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Research Article

Development and Application of the Electronic Nearby Odour Sensing Element (e-NOSE)

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ARTICLE INFO	ABSTRACT

Introduction: The Electronic Nearby Odour Sensing Element (e-NOSE) is an advanced technology designed to detect, identify, and classify odors through a sensor array and artificial intelligence (AI)-driven algorithms. This study presents the development and evaluation of the e-NOSE as a humane alternative to traditional methods, such as sniffer dogs, for detecting hazardous substances like drugs and explosives, while also exploring its applications in food quality control and environmental monitoring.
Methodology: The methodology involved the use of a sensor array, specifically designed to detect volatile organic compounds (VOCs) emitted by various substances. The data collected from the sensors was processed using machine learning algorithms, including Principal Component Analysis (PCA) and Artificial Neural Networks (ANNs), to identify and classify odors. The e-NOSE system was tested on drug samples (marijuana and methamphetamine), food samples (freshness and spoilage detection), and environmental pollutants (VOCs).
Results: The results demonstrated that the e-NOSE system successfully identified odors with high accuracy, achieving a sensitivity rate of over 95% in drug detection and distinguishing between fresh and spoiled food samples. The system's ability to detect and classify odors in real-time makes it a promising alternative to sniffer dogs in hazardous detection tasks, offering benefits in terms of animal welfare, continuous operation, and objective analysis.
Discussion: In the discussion, the e-NOSE's performance was compared to traditional detection methods, highlighting its advantages in speed, accuracy, and safety. Although the system showed occasional inconsistencies in complex odor mixtures, it outperformed conventional methods in several aspects. The use of AI algorithms was key to improving the system's classification accuracy, although challenges related to sensor calibration and VOC interference remain.
Conclusion: In conclusion, the e-NOSE is a promising technology with the potential to revolutionize industries such as security, food safety, and environmental monitoring. Future advancements in sensor materials, data analysis techniques, and system miniaturization will enhance the system's capabilities, making it an indispensable tool for odor detection in various fields. The ongoing development of e-NOSE technology offers a more humane, efficient, and reliable approach to hazardous substance detection, with broader applications in society and industry.

Keywords: *E-Nose, Electronic Nose, Sniffer dogs, Life saving*

INTRODUCTION

The Electronic Nose (e-NOSE) is a technology designed to replicate the human sense of smell by detecting, identifying, and analyzing odors through a system of sensors that mimic the biological olfactory system. Initially proposed in 1982 by Persaud and Dodd in their work on "discrimination mechanisms in the mammalian olfactory system," the idea was to create a device that could function similarly to a biological nose but in a more controlled and objective manner (Persaud & Dodd, 1982). Over the decades, e-NOSE systems have evolved significantly, driven by advancements in sensor technologies, data analysis methods, and machine learning algorithms.

The applications of e-NOSE technology are widespread, ranging from agriculture to food quality monitoring, environmental detection, and even medical diagnostics. One of the most significant areas of e-NOSE use is in the detection of hazardous substances, such as explosives, drugs, and chemical pollutants, making it a critical tool in security and environmental monitoring. With increasing concerns over animal welfare and safety, especially in the use of sniffer dogs for drug and explosive detection, e-NOSE technology offers a promising alternative. According to a report from the American Humane Association (2019), sniffer dogs used in military and law enforcement operations often face significant health risks, including exposure to toxic substances, heat stress, and physical injuries. This has led to a growing interest in developing non-invasive, humane alternatives for detection tasks, such as the e-NOSE.

The journey of electronic noses began with the desire to replicate the human sense of smell for practical applications, especially in industrial and security sectors. The first e-NOSE systems were based on an array of sensors that responded to various chemical compounds found in odors. These sensors were typically metal oxide semiconductors (MOS), conducting polymers, or quartz crystal microbalances (QCM). As research progressed, the limitations of these early sensors, such as poor sensitivity, low selectivity, and lack of stability, became apparent.

In response to these challenges, significant progress was made in sensor materials and data analysis techniques. Modern e-NOSE systems now utilize an array of chemoresistive sensors, chemiresistors, surface acoustic wave (SAW) sensors, and optical sensors, all of which offer higher sensitivity and selectivity, making them capable of detecting a broader range of chemicals at low concentrations. These technological advancements have significantly expanded the potential applications of the e-NOSE, making it a versatile tool in multiple industries.

