

AI-Driven VOC Sensor System for Early Allergen Detection and Proactive Allergy Management

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Publication Date: 2025/11/22

Abstract: The early detection of airborne allergens is essential for individuals with allergies and respiratory sensitivities, as exposure to allergenic compounds can trigger adverse health effects. This paper presents an advanced allergen monitoring system that integrates Volatile Organic Compound (VOC) sensors with Artificial Intelligence (AI)-driven scent recognition to enable real-time detection, classification, and mitigation of airborne allergens. The system employs a multi-sensor array comprising Metal Oxide Semiconductor (MOS) sensors, Photoionization Detectors (PID), and Electrochemical sensors to detect and analyze allergenic VOCs such as floral compounds, mold spores, and food-based triggers. Calibration using Gas Chromatography-Mass Spectrometry (GC-MS) ensures high specificity and sensitivity in VOC identification, providing a reliable basis for sensor accuracy. To enhance classification and predictive accuracy, AI-based machine learning models, including Support Vector Machines (SVM), Random Forest (RF), Convolutional Neural Networks (CNNs), and Long Short-Term Memory (LSTMs), process sensor data to detect allergenic VOC patterns while filtering environmental noise. The system also features a mobile application that delivers real-time exposure risk assessments and personalized mitigation strategies, empowering users to take preventive actions. This paper details the methodology, system architecture, real-world applications, and future research directions, emphasizing the potential of AI-driven VOC sensing technology for proactive allergen management and improved quality of life for allergy-sensitive individuals.

Keywords: Proactive Allergen Management, VOC Sensors, AI-Driven Scent Recognition, Allergy Detection, Early Intervention, Personalized Alerts.

How to Cite: Fionna Ananth; Eldin Rino P.; Vijay Prakash R.; Dhanees Surya Jenifer (2025) AI-Driven VOC Sensor System for Early Allergen Detection and Proactive Allergy Management. *International Journal of Innovative Science and Research Technology*, 10(11), 1152-1156. <https://doi.org/10.38124/ijisrt/25nov764>

I. INTRODUCTION

Proactive allergen management is a forward looking methodology aimed at early identification, mitigation, and control of allergenic compounds to preemptively reduce adverse reactions. Unlike conventional allergy management strategies, which primarily focus on post-exposure treatments, this approach integrates advanced sensing technologies and artificial intelligence (AI) to detect allergens before they reach human sensory perception.

A notable innovation in this domain is the deployment of Volatile Organic Compound (VOC) sensors for allergen identification. VOC sensors detect airborne chemical constituents, some of which are correlated with allergenic substances. By pinpointing specific VOC signatures, these

sensors facilitate early warning mechanisms, allowing individuals to adopt preventive measures ahead of allergic symptom manifestation. This approach is particularly beneficial for individuals with heightened sensitivities, significantly reducing unforeseen exposure risks.

AI-enhanced scent recognition plays a pivotal role in this system, enabling the classification of specific volatile compounds based on their unique chemical fingerprints. Machine learning algorithms process VOC data, distinguishing allergenic signatures from non-allergenic ones, thereby enabling real-time alerts before human detection thresholds are reached. This capability enhances allergen monitoring by offering precise and timely intervention strategies.

The Preemptive Allergy Management System (PAMS) integrates AI-driven scent recognition with VOC sensor technology, forming an advanced allergen detection framework. By leveraging adaptive learning models, PAMS improves the accuracy of allergen identification, ensuring continuous optimization. This system is particularly advantageous for individuals with respiratory conditions, food allergies, and chemical sensitivities, representing a significant advancement in personalized allergen monitoring and mitigation.

