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Original Article

An AI-Based Ventilation KPI Using Embedded IoT Devices

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Abstract :*An AI-based Key Performance Indicator (KPI) framework is developed for monitoring and controlling ventilation quality using embedded devices.The system integrates real-time data from MQ-02 and MQ-135 gas sensors, processed through machine learning algorithms to generate predictive outputs that guide ventilation control decisions. The trained models, optimized for embedded deployment, track essential KPIs such as air quality index, ventilation efficiency, and response time, enabling smart, adaptive ventilation management. By embedding these models into compact, low-cost IoT devices, the solution ensures scalability, low power consumption, and reliable operation in diverse environments. This approach transforms raw sensor data into actionable insights, enhancing ventilation performance while supporting sustainable and intelligent infrastructure within the broader vision of Smart Cities.*

Keywords: *AI-based Ventitilation, IOTdevices, KPI, Real time monitoring, Gas sensor, Embedded device.*

I. INTRODUCTION

With the increasing focus on health, sustainability, and smart infrastructure, there is a growing need to ensure effective air ventilation in enclosed public spaces, especially in educational institutions where large groups of people gather for extended periods. Traditional ventilation systems often lack real-time adaptability and do not consider dynamic factors such as occupancy levels and CO_2 accumulation. This can lead to poorly ventilated environments that contribute to fatigue, reduced concentration, and the spread of airborne illnesses.

The need for this project arises from the gap in intelligent, low-cost, and scalable solutions that can continuously monitor and optimize indoor air quality. By integrating AI-driven predictive models and embedded IoT technology, this project addresses a critical requirement for smarter, healthier learning spaces, making it essential for modern Smart University ecosystems and the broader vision of Smart Cities.

A. Problem Statement

The problem addressed is that traditional building ventilation systems often operate inefficiently due to a lack of real-time monitoring and actionable metrics, causing poor Indoor Air Quality (IAQ) and high energy consumption. Existing methods fail to dynamically adjust to occupancy changes, leaving spaces underserved or over-ventilated. A scarcity of objective, real-time performance indicators (KPIs) to measure ventilation effectiveness. Improperly regulated ventilation in enclosed spaces (e.g., classrooms) can lead to disease transmission, particularly due to high accumulation. Outdated systems waste energy because they do not adjust ventilation rates based on actual occupancy or environmental data. Difficulty in remote, real-time monitoring and integration of IoT sensor data (temperature, humidity,) for automated, data-driven decisions.

B. Objective

Creating a new KPI that acts as a decision-making tool to evaluate the effectiveness of ventilation, ensuring it remains within safe, healthy limits. Using AI techniques, specifically regressive neural networks, to estimate the number of occupants (via Wi-Fi data) and predict CO2 accumulation based on sensor data. Balancing occupant comfort and safety (preventing disease) with energy-efficient ventilation control. Utilizing small, inexpensive embedded IoT proto types (such as LoRa-based sensors) to monitor IAQ parameters like, temperature, and humidity.

C. Scope and Study

The proposed Embedded Ventilation KPI System using IoT technology holds immense potential for future development and real-world implementation. As technology continues to advance, the system can be further enhanced by integrating Artificial Intelligence (AI) and Machine Learning (ML) algorithms to enable predictive analysis and autonomous control of ventilation systems. This would allow the system to learn from historical data, anticipate air quality fluctuations, and automatically adjust airflow for optimal performance. Future versions can also incorporate cloud-based analytics platforms for centralized data management, enabling large-scale monitoring across multiple buildings or campuses in smart city infrastructures. Integration with renewable energy sources, such as solar-powered ventilation units, could improve sustainability and energy efficiency.

II. COMPONENTS

A. Components And Specifications:

- ATMEGA 328
- MQ 2 Smoke Sensor
- MQ-135 Gas Sensor
- LCD-Liquid Crystal Display
- Relay Driver
- Python IDE software
- Embedded C programming