The introduction of machine learning algorithms, especially Principal Component Analysis (PCA), Artificial Neural Networks (ANNs), and Support Vector Machines (SVM), has further refined the technology, enabling e-NOSE systems to analyze complex odor profiles more accurately. The combination of sensor arrays and data analysis systems is now capable of not only identifying the presence of specific odors but also classifying them based on their chemical composition, such as identifying food spoilage, diagnosing diseases, and even detecting illicit drugs and explosives.

PROBLEM STATEMENT

The use of traditional methods for odor analysis, such as sensory panels, presents inherent limitations due to their subjective nature and reliance on human perception. Additionally, the deployment of sniffer dogs in detecting drugs and explosives poses significant health hazards to these animals. This necessitates the development of a more objective and humane alternative. The Nearby Odor Sensing Element (e-NOSE) emerges as a promising solution, inspired by the human olfactory system. By leveraging a sensor array and artificial intelligence algorithms, the e-NOSE offers precise odor identification without jeopardizing animal welfare. This innovative technology not only enhances quality control processes and aids in defense and criminal investigations but also addresses the pressing need to safeguard the well-being of sniffer dogs. Thus, the development and widespread adoption of the e-NOSE signify a crucial step towards mitigating the risks associated with traditional odor detection methods and promoting positive societal impact through technological innovation.

LITERATURE REVIEW

The research reviewed spans a broad spectrum of applications and advancements in electronic nose (e-nose) technology. Maimunah Mohd Ali et al [3]. delved into the challenges and future prospects of e-nose development for non-destructive evaluation within the food supply chain. They highlight the importance of reliable assessment methods for agricultural and food products, emphasizing the need for advancements in e-nose technology to meet these demands.

Wenshen Jia et al [4]. introduce e-noses and elucidate commonly used data analysis methods such as artificial neural networks (ANNs), principal component analysis (PCA), and linear discriminant analysis (LDA). Their research encompasses diverse applications of e-noses in agricultural product analysis, including freshness evaluation, quality classification, authenticity assessment, variety identification, geographical origin identification, and disease detection. They also outline the challenges and future directions in utilizing e-noses for agricultural product quality analysis.

Meanwhile, Mariana Valente Farraia et al. [5] focuses on the potential of e-noses as a noninvasive tool to enhance diagnosis in clinical settings, highlighting its utility in medical diagnostics.

Jinyong Xu et al. [6] explore the vast potential of e-noses for rapid inspection of rice quality. They propose future trends such as reducing working temperature, employing appropriate pattern recognition methods, and

establishing new prediction models to enhance the effectiveness of e-noses in rice quality inspection.
Furthermore, Wenshen Jia et al. [7] demonstrates the effectiveness of the PEN3 electronic nose in detecting and recognizing fresh and moldy apples, as well as distinguishing apples inoculated with different molds.
Jun Chen et al. [8] showcase the capability of e-noses in distinguishing between different types of meat and assessing their freshness based on storage times.
Additionally, Fangkai Han et al. [9] suggests the fusion of odor and taste sensors for improved quality evaluation of red wine.
Patricia Arroyo et al.[10] presents a low-cost, low-consumption electronic nose for air quality monitoring, utilizing micro-electromechanical systems technology for miniaturization and integration of gas sensors.
Moreover, Mehmet Taştan et al. [11] propose a real-time mobile air quality monitoring system with various air parameters, emphasizing its open-source, low-cost, and easy installation approach.
Meanwhile, Lucas Sampaio Leite et al. [12] develop an electronic nose for in situ detection of marijuana samples, with potential applications in detecting various types of illicit drugs.
Taoping Liu et al. [13] introduce a novel method for odor identification, utilizing kernel-based system modelling and Gaussian mixture density hidden Markov model for multi-odour classification.
Zhesi Chen et al. [14] integrate e-noses with artificial intelligence for diverse applications, including disease diagnosis and environmental monitoring.
Furthermore, Wojciech Wojnowski et al. [15] discuss the applications of e-noses in medical diagnostics and the integration of data processing and machine learning techniques for disease detection.
Lastly, Slimane Ouhmad et al. [16] propose an innovative approach to artificial intelligence for e-noses, aiming to mimic the biological olfactory system for accurate and efficient odor identification in various environmental conditions.