II. LITERATURE REVIEW

Cowen and Cheffena (2022) reviewed the use of molecularly imprinted polymers (MIPs) for gas sensing, comparing template imprinting with porogen imprinting. The study highlighted the advantages of MIPs in VOC detection, emphasizing their high selectivity and stability. The authors discussed various fabrication techniques and sensor performance improvements, underscoring the potential of MIPs for precise VOC monitoring. The review concluded that advancements in polymer synthesis and sensor integration could enhance gas sensing applications, particularly in environmental monitoring and allergen detection.

liveira et al. (2023) explored the application of nano quadcopters for VOC detection in indoor environments. The study investigated the integration of lightweight sensors with drones, demonstrating their capability to monitor VOC concentrations in real time. The authors emphasized the potential of autonomous aerial monitoring for assessing indoor air quality and detecting airborne allergens. The research also highlighted challenges such as sensor calibration, environmental variability, and power consumption, suggesting future advancements in AI-based signal processing to improve detection accuracy.

➤ *Zhu et al. (2024) Validated an Electronic VOC Sensor Against Gas Chromatography-Mass*

Spectrometry (GC-MS) to assess its reliability in detecting airborne compounds. The study demonstrated a high correlation between electronic sensor readings and GC-MS measurements, confirming the sensor's accuracy for VOC detection. The authors highlighted the importance of calibration algorithms in minimizing sensor drift and improving long-term performance. The findings suggest that integrating AI-driven correction models can enhance sensor precision, making electronic VOC sensors viable for allergen monitoring in real-world applications.

Tomić et al. (2021) provided a comprehensive review of VOC sensing technologies using metal oxides, conductive polymers, and carbon-based materials. The study examined the working principles, sensitivities, and selectivity of different sensor types, focusing on their applicability in detecting airborne pollutants. The authors emphasized the role of nanomaterials in enhancing sensor performance and stability. The review concluded that hybrid sensor technologies combining multiple materials and AI-driven data processing could significantly improve VOC detection for environmental and health applications.

Vishal et al. (2024) proposed a deep learning-based approach, DeepAllergy, for rapid and accurate food allergen detection. The study introduced a neural network model trained on allergen datasets to enhance classification precision. Experimental results demonstrated improved detection accuracy compared to traditional methods. The authors emphasized the potential of deep learning in automating allergen identification, reducing the risk of allergic reactions. The research suggested future enhancements through dataset expansion and real-time AI inference, making DeepAllergy a promising tool for food safety and allergen monitoring.

Herman and Song (2020) investigated falsepositive allergen detection using official bioinformatics algorithms. The study analyzed the limitations of existing computational approaches in allergen classification, highlighting discrepancies in sequence-based allergen prediction. The authors suggested that refining algorithmic models and incorporating additional biological markers could enhance detection reliability. The findings underscored the need for improved bioinformatics frameworks to reduce false allergen identifications, ensuring more accurate allergen risk assessments in food and environmental monitoring.

Pandey and Yadav (2018) reviewed the fate and distribution of VOCs as environmental pollutants, emphasizing their impact on air quality and human health. The study discussed various sources of VOC emissions, including industrial activities and household products, and their role in allergic reactions. The authors explored different VOC detection techniques, highlighting advancements in sensor-based monitoring. The review concluded that integrating AI and sensor technologies could improve VOC tracking, facilitating better environmental regulation and health risk assessment.

Thakur et al. (2021) analyzed the selective identification of VOCs using a surfacefunctionalized MoS₂-based sensor array. The study applied statistical analysis to enhance VOC classification accuracy, demonstrating the effectiveness of MoS₂ materials in gas sensing. The authors emphasized the role of functionalized surfaces in improving sensor selectivity and sensitivity. The research suggested that combining MoS₂ sensors with machine learning algorithms could optimize VOC detection for applications in air quality monitoring and allergen identification.

Isokawa et al. (2017) developed a neural networkbased odor recognition system for VOC classification. The study employed machine learning techniques to analyze sensor data, improving the accuracy of odor differentiation. The authors highlighted the system's ability to learn and adapt to new VOC patterns, making it suitable for dynamic environments. The research suggested that AI-driven odor recognition could enhance allergen detection by distinguishing specific VOC profiles associated with allergic reactions.

