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AI Based Ventilation KPI Using Embedded IoT Devices

Bindu T[1], Chandana CV[2], Chithra D[3], Dhanusha DS[4], Dr. Kavitha[5]
Dept. of Electronics and Communication Engineering CMR Institute of Technology Bengaluru, India

Abstract: This paper presents an Artificial Intelligence (AI)- based Key Performance Indicator (KPI) system for ventilation, integrating embedded Internet of Things (IoT) devices to enhance indoor air quality management. The proposed model employs sensors such as MQ135, MQ2, DHT11, and a dust sensor, interfaced with a Raspberry Pi for real-time monitoring. The system uses a linear regression algorithm to predict ventilation efficiency and automatically activates actuators such as a relay-controlled ozone generator and CPU fan to optimize airflow and purification. The results show that the system effectively improves air quality, energy efficiency, and automation for smart building environments.
Keywords: IoT, Air Quality, Raspberry Pi, Artificial Intelligence, Ventilation KPI, Automation

I. INTRODUCTION

Indoor air quality (IAQ) plays a vital role in ensuring human health, comfort, and overall well-being. With increasing urbanization, industrialization, and the rise of enclosed working environments, maintaining clean indoor air has become a growing challenge. Poor IAQ has been linked to several health complications, including asthma, allergies, chronic respiratory illnesses, and cardiovascular diseases. According to the World Health Organization (WHO), indoor air pollution accounts for nearly 4.2 million premature deaths annually worldwide, primarily due to prolonged exposure to fine particulate matter (PM2.5), volatile organic compounds (VOCs), and carbon- based pollutants.

Traditional ventilation and purification systems are often manually operated or use simple on–off control mechanisms based on threshold detection. These systems lack intelligence and adaptability, leading to inefficient energy usage and poor air quality regulation. For example, fixed-schedule ventilation often runs continuously, even when air quality is already within acceptable limits, resulting in unnecessary power consumption. Conversely, systems that depend solely on threshold triggers often respond too late, allowing pollutant levels to exceed safe limits before corrective actions occur.

With the emergence of Artificial Intelligence (AI) and the Internet of Things (IoT), it has become possible to integrate sensor networks, embedded control, and machine learning algorithms to create self-regulating smart systems. AI enhances the ability to analyze sensor data, learn environmental patterns, and predict changes before they occur. When combined with IoT- enabled sensors and actuators, it enables predictive, adaptive, and energy-efficient control over ventilation systems.

This paper introduces an AI-based Ventilation Key Performance Indicator (KPI) system, designed using embedded IoT devices for real-time monitoring and intelligent control of air quality. The system employs multiple sensors (MQ135, MQ2, Dust Sensor, and DHT11) connected to a Raspberry Pi micro controller via an MCP3208 ADC module. A linear regression algorithm processes the sensor data to calculate and predict a ventilation efficiency KPI, which quantifies air quality performance over time. Based on the predicted KPI, the system activates a relay-driven ozone generator and CPU fan to purify and circulate air automatically. This allows the environment to maintain optimal air quality while minimizing power usage.

The proposed model introduces a data-driven, predictive approach to environmental control, overcoming the limitations of traditional systems. By incorporating intelligent analytics, automated actuation, and continuous feedback loops, the system ensures both health safety and energy efficiency—two major pillars of modern smart infrastructure.

II. LITERATURE REVIEW

Several prior studies have addressed air quality monitoring using IoT frameworks. Smart ventilation systems [1] implemented AI-driven regression models for CO_2 prediction and occupancy detection. Other works [2] used AI to control air quality in industrial settings with pollutant sensors. Studies like [3] explored IoT-driven frameworks that combine real- time sensing with machine learning algorithms for predictive analysis. However, these systems often lack hardware-level integration or end-to-end automation. The proposed system bridges this gap by combining AI, embedded sensors, and actuators into a single integrated model that performs autonomous ventilation control.

A. Existing Model

Conventional ventilation and air quality management rely mainly on threshold-based systems or manual monitoring. While capable of basic pollutant detection, they lack predictive analytics and automation, leading to inefficient energy use and delayed air purification.

B. Proposed Model

The proposed system uses a Raspberry Pi as the processing core to collect data from multiple environmental sensors (MQ135, MQ2, DHT11, Dust sensor) via an MCP3208 ADC module. The AI component uses linear regression to compute ventilation KPIs, enabling predictive control. When pollutants exceed safe limits, the relay activates a mini ozone generator for purification and a CPU fan for ventilation. Data is displayed on an LCD, and alerts are triggered through a buzzer.