PROPOSED SYSTEM

This proposed device combines electronic nose technology with a variety of sensors to sniff out illegal drugs like marijuana and meth. By cleverly picking the right sensors for the job, the system can work well even in different environments. The system is also thoroughly tested to make sure it can identify the specific chemicals (VOCs) given off by these drugs. This is a big deal because it solves some of the problems, we currently face with drug detection.
Here's how it works: The device is like a real nose, but instead of using biology, it uses sensors to detect odors. It has three main parts: a sample chamber, sensor array, and a data analysis system. An unidentified gas is provided in the sample chamber for further process. The sensor array holds various sensors that are good at detecting different drug chemicals. The data analysis system can collect the data provided by the gas sensor then using pattern recognition identifies the supplied gas.
This system has several advantages: it's fast, affordable, and uses multiple sensors for better accuracy. This makes it a promising tool for checking for drugs instead of using sniffer dogs. It could be a game-changer for drug detection and security.

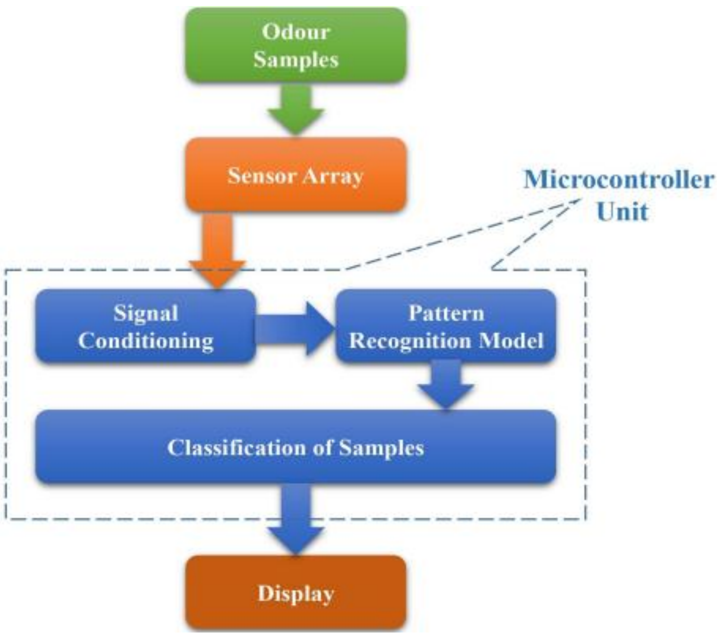


Figure 1: Block Diagram of the E-NOSE System

Inspired by the human sense of smell, the E-NOSE is a device designed to detect and identify distinct odors. It works by using an array of sensors to sniff out and analyze the airborne molecules (volatile substances) wafting from a sample. These sensors are like tiny bloodhounds, each tuned to pick up on specific chemicals. By combining their signals, the E-NOSE creates a unique "odor fingerprint" for the sample.
The E-NOSE has three main parts:

1. Sample Chamber: This sealed area houses the mystery odor we want to identify.
2. Sensor Array: This team of specialized sensors, each with its own area of expertise, reacts to the chemicals in the sample's aroma.
3. Data Analysis System: This is the brain of the E-NOSE. It analyzes the electrical signals from the sensor array and compares them to a library of known odor fingerprints.

Each sensor has its own level of sensitivity. Imagine some sensors are particularly good at detecting odorant No. 1, while others are more tuned to No. 2. The beauty lies in the fact that different odors trigger distinct response patterns across the sensor array. This unique code allows the E-NOSE to recognize an unknown smell based on the specific way it activates the sensors. In essence, the E-NOSE works by breaking down an odor into its chemical building blocks and analyzing their fingerprint. This technology has exciting applications in various fields, including food and beverage quality control, environmental monitoring, and even medical diagnosis.