III.BLOCK DIAGRAM

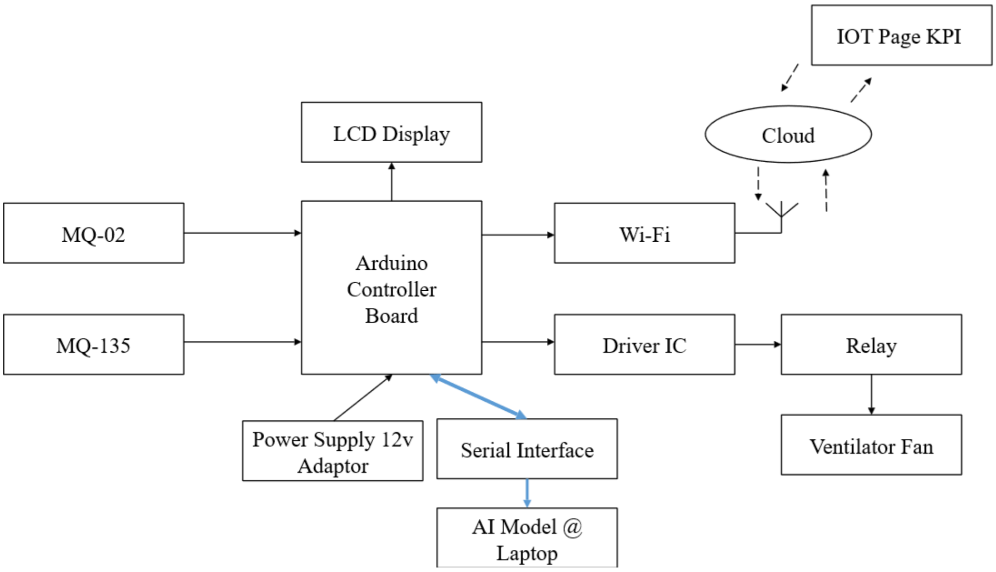

Figure 1: Block Diagram of System

A. Working

The block diagram illustrates an AI-based ventilation KPI system using embedded IoT devices. The setup integrates MQ-02 and MQ-135 gas sensors with a controller board (Arduino shown here, but can be replaced with Node MCU for Wi-Fi-based IoT applications) to monitor air quality. The controller board processes sensor inputs and displays real-time readings on an LCD display. Through Wi-Fi connectivity, the data is transmitted to the cloud, where it can be analysed further and displayed on an IoT KPI dashboard. The system also includes a serial interface for communication with an AI model on a laptop, enabling intelligent decision-making for predictive ventilation control. A power supply (12V adapter) powers the entire circuit. For actuation, the controller drives a ventilator fan through a driver IC and relay mechanism, automatically maintaining optimal air quality levels. This ensures real-time monitoring, smart decision-making, and remote accessibility through cloud-based IoT platforms.

VI. CIRCUIT DIAGRAM

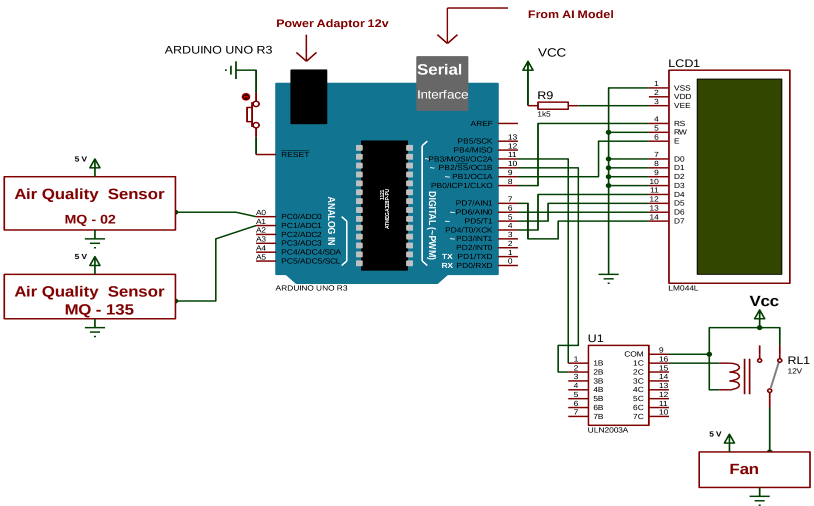

Figure 2: Circuit Diagram of the system

V. RESULT AND DISCUSSIONS

"An AI-Based Ventilation KPI Using Embedded IoT Devices" presents a system using low-cost sensors and regression neural networks to calculate a ventilation Key Performance Indicator based on levels and Wi-Fi occupancy data. The study demonstrates that this effectively enables proactive monitoring of indoor air quality and ventilation efficiency in classrooms via the SmartUA platform.

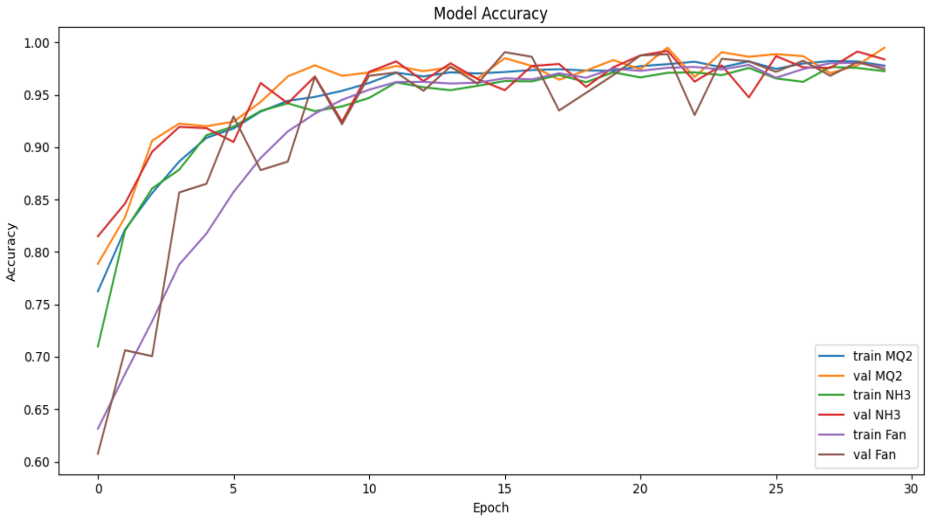

Figure 3: Model Accuracy

The plotted graph illustrates the training and validation accuracy trends for three sensor-based models (MQ2, NH3, and Fan) over 30 epochs. Initially, all models show a steady increase in accuracy, indicating effective learning during early training phases. The MQ2 and NH3 models quickly achieve high accuracy levels above 90% within the first few epochs, while the Fan model starts lower but gradually catches up. As training progresses, both training and validation curves for all models converge closely, suggesting minimal overfitting and good generalization performance. Minor fluctuations are observed in validation accuracy, especially for the Fan model, but overall stability is maintained. By the final epochs, all models achieve high accuracy levels nearing 97–99%, demonstrating that the models are well-trained and capable of reliable predictions across the dataset.