III. METHODOLOGY

This section describes the architectural design, hardware components, and software implementation of the proposed AI- based ventilation KPI system. The methodology emphasizes modularity, real-time data acquisition, predictive analytics, and automated actuation.

A. System Architecture

The overall system architecture consists of four functional layers that work together to monitor, analyze, and improve indoor air quality:

- Sensor Layer: This layer performs continuous environmental data collection. It consists of gas sensors (MQ135 and MQ2), a dust sensor, and a DHT11 temperature–humidity sensor. These sensors gather critical parameters including CO_2 concentration, smoke/VOCs, particulate matter, ambient temperature, and moisture levels.
- Processing Layer: The Raspberry Pi serves as the main controller, receiving analog sensor inputs through the MCP3208 12-bit ADC.
- Actuation Layer: This layer handles environmental correction based on predicted ventilation needs. A relay module controls the on/off switching of the ozone generator for air purification. A CPU cooling fan is activated to improve airflow and reduce temperature and gas buildup. Actuation occurs only when KPI or sensor readings cross predefined safety thresholds.
- Display and Alert Layer: This layer provides user interaction and prompt notification. A 16×2 LCD displays real-time values for temperature, humidity, gas levels, and KPI status. A buzzer generates audible alerts during hazardous conditions or when toxin levels rise sharply.

This multi-layer architecture ensures efficient sensing, intelligent decision-making, and safe human–machine interfacing.

B. Hardware Implementation

The system integrates low-cost, reliable embedded components suitable for continuous monitoring:

- MQ135 and MQ2 Gas Sensors:Measure CO_2 equivalents, NH_3, benzene, smoke, LPG, and VOC concentrations. MQ135 provides wide-range air quality data, while MQ2 is optimized for smoke and flammable gases.
- Dust Sensor: Measures particulate matter concentration using optical scattering. Important for detecting dust, smog particles, and fine pollutant aerosols.
- DHT11 Temperature and Humidity Sensor: Provides ambient climate data to improve KPI accuracy. Temperature and humidity significantly influence gas sensor readings and ventilation effectiveness.
- MCP3208 ADC Module: Converts 8 channels of analog sensor signals into 12-bit digital values recognizable by the Raspberry Pi. Ensures stable and accurate signal acquisition from MQ-series sensors.
- Relay with Ozone Generator: The relay acts as an electrical switch to enable or disable the ozone generator. The ozone generator removes microbial contaminants, odors, and harmful gases.
- CPU Cooling Fan: Enhances air movement and reduces pollutant accumulation. Operates at PWM-controlled speeds depending on predicted KPI severity.
- LCD Display and Buzzer: Provide real-time feedback and alerts. The buzzer activates during unsafe air quality events to ensure rapid attention.

All components are powered through a stable 5V/12V supply with necessary isolation to protect the Raspberry Pi.

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C. Software Implementation

The software uses Embedded C and Python. The system's data analytics uses a linear regression model to predict air quality variations and automate responses. Thresholds for CO_2, PM, and humidity are set programmatically.

D. Work Flow

Data acquistion from sensors
↓
Analog-to-digital conversion
↓
Data processing through regression model
↓
KPIcomputation and prediction
↓
Display and alert
↓
Relay activation for fan or ozone generator
↓
Repeat/End

E. Evaluation Parameters

The system is evaluated based on:

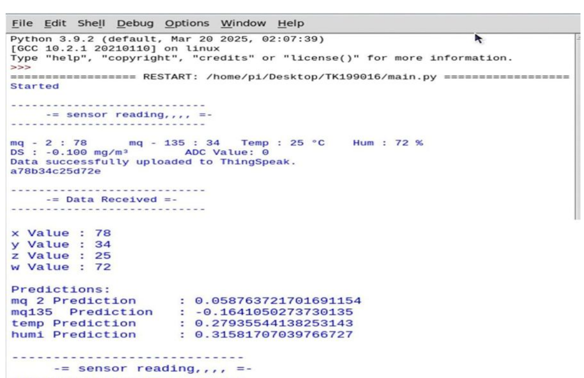
- Accuracy of sensor readings
- Response time of automated actions
- Energy efficiency of operation
- Reliability during long-term monitoring

IV. RESULTS AND DISCUSSIONS

TABLE I. Sensor Safety Classification Based On Thresholds

Sl. no	Table Column Head		
	Parameters	*Safe range, value(0)*	*Unsafe range, value(1)*
1.	MQ135 Gas Sensor	0-150	>150
2.	MQ2 Gas Sensor	0-500	>500
3.	Temperature	25-35	<24 or >35
4.	Humidity	60-100	<60 or >100

The sensor classification results demonstrate that the system can accurately distinguish between safe and unsafe indoor conditions using a simple threshold-based evaluation. This binary classification approach enables rapid and reliable decision-making, ensuring that the system activates ventilation or purification only when necessary, leading to efficient air- quality management.