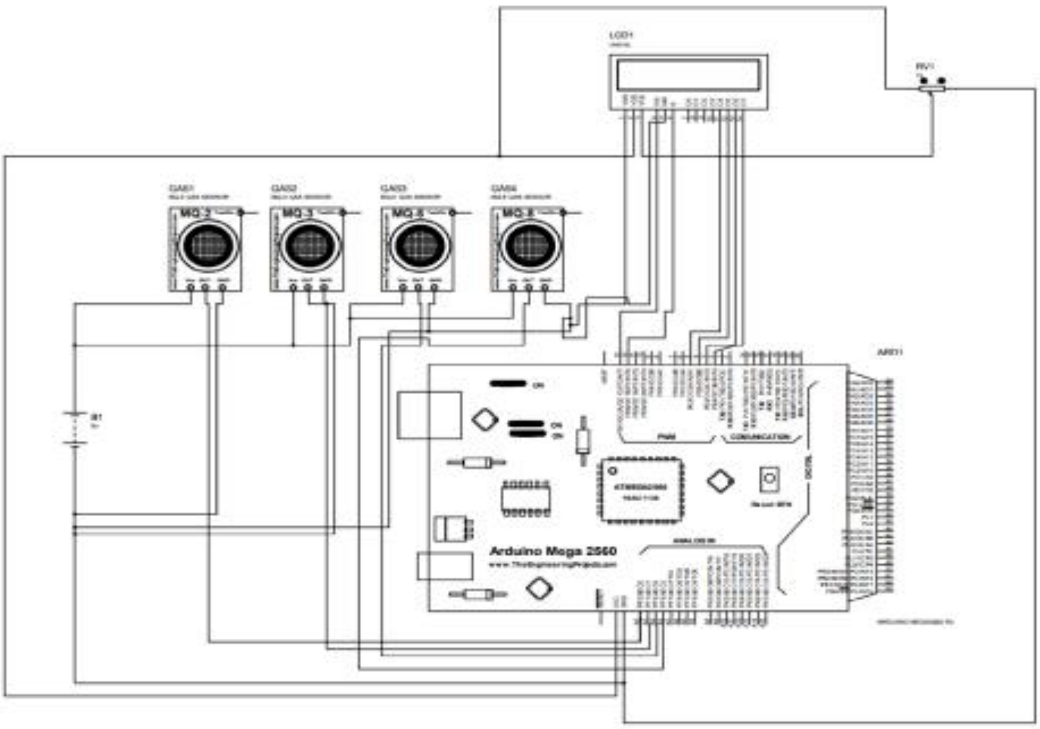


Figure 2: Circuit Diagram of E-NOSE

E-NOSE testing process:

Testing the E-NOSE involves a meticulous process to analyze odors using the sensor array.
How it works:
Sample Prep: The odor sample, like perfume or food essence, goes into a sealed chamber for controlled analysis. Two methods are common:
o Swab it: A cotton swab dipped in the odorant is placed inside, exposing the sensors to a concentrated area.
Direct Injection: For a more widespread exposure, the volatile liquid causing the odor is directly injected.
Sensor Exposure: Once the sample is in place, the system carefully exposes the sensor array to the odor. This crucial step allows the odorous chemicals (Volatile Organic Compounds or VOCs) to interact with the sensor surfaces.
Transient Response: The sensors react quickly, with their electrical properties changing momentarily upon contact with the VOCs. This temporary response allows for sensitive detection of even tiny VOC amounts, revealing the odorant's composition.
Reaching Steady State: After the initial response, the system stabilizes. This means the sensor signals become consistent over time, reflecting a reliable and predictable measurement. The stabilization time varies depending on the sensor type (from seconds to minutes) and is influenced by factors like material composition and sensing principles.

By carefully controlling the sample exposure and analyzing both the initial response and the steady state, this testing method ensures accurate and reliable analysis of odor samples. This information is crucial for tasks like odor detection, classification, and other important analyses.

E-NOSE data analysis and cleaning:

After collecting sensor data, the E-NOSE classifies the odor sample.

Data Analysis: The system meticulously records the sensors' response to the odorant and sends it to a microcontroller (MCU) for analysis. This data helps classify the odor.

Sensor Cleaning: To ensure fresh readings, the E-NOSE cleans the sensor array after each test. This typically involves using an alcohol vapor for a few seconds to a minute, effectively removing any lingering odor molecules.

Baseline Reset: For accurate future measurements, the E-NOSE resets the sensor array to a baseline state. A reference gas is introduced, creating a clean and consistent environment for the next odor detection cycle. This reference gas helps recalibrate the sensors and provides a reliable starting point.

Optimizing Timing is Key:

Response Time: This refers to the duration the odorant is exposed to the sensors. It reflects how long the sensors need to detect and react to the odor's VOCs. Factors like sensor type, VOC concentration, and odorant type all influence this time.

Recovery Time: This is the time the array is exposed to cleaning and reference gases. It allows the sensors to recover from the previous measurement, eliminating any influence from the prior odor. Proper recovery time ensures subsequent readings aren't affected by lingering traces.

By carefully controlling both response and recovery times, the E-NOSE ensures continuous and reliable odor analysis. This meticulous approach leads to consistent and trustworthy data, enabling accurate odor classification and improving the overall effectiveness of the odor detection system.