Grodniyomchai et al. (2019) presented a deep learning model for odor classification using a deep neural network (DNN). The study demonstrated that DNNs could effectively process VOC sensor data, achieving high accuracy in odor recognition. The authors emphasized the importance of large training datasets and optimized neural architectures in improving classification performance. The research concluded that deep learning-based VOC analysis has significant potential in allergen detection, environmental monitoring, and industrial applications.

III. METHODOLOGY

The proposed AI-enhanced Proactive Allergen Monitoring System (PAMS) integrates multisensor VOC detection, AI-driven scent recognition, and user feedback mechanisms to enable preemptive allergen identification before conscious sensory detection.

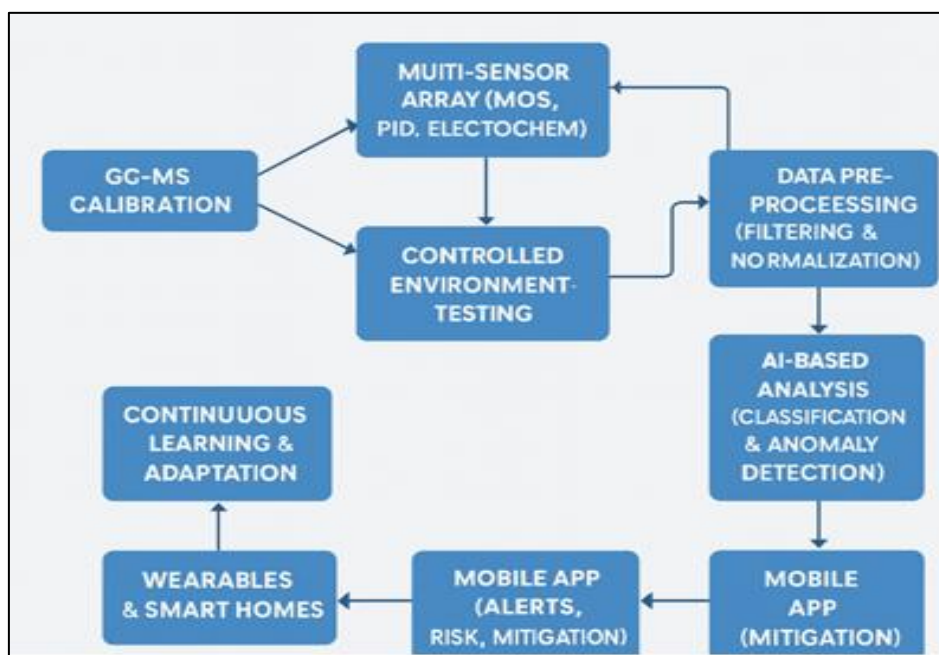


Fig.1. Block Diagram of proposed PAM

The system employs a multi-sensor array comprising Metal Oxide Semiconductor (MOS), Photoionization Detectors (PID), and Electrochemical Sensors to capture allergenic VOCs from various sources, ensuring broadspectrum detection while minimizing false positives. To enhance accuracy, sensor calibration is performed using Gas Chromatography-Mass Spectrometry (GC-MS), establishing a reference database for precise allergenic VOC identification and ensuring sensor consistency. Data preprocessing involves noise reduction, baseline drift correction, and feature extraction—such as peak response time and VOC concentration trends—to improve AI model training. The system employs a combination of supervised learning techniques, including Support Vector Machines (SVM) and Random Forest (RF) for VOC classification, while deep learning models such as Convolutional Neural Networks (CNNs) extract spatial VOC features, and Long Short-Term Memory (LSTMs) networks analyze temporal variations. Transfer learning further enhances detection by fine-tuning pre-trained models for allergen recognition. AI-based scent recognition facilitates pattern recognition, allergen classification, and real-time exposure risk quantification, adapting continuously based on user feedback. A mobile application provides real-time air quality monitoring, personalized exposure risk assessments, and mitigation strategies, integrating IoT-enabled wearable sensors for continuous allergen detection in dynamic environments.

