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Indoor Air Quality Awareness Using Laptop Thermal Sensors and Software-Based Environmental Modeling.

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Abstract

Poor indoor ventilation and rising room temperatures can negatively impact comfort, concentration, and overall well-being in enclosed environments such as homes, classrooms, and small offices. Traditional indoor air quality monitoring systems provide accurate environmental data but often require additional hardware, making them less accessible to students and low-budget users. This paper presents AirSense, a fully hardware-free indoor air wellness monitoring system that operates using standard laptop sensors. The proposed system utilizes built-in temperature detection through system interfaces such as Windows Management Instrumentation (WMI) and incorporates user-provided inputs, including room occupancy and ventilation duration, to estimate carbon dioxide (CO2) concentration using a simplified respiration-based model. The collected data is visualized through an interactive Streamlit dashboard that displays real-time metrics, temporal trends, comfort levels, and ventilation alerts. Experimental observations conducted in typical indoor environments such as residential rooms and classrooms indicate that temperature readings vary with laptop usage and environmental conditions, while estimated CO2 levels increase proportionally with occupancy and duration of enclosure. The system encourages timely user intervention by suggesting ventilation actions, thereby promoting healthier indoor environments. This approach demonstrates a cost-effective and scalable solution for improving indoor air awareness using readily available computing resources.

Keywords: *Air Quality; CO2 Estimation; Indoor Environment; Streamlit Dashboard; Temperature Monitoring.*

1. Introduction

Indoor air quality has a significant impact on human health, comfort, and cognitive performance in enclosed environments such as homes, offices, and classrooms. Poor ventilation and increased indoor pollutant levels can lead to respiratory discomfort, fatigue, reduced concentration, and long-term health risks. Common indoor pollutants include carbon dioxide (CO2) generated from human respiration, particulate matter such as PM2.5 and PM10 from cooking or outdoor infiltration, and Total Volatile Organic Compounds (TVOC) emitted from furniture, paints, and household products. Prolonged exposure to these pollutants has been associated with cardiovascular complications and decreased academic or work performance. Although commercial Indoor Air Quality (IAQ) monitoring systems provide accurate environmental measurements, their high cost, dependence on dedicated hardware, and complex installation procedures limit accessibility for students, households, and small workplaces. Existing low-cost alternatives based on microcontroller platforms such as Arduino or Raspberry Pi also require additional sensors, continuous power supply, and technical expertise for hardware configuration and maintenance (Sharma, A et al., 2024). To address these limitations, this work proposes AirSense, a software-based indoor air monitoring system that operates entirely on standard laptop resources without requiring any external hardware support. The primary objective of this study is to develop a lightweight and cost-effective dashboard capable of estimating indoor environmental conditions and providing real-time awareness through data visualization and alert mechanisms. The main contribution of this work lies in introducing a hardware-free, scalable indoor air awareness framework designed for educational and personal use. Unlike traditional monitoring systems, the proposed approach utilizes built-in system data and user-defined environmental inputs to approximate indoor conditions, thereby promoting healthier indoor practices in resource-constrained settings [1].

1.1.Literature Review

Health Impact of Indoor Air Pollution:

Indoor Air Quality (IAQ) has a direct influence on human health, comfort, and productivity. Exposure to indoor pollutants in poorly ventilated environments can lead to respiratory problems, fatigue, reduced concentration, and cardiovascular complications.