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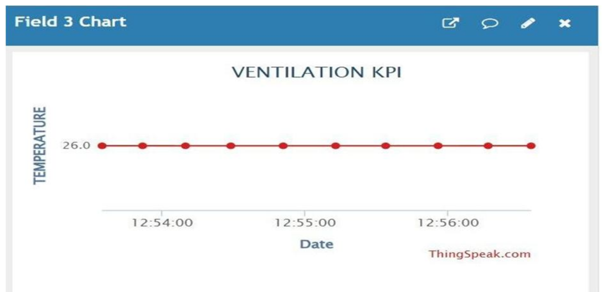

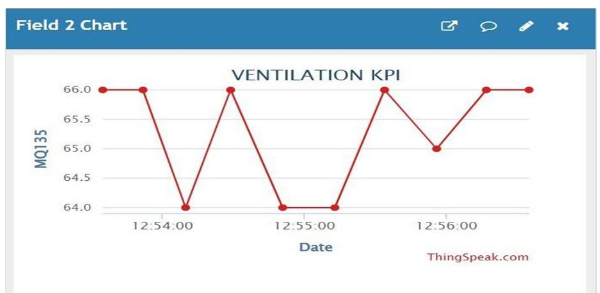

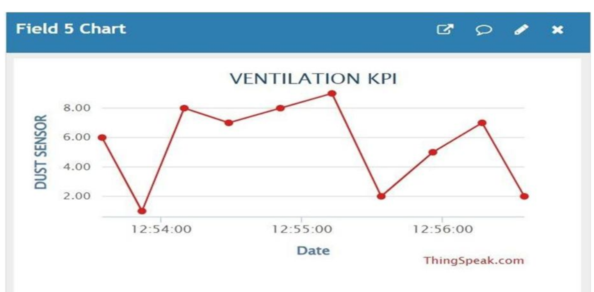

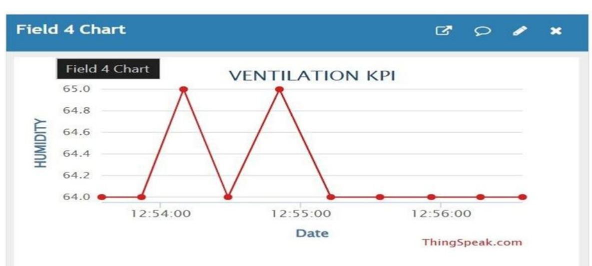

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In this work, a supervised machine-learning approach based on the Random Forest Classifier is employed to predict abnormal environmental conditions from multi-sensor data. The Random Forest algorithm is selected due to its ability to model complex and non-linear relationships between gas concentrations, temperature, humidity, and dust density, which traditional linear models cannot accurately capture. The model consists of an ensemble of decision trees, where each tree independently learns patterns from the input features, and the final prediction is obtained through majority voting or probability averaging. This ensemble structure significantly improves robustness against noise and sensor fluctuations, which are common in real-time embedded systems. The model outputs four probability scores corresponding to MQ2, MQ135, temperature, and humidity abnormality levels, enabling the system to perform reliable threshold-based decision making for ventilation control.

V. APPLICATIONS

1) Smart homes and buildings
2) Hospitals and laboratories
3) Industrial environments
4) Educational institutions

VI. CONCLUSION

The proposed framework offers a robust and intelligent solution for monitoring and optimizing ventilation performance by seamlessly integrating embedded IoT devices with AI- driven KPI analytics. Leveraging a network of environmental sensors, microcontroller-based processing, and advanced data analysis, the system provides continuous, real-time evaluation of indoor air quality and overall operational efficiency. This integration enhances the accuracy, adaptability, and responsiveness of ventilation control while simultaneously enabling energy optimization and predictive maintenance. By transforming conventional ventilation systems into dynamic, data-informed, and self-regulating infrastructures, the approach demonstrates significant potential to improve occupant health, operational reliability, and environmental sustainability. Overall, the system advances the development of smart building technologies and contributes to healthier and more resilient indoor environments.

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