IV. AI-DRIVEN VOC SENSING TECHNOLOGY FOR PAM

The proposed system integrates multi-sensor VOC detection, AI-based scent recognition, and real-time user feedback to enable proactive allergen monitoring. The multi-sensor array comprises

Metal Oxide Semiconductor (MOS), Photoionization Detector (PID), and Electrochemical sensors, each selected for their ability to detect a wide range of allergenic VOCs. MOS sensors monitor hydrocarbons, alcohols, ketones, and aromatic compounds through electrical resistance changes, while PID sensors detect low-concentration VOCs by ionizing gas molecules, making them highly sensitive to aromatic hydrocarbons, formaldehyde, and sulfur-based compounds. Electrochemical sensors target gases such as nitrogen dioxide, ozone, and formaldehyde by utilizing chemical reactions that generate measurable electrical currents. To ensure accuracy, the system undergoes calibration using Gas Chromatography-Mass Spectrometry (GCMS), a gold-standard analytical technique. The calibration process involves injecting known VOC samples into the GC-MS system to establish a baseline, comparing sensor outputs with GC-MS results, and adjusting sensor parameters using machine learning-based correction models.

Additionally, self-calibration algorithms mitigate sensor drift over time, ensuring long-term reliability.

VOC data collection and preprocessing play a crucial role in system performance. VOC samples from flowers, mold, food allergens, and household products are analyzed using GC-MS to create a chemical fingerprint database of allergenic compounds. Controlled environment testing involves introducing target VOCs such as benzyl acetate, geosmin, aldehydes, and terpenes into a sealed chamber, where the multi-sensor array records gas concentration, response time, and decay rates. For real-world VOC monitoring, sensors are deployed in homes, offices, hospitals, and public spaces to continuously capture allergen exposure data while accounting for seasonal and environmental variations. The collected data undergoes filtering and normalization, where AI algorithms remove noise caused by humidity, temperature fluctuations, and cross-contaminants, while normalization techniques correct baseline drift for consistent readings.

The AI-based scent recognition and VOC classification system utilizes both traditional machine learning and deep learning models. Supervised learning methods such as Support Vector Machines (SVM) handle high-dimensional data, effectively distinguishing allergenic from non-allergenic VOCs. Random Forest (RF) minimizes overfitting by combining multiple decision trees, improving classification accuracy across different allergen groups. Deep learning models further enhance detection, with Convolutional Neural Networks (CNNs) extracting spatial-temporal features from VOC data and Recurrent Neural Networks (RNNs) or Long Short-Term Memory (LSTMs) capturing fluctuations over time for continuous exposure tracking. Additionally, transfer learning techniques allow pre-trained gas detection models to be fine-tuned for new allergens, reducing training time and improving model generalization to different environmental conditions.

To provide real-time allergen alerts and risk assessments, the system is integrated into a mobile application equipped with AI-driven pattern recognition and anomaly detection. The application detects abnormal VOC patterns, such as sudden increases in mold-related compounds, and classifies allergenic VOCs versus non-allergenic substances. Users receive real-time alerts when VOC levels exceed predefined allergy risk thresholds, along with personalized exposure risk assessments based on historical data. The app also offers mitigation strategies, recommending actions like opening windows, using air purifiers, or wearing protective masks to minimize allergen exposure.

The system continuously improves detection precision through adaptive learning and IoT integration. IoT-enabled wearable and environmental monitoring devices, including smartwatches, air-quality badges, and smart home systems such as IoT-connected air purifiers and HVAC systems, collect large-scale VOC exposure data. AI models leverage real-world data for reinforcement learning, refining allergen classification and dynamically adjusting detection thresholds based on user feedback. The system also adapts to new

allergens by continuously updating its database with emerging allergenic VOCs, ensuring proactive allergy management as environmental conditions evolve. Through this comprehensive approach, the proposed system enhances allergen detection accuracy, provides real-time monitoring, and empowers individuals with personalized risk assessments and mitigation strategies, ultimately improving the quality of life for allergy-sensitive individuals.