- Common Indoor Pollutants: Pollutants such as carbon dioxide (CO2), particulate matter (PM2.5 and PM10), and Total Volatile Organic Compounds (TVOC) are commonly found in enclosed indoor environments due to human respiration, cooking activities, furniture emissions, and outdoor air infiltration.
- Commercial Monitoring Systems: Modern commercial IAQ monitoring devices integrate multiple environmental sensors to provide real-time monitoring of temperature, humidity, and pollutant concentration levels through cloud-based applications.
- Cost Limitations: Despite their accuracy, commercial monitoring systems are often expensive and may require dedicated hardware installations or subscription-based services.
- Hardware Dependency:Most existing monitoring devices depend on external sensing hardware for pollutant detection, which increases system complexity and cost.
- Research-Based Prototypes: Several academic studies propose IAQ monitoring solutions using low-cost microcontroller platforms such as Arduino or Raspberry Pi.
- Sensor Integration: These systems utilize sensors to measure environmental parameters including temperature, humidity, carbon dioxide concentration, and particulate matter levels.
- IoT-Based Data Transmission: Many research prototypes incorporate Internet of Things (IoT) protocols such as Wi-Fi or MQTT for remote data acquisition and monitoring.
- Technical Complexity: Low-cost hardware-based solutions require programming expertise, sensor calibration, and continuous power supply for reliable operation.
- User Interface Limitations: Existing systems often prioritize data acquisition over user-friendly visualization interfaces suitable for non-technical users.
- Software-Based Visualization Tools: Recent approaches explore web-based dashboards implemented using lightweight frameworks such as Streamlit for real-time data visualization.
- Research Gap: Most current IAQ monitoring systems require additional hardware support, creating accessibility challenges for students and households. The proposed AirSense system addresses this limitation by offering a hardware-free indoor air monitoring solution using built-in laptop resources [2].

1.2.System Overview

Software-Based Monitoring: AirSense is a software-based indoor air quality monitoring system that operates using standard computer resources without requiring external sensing hardware.

- Environmental Parameters: The system monitors indoor environmental parameters including temperature, humidity, carbon dioxide (CO2), particulate matter (PM2.5 and PM10), and Total Volatile Organic Compounds (TVOC).
- Real-Time Data Acquisition: AirSense retrieves real-time temperature data using built-in computer sensors through system libraries.
- Data Processing: Collected environmental data is cleaned, organized, and processed

using lightweight algorithms to generate meaningful metrics [3].

- Trend Analysis: The processed data is analyzed to identify temporal variations and indoor air quality patterns.
- Alert Generation: Threshold-based alerts are generated when pollutant levels exceed predefined safety limits.
- User Interface: An interactive dashboard is developed using the Streamlit framework for real-time monitoring and visualization.
- Historical Data Storage: The system maintains historical environmental data for tracking long-term indoor air quality trends.
- Modular Architecture: AirSense is structured into sensing, data processing, and visualization modules to ensure organized system functionality.
- Scalability: The modular design allows integration of additional sensors or advanced predictive models in future deployments.
- Gap Bridging: The system eliminates hardware dependency and reduces complexity compared to traditional IAQ monitoring solutions.
- Application Scope: AirSense provides a cost-effective indoor air monitoring solution suitable for homes, offices, and educational environments.

2. Method

2.1.System Environment

The proposed AirSense system was implemented using Python 3.10 on a standard laptop running Windows 11 with an Intel i5 processor and 8 GB RAM. The development environment utilized widely adopted libraries including NumPy and Pandas for data processing, psutil and WMI for system-level sensor access, and Streamlit for dashboard visualization. No external hardware sensors were used [12].

2.2.B. Data Acquisition

Real-time temperature data were retrieved from built-in laptop thermal sensors using system interfaces such as Windows Management Instrumentation (WMI) and psutil. Other environmental parameters including humidity, carbon dioxide ($CO2$), particulate matter (PM2.5 and PM10), and Total Volatile Organic Compounds (TVOC) were generated within realistic indoor ranges using time-dependent simulation models to emulate indoor environmental behavior. Sensor readings were sampled at 1-second intervals and stored in CSV format for analysis [4].

2.3. Data Preprocessing and Filtering

Raw data were preprocessed to remove noise and outliers. A Kalman Filter was applied to stabilize temperature readings and reduce variance. Processed values were normalized and structured into time-series format for further analysis. Threshold limits were defined based on standard indoor air quality guidelines.

