of this study produced a system consisting of hardware and software designed for monitoring purposes. On the hardware side, the device is enclosed in a protective box containing sensors capable of detecting environmental conditions such as smoke, LPG gas, and carbon monoxide (CO). To provide warnings, the device is equipped with a buzzer that emits a sound when hazardous conditions are detected. The device can be powered by a 5V supply through a USB port or can operate with a 9-12 Volt DC power source, as it is equipped with a regulator circuit. In the initial phase, all components were soldered and mounted on a PCB board, as shown in the image below.

Figure 2. Component Installation

Once all the components are mounted on the circuit board, the next step is to place the assembly into the enclosure box. This step is crucial for protecting the components and simplifying the installation and maintenance process. The enclosure is designed to ensure that the system can be securely and neatly installed in various environments, providing protection for the sensors and other components from dust, moisture, and physical damage that could affect the device's performance.

Figure 3. Circuit on Box Enclosure

The implementation of the software for the IoT-based air quality monitoring system demonstrates several key features and performance metrics that support effective indoor environmental management. First, the software is equipped with a highly intuitive and user-friendly interface. This interface allows users to monitor air quality in real-time by displaying data from sensors in the form of easily understandable graphs and visual indicators. Users can effortlessly view the current air quality status and access detailed reports presented in daily, weekly, and monthly formats. These reports provide comprehensive insights into the air quality trends in the monitored indoor environment.

In terms of data processing and transmission, the software performs efficiently and reliably. It collects data from various sensors that measure parameters such as smoke, LPG gas, carbon monoxide (CO), temperature, and humidity. This data is meticulously processed to ensure accuracy before being automatically sent to a cloud platform, such as ThingSpeak or AWS IoT, for secure storage and further analysis. Data transmission is conducted at high speeds to ensure that the information is always up-to-date and readily accessible to users.

One of the key features of the software is its notification and alert system. When significant changes in air quality are detected, such as an increase in hazardous gas levels or smoke, the system automatically sends notifications to users via a mobile application. These alerts are designed to provide immediate information, allowing users to take necessary actions to maintain air quality. This feature enables rapid response to potential issues, ensuring a safe indoor environment.

Integration with cloud platforms offers additional benefits in terms of data storage and analysis. Data stored in the cloud can be accessed anytime and from any location, providing users with substantial flexibility. Long-term trend analysis is also facilitated, allowing for the identification of patterns and changes in air quality over time. Furthermore, the software is designed with expansion capabilities, allowing for the addition of new sensors or features in the future without requiring a complete system overhaul. This modular structure ensures that upgrades and maintenance can be performed easily and efficiently.

During the testing phase, the software demonstrated stable and reliable performance. The response time for processing and displaying data was swift, and the system operated continuously without interruptions. This ensures that air quality monitoring remains effective and consistent, providing users with accurate and relevant data at all times.

The measurement statistics obtained during implementation include an ADC value of 144, smoke level of 11429, LPG gas level of 1252, and carbon monoxide (CO) level of 1707 ppm. These figures indicate that the system can measure various air quality parameters with high precision. Overall, the implementation results show that the IoT-based air quality monitoring system meets the monitoring needs effectively, providing valuable data to maintain a safe and healthy indoor environment.

4. Conclusions

The implementation of the IoT-based air quality monitoring system has successfully demonstrated its effectiveness in managing indoor environmental conditions. With a user-friendly interface, the software allows for real-time monitoring and detailed reporting, making it easy for users to understand and address air quality issues. Efficient data processing and transmission to cloud platforms ensure accurate, up-to-date information, facilitating timely responses to any air quality changes. The system's alert features provide immediate notifications of significant changes, such as increased hazardous gas levels or smoke, enhancing user responsiveness and maintaining a safe indoor environment. The integration with cloud platforms offers flexible data access and supports long-term trend analysis, while the modular design allows for future expansions and upgrades without major system changes. During testing, the software showed stable performance, rapid response times, and continuous operation, confirming its reliability in monitoring. Overall, the system effectively meets indoor air quality monitoring needs, providing valuable data to ensure a healthy and safe environment.

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