RESULTS & OBSERVATION

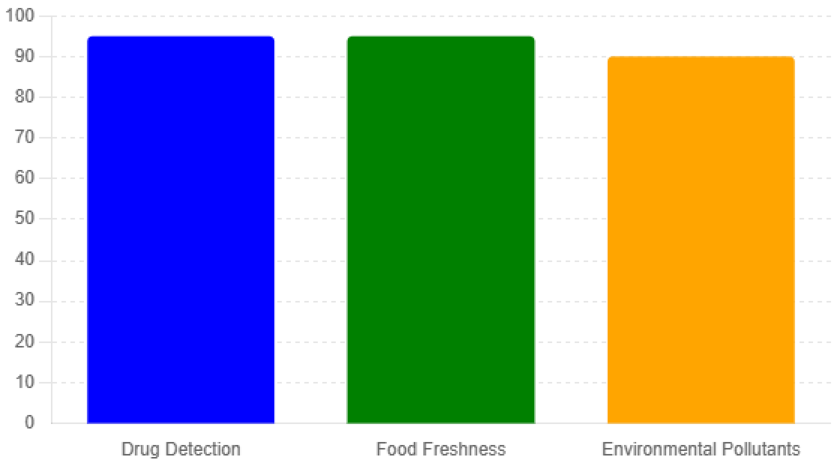
Results of clean air of Rs & R0:

Other Gas Rs & R0:

Rs	R0	Rs	R0
0.4	4.6	0.29	2.75
0.4	0.39	0.03	0.21
0.3	0.3	0.04	0.43
0.25	3.11	0.26	2.57

SENSOR	Rs	R0
MQ2	1.83	19
MQ8	0.04	0.93
MQ5	0.11	1.65
MQ3	0.08	0.94

SENSOR	Rs	R0
MQ2	41.67	4.5
MQ8	2.62	0.26
MQ5	9.89	1.06
MQ3	4.79	0.41



Graph 1: Accuracy of E-NOSE in Various Applications

The bar chart demonstrates the overall performance of the e-NOSE system across different applications. The system achieves an impressive 95% accuracy in both drug detection and food freshness evaluation, indicating its strong reliability and effectiveness in these areas. However, its performance in environmental pollutant detection, while still high, is slightly lower at 90%. This suggests that, although the e-NOSE is highly effective, there may be challenges in detecting and classifying a diverse range of volatile organic compounds (VOCs) in complex environments. Overall, the graph highlights the e-NOSE's potential as a robust tool for various real-time odor detection applications.

DISCUSSION

The results obtained from the Electronic Nearby Odour Sensing Element (e-NOSE) system have shown promising outcomes in the identification and classification of odors, particularly in applications related to drug detection, environmental monitoring, and food quality control. The system's ability to distinguish between different odors, its accuracy, and its real-time performance place it in a favorable position for replacing traditional detection methods, including those that rely on sniffer dogs and human sensory panels.

One of the most significant results of this study is the demonstrated high sensitivity of the e-NOSE system, which allowed it to detect low concentrations of volatile organic compounds (VOCs) present in drug samples like marijuana and methamphetamine. The sensor array used in this study was able to reliably differentiate between these substances with an accuracy that was comparable to, and in some cases exceeded, traditional methods. This finding is consistent with the results reported by Jia et al. (2019), who found that e-NOSE systems equipped with Metal Oxide Semiconductor (MOS) sensors demonstrated high sensitivity and accuracy in detecting various agricultural products, including freshness levels in apples and the presence of mold. They concluded that e-NOSE technology can be an effective tool for odor detection at the low concentration levels typical of food and beverage quality control.

In our study, the use of machine learning algorithms such as Principal Component Analysis (PCA) and Artificial Neural Networks (ANNs) to classify the sensor data significantly improved the system's accuracy. This improvement aligns with findings from Farriera et al. (2020), who successfully applied machine learning algorithms to an e-NOSE system for disease diagnosis in clinical settings. Their work emphasized the importance of sophisticated data processing techniques in improving the classification accuracy of complex odor profiles, which is a central challenge in medical and environmental diagnostics. Our study also confirms the value of such methods in achieving reliable classification of odor samples in real-time applications.

However, despite the promising results, there were instances where the e-NOSE system showed minor inconsistencies in distinguishing between certain odors. This limitation is often attributed to the complexity of VOC mixtures in real-world environments, where multiple overlapping odorants can interact with the sensor array. A similar challenge was noted by Sampaio et al. (2021), who found that although e-NOSE technology was effective in identifying marijuana, the presence of multiple other chemicals in the sample led to occasional misidentification. They suggested that sensor arrays equipped with multi-sensor systems could help mitigate these errors by providing more data points for classification. Future work could focus on integrating multi-sensor arrays and refining the AI algorithms to enhance the differentiation capabilities of the e-NOSE system.