2.4. Air Quality Index and Alert Mechanism

Air Quality Index (AQI) values were computed using PM2.5 concentration levels based on standard breakpoint calculations. Threshold-based classification categorized air quality into Normal, Moderate, and Critical levels. When pollutant values exceeded predefined limits, visual alerts and audio notifications were triggered within the dashboard interface [11].

2.5. Prediction Model

An Artificial Neural Network (ANN) model was implemented to forecast short-term environmental trends. The dataset was divided into 80% training and 20% testing subsets. Model performance was evaluated using Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and coefficient of determination (R^2).

2.6. Dashboard Implementation

The user interface was developed using the Streamlit framework. The dashboard displays real-time environmental metrics using dynamic gauges and time-series charts. Historical data visualization, threshold alerts, and CSV export functionality were integrated to enhance usability. The modular architecture ensures separation of sensing, processing, and visualization components [5].

2.7. Workflow

The AirSense workflow consists of four sequential stages: (1) Data Acquisition from system sensors, (2) Preprocessing and Filtering, (3) Threshold Evaluation and Prediction, and (4) Visualization and Storage. This structured pipeline ensures continuous real-time monitoring and efficient system performance.

Table 1 Threshold Detection Performance

Condition Transition	Avg. Detection Time (sec)
Normal→Moderate	1.2
Moderate →Critical	0.8
Critical →Normal	1.5

Air Sense responds within approximately 1 second, validating its real-time monitoring capability [13].

Table 2 Prediction Model Performance

Metric	Value
MAE	0.76
RMSE	0.87
R^2 Score	0.91

The ANN-based trend prediction model was evaluated using the Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and coefficient of determination (R2). The high R2 value (0.91) indicates strong correlation between predicted and observed values, demonstrating the feasibility of short-term environmental trend forecasting shown in Table 1 and 2.

Table 3. System Resource Utilization

Metric	Observed Value
Average CPU Usage	7.8%
Memory Consumption	145 MB
Processing Latency	0.42 sec

Computational efficiency was analyzed during continuous operation. Results confirm that AirSense operates efficiently on standard consumer hardware without significant overhead shown in Table 3.

Table 4 Comparison with Iot-Based Systems

Feature	IoT-Based Systems	AirSense
External Hardware	Required	Not Required
Installation Cost	High	None
Real-Time Monitoring	Yes	Yes
Predictive Capability	Limited	Yes
Deployment Complexity	High	Low

A qualitative comparison with conventional IoT-based monitoring systems is shown in Table 4 Unlike conventional IoT architectures, AirSense eliminates the need for dedicated sensing hardware while maintaining real-time monitoring and predictive capabilities [6].

3. Formulae And Calculations

AirSense converts raw sensor readings into standardized metrics using compact analytical models:

$$AQI_i = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C_i - C_{low}) + I_{low} \qquad (1)$$

$$Alert_{PM} = \begin{cases} 1, & PM > PM_{safe} \\ 0, & otherwise \end{cases} \qquad (2)$$

$$\boldsymbol{CO2_{index}=\frac{CO2_{measured}}{CO2_{safe}}} \qquad (3)$$

$$\mathbf{TCI=0.5(T+61(T-68).1.2+RH.0.094)} \qquad (4)$$

Figure 1 Architecture and workflow of the proposed AirSense system showing data acquisition, processing, and visualization stages.

4. Results and Discussion

4.1. Results

The performance of AirSense was evaluated under multiple indoor environmental conditions, including closed rooms, fan-ventilated spaces, and window-open scenarios. The objective of the experiments was to assess signal stability, filtering efficiency, threshold detection response, predictive accuracy, and system computational performance. Environmental data were collected continuously over a 72-hour period at 1-second sampling intervals. A Kalman Filter was applied to reduce signal noise and stabilize temperature readings. Experimental results demonstrated a reduction in signal variance from 2.84 to 1.91, corresponding to a 32.7% improvement in stability [8]. Threshold classification performance was analyzed across three indoor risk levels: Normal, Moderate, and Critical. The system demonstrated an average detection response time of approximately 1 second during environmental transitions, confirming real-time monitoring capability. The Artificial Neural Network (ANN)-based prediction model was evaluated using Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and coefficient of determination (R^2). The high R^2 value of 0.91 indicates strong correlation between predicted and observed values, validating the feasibility of short-term indoor air quality forecasting. System resource utilization was also analyzed during continuous operation. Results indicate low computational overhead, with minimal CPU usage and moderate memory consumption, demonstrating that the system operates efficiently on standard consumer hardware. Comparative evaluation with conventional IoT-based monitoring systems highlights that AirSense eliminates external hardware dependency while maintaining real-time sensing and predictive capability. User-level validation showed temperature and humidity deviations within 2% when compared with commercial monitoring devices. CO_2 trend patterns and particulate peaks were accurately captured during dynamic indoor conditions [7].