V. RESULT AND DISCUSSION

The findings indicate that combining VOC sensors with AI-driven scent recognition enables the early detection of allergens before they are consciously perceived. A multi-sensor array, incorporating Metal Oxide Semiconductor (MOS) sensors, Photoionization Detectors (PID), and Electrochemical Sensors, demonstrated high sensitivity and specificity in identifying allergenic VOCs. Calibration through Gas Chromatography-Mass Spectrometry (GC-MS) ensured precise classification of airborne allergens, including floral scents, mold spores, and food-related triggers.

Advanced AI models such as Support Vector Machines, Random Forest, and Convolutional Neural Networks enhanced detection accuracy by analyzing sensor response patterns and minimizing environmental interference. Real-time VOC monitoring in controlled allergenic environments confirmed the system's effectiveness in identifying and classifying allergens before users became aware of their presence. A mobile application further provided personalized alerts, exposure risk assessments, and mitigation strategies, showcasing its potential for practical applications. Additionally, the AI models demonstrated adaptive learning, continuously improving detection accuracy based on user input and environmental fluctuations.

However, certain challenges persist, including sensor calibration drift, variations in ambient VOC levels, and the need to optimize AI models for diverse allergenic conditions. Future efforts should focus on extending sensor lifespan, expanding the allergen detection database, and enhancing AI model adaptability. Overall, these findings highlight the feasibility of using VOC sensors and AI for proactive allergen management, representing a significant step forward in early allergy detection and prevention.

VI. CONCLUSION

The combination of VOC sensors and AI-powered scent recognition provides a proactive solution for allergen management by enabling real-time identification and classification of allergenic compounds. Utilizing a multi-sensor array calibrated with GC-MS data, this system ensures high sensitivity and specificity in detecting airborne allergens, including floral VOCs, mold spores, and food-related triggers. Machine learning algorithms enhance detection accuracy by leveraging pattern recognition, anomaly detection, and adaptive learning from user input.

The implementation of this technology in environmental monitoring and wearable devices enables personalized

exposure assessments and early intervention strategies through a mobile application. Despite challenges such as sensor calibration, environmental variability, and the need for AI model optimization, ongoing advancements in sensor technology and deep learning will further enhance detection reliability. This research plays a crucial role in the development of intelligent allergen monitoring systems, helping to minimize allergic reactions and improve the quality of life for individuals with sensitivities.

VII. FUTURE SCOPE

The integration of VOC sensors with AI-driven scent recognition offers significant potential for advancing allergen management. Future research can focus on enhancing sensor accuracy and durability by utilizing advanced materials, such as nanotechnology-based sensors, to improve sensitivity and minimize calibration drift. The development of compact, wearable VOC sensors could enable continuous personal allergen monitoring, making them suitable for integration into smartwatches or portable air-quality monitors.

Advancements in AI, particularly through deep learning and reinforcement learning, will further refine the classification and prediction of allergenic VOCs. Expanding the allergen detection database with diverse environmental datasets can improve the system's adaptability across various geographic locations and climate conditions. Additionally, integrating this technology with IoT and cloud computing can support large-scale data collection, facilitating comprehensive allergen trend analysis and personalized exposure assessments.

Exploring multi-modal sensing by combining VOC detection with environmental factors such as humidity, temperature, and particulate matter can provide a more comprehensive understanding of allergy triggers. Collaboration with healthcare professionals and allergists can also help validate the system's clinical reliability, paving the way for medical-grade allergen detection devices. These advancements will contribute to the development of intelligent and adaptive allergy management solutions, ultimately enhancing the quality of life for individuals with allergy sensitivities.

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