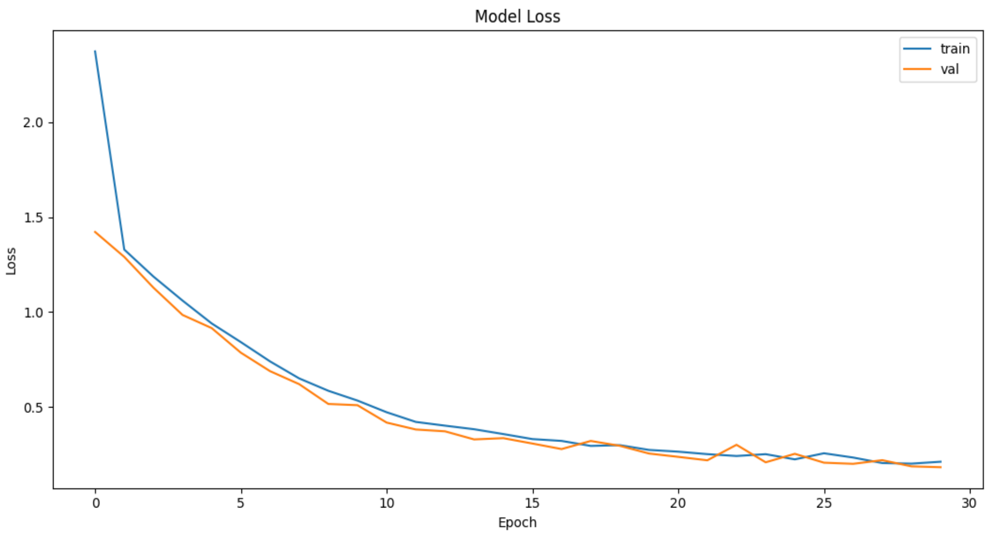

Figure 4: Model Loss

The loss graph shows a clear and consistent decrease in both training and validation loss over the 30 epochs, indicating effective model learning and convergence. At the beginning, the training loss starts relatively high (around 2.3) and rapidly declines, while the validation loss follows a similar downward trend, slightly lower in the early stages. As training progresses, both curves gradually flatten, suggesting that the model is stabilizing and approaching optimal performance. The close alignment between training and validation loss indicates minimal overfitting and strong generalization capability. Although there are minor fluctuations in validation loss during later epochs, the overall trend remains downward, with both losses reaching low values near 0.2 by the end, demonstrating that the model has successfully minimized error and learned meaningful patterns from the data.

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MQ2 Status Accuracy: 0.9944999814033508
MQ135 Status Accuracy: 0.9860000014305115
Fan Control Accuracy: 0.9710000157356262
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Figure 5: Accuracy of AI control of load in response to sensor input

The displayed results indicate that the trained models have achieved very high prediction accuracy across all components of the system. The MQ2 status model shows an accuracy of approximately 99.45%, demonstrating excellent performance in detecting gas-related conditions. Similarly, the MQ135 model achieves around 98.60% accuracy, indicating strong reliability in air quality or gas classification tasks. The fan control model records an accuracy of about 97.10%, which, while slightly lower than the sensor models, still reflects highly effective decision-making capability. Overall, these results confirm that the system is well-trained, highly precise, and suitable for real-time environmental monitoring and automated control applications with minimal error

VI. CONCLUSION

This study highlights the crucial role of effective air ventilation in maintaining the health, comfort, and productivity of occupants in enclosed environments. Poor ventilation can lead to elevated CO_2 concentrations and the accumulation of airborne pollutants, adversely affecting well-being and cognitive performance. To address this challenge, the research introduced a novel Ventilation Key Performance Indicator (KPIv), specifically designed for Smart City and Smart University environments. The KPIv serves as a quantitative measure to support informed decision-making related to indoor air quality management and ventilation efficiency. By estimating occupancy levels and CO_2 build-up, it provides a clear and dynamic assessment of ventilation performance in real time. In conclusion, the proposed Embedded Ventilation KPIv system represents a forward-looking solution for intelligent air management in academic and urban environments. It not only improves the understanding and control of indoor air quality but also aligns with the broader vision of sustainable, data-driven Smart Cities. Future developments may incorporate AI-based predictive controls, cloud-based analytics, and multi-sensor fusion to further enhance accuracy, responsiveness, and scalability, ultimately contributing to healthier and more energy-efficient indoor ecosystems.

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