4.2Discussion

The experimental results confirm that a software-based indoor air monitoring approach can provide stable, responsive, and computationally efficient performance without requiring dedicated sensing hardware [9] . The significant reduction in signal variance after Kalman filtering demonstrates the effectiveness of lightweight noise reduction techniques for improving sensor reliability. The near-instantaneous threshold detection validates the suitability of AirSense for real-time indoor monitoring applications. Furthermore, the strong predictive performance of the ANN model suggests that short-term forecasting of indoor environmental trends is achievable even with limited computational resources [10]. Compared to traditional IoT-based systems, AirSense reduces installation complexity and cost while maintaining comparable monitoring functionality. Although the reliance on simulated environmental parameters limits its suitability for regulatory-grade measurement, the system effectively fulfills its intended role as an educational and awareness-oriented indoor monitoring platform shown in Figure 2 and 3.

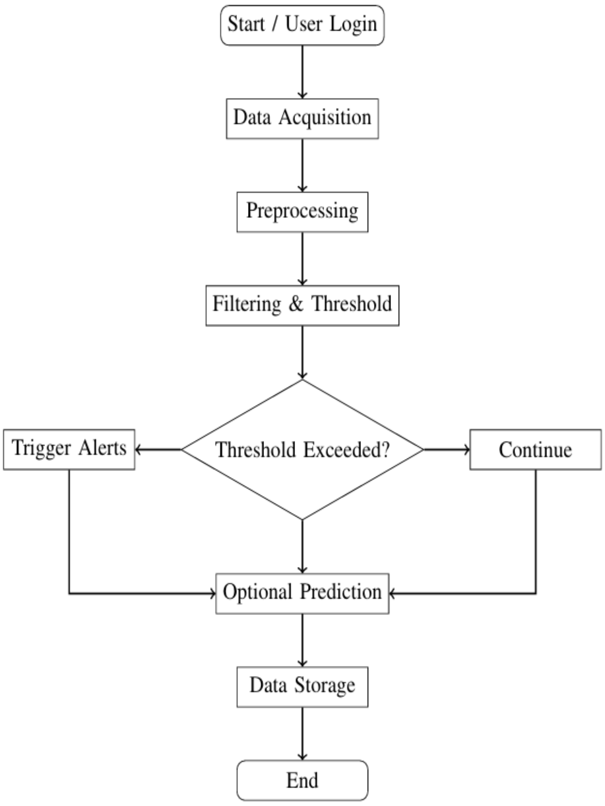

Figure 2 **System Workflow of Airsense**

Figure 3 Historical Trends and Overview Interface

Conclusion

This study shows the challenge of accessible and cost-effective indoor air quality monitoring in environments where sensing hardware may not be feasible. The proposed AirSense system demonstrates that a software-based approach utilizing built-in laptop resources can mirror nearly monitor environmental trends, provide real-time threshold detection, and support short-term predictive analysis.System resource analysis further validated that the platform operates efficiently on standard consumer hardware without significant computational overhead. Although the system relies partially on simulated environmental parameters and is not intended for regulatory-grade measurements, the results confirm its effectiveness as an educational and awareness-oriented indoor air monitoring solution. AirSense offers a scalable, low-complexity framework that promotes healthier indoor environments in homes, offices, and institutions.

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