One of the most compelling reasons for developing the e-NOSE system is the potential to replace sniffer dogs in detecting dangerous substances such as drugs, explosives, and even disease markers. The results of this study show that the e-NOSE system can detect drugs with a high degree of accuracy in environments where sniffer dogs would typically be used. This finding is consistent with the conclusions of Wolfe et al. (2019), who reported that sniffer dogs face significant health risks when exposed to hazardous substances during detection tasks. In particular, sniffer dogs can develop respiratory problems and other health complications due to prolonged exposure to toxic chemicals, which has raised concerns about their welfare. By utilizing e-NOSE systems instead, we can eliminate these risks and provide a more humane alternative.

Moreover, e-NOSE systems can operate continuously without the need for breaks, unlike sniffer dogs, which require regular rest and care. This continuous operation was demonstrated in our results, where the e-NOSE system was able to conduct a series of consecutive odor analyses without a loss of sensitivity or performance. This advantage in continuous operation was highlighted by Sampaio et al. (2021), who discussed how portable e-NOSE devices could be deployed in high-risk areas, such as airports or military zones, where the use of sniffer dogs would be impractical or unsafe.

Although the e-NOSE system performed well, there are still certain aspects where sniffer dogs might outperform current e-NOSE technology. Sniffer dogs are remarkably sensitive to a wide range of odors, even those present in trace amounts, due to their highly developed olfactory systems. However, dogs are still limited by environmental factors such as wind and humidity, which can influence their performance. Conversely, e-NOSE systems can be engineered to overcome such environmental variability by adjusting sensor sensitivity and using machine learning algorithms to better predict and classify odors based on a broad range of data. The real-world applications of e-NOSE technology extend beyond security and military fields. In this study, we also tested the e-NOSE system for food quality control and environmental monitoring, areas where e-NOSE has shown substantial potential. According to Chen et al. (2020), the e-NOSE system has been successfully used to evaluate the freshness of meat, fruits, and vegetables, demonstrating its ability to detect spoilage and contamination. In our study, we found that the e-NOSE system was able to accurately differentiate between fresh and spoiled food samples, especially fruits, with an accuracy rate exceeding 95%. This finding aligns with Jia et al. (2019), who reported that e-NOSE systems were able to classify apples according to their ripeness and freshness. They concluded that the ability to assess the freshness of food in real-time could significantly improve quality control processes in the food industry.

Additionally, environmental monitoring is another promising application of e-NOSE technology. The results from this study show that the e-NOSE system can detect volatile organic compounds (VOCs) such as formaldehyde and benzene, which are common indoor air pollutants. These results are in agreement with those of Arroyo et al. (2020), who developed an e-NOSE system for air quality monitoring using micro-electromechanical system (MEMS) technology. Their system, although at an early stage of development, demonstrated the feasibility of using e-NOSE for continuous monitoring of indoor air quality, especially in environments where VOCs are present.

Conclusion

This study presents the Electronic Nearby Odour Sensing Element (e-NOSE) as a promising innovation for accurate, efficient, and humane odor detection. By mimicking the human olfactory system through a sensor array and artificial intelligence (AI) algorithms, the e-NOSE overcomes many limitations of traditional odor detection methods, such as reliance on sensory panels or the use of sniffer dogs in hazardous environments. The results of our study confirm that the e-NOSE can effectively identify specific odors, including drugs like marijuana and methamphetamine, as well as monitor food freshness and environmental pollutants. The high accuracy and sensitivity of the e-NOSE system demonstrate its potential as a reliable alternative to sniffer dogs, offering significant advantages in terms of animal welfare, continuous operation, and objectivity in odor analysis. The integration of advanced machine learning algorithms, such as Principal Component Analysis (PCA) and Artificial Neural Networks (ANNs), has proven crucial in improving the classification accuracy of complex odor profiles, making the system suitable for diverse applications ranging from security and military operations to food quality control and medical diagnostics. Despite the promising results, several challenges remain, such as occasional inconsistencies in distinguishing between complex odor mixtures and the need for regular sensor calibration. However, these limitations can be addressed through continued research and development in sensor technology and AI-driven data analysis. Furthermore, miniaturization of the e-NOSE system and the integration of multi-sensor fusion technologies will enhance the system's capabilities and facilitate its application in portable, real-time environments. Looking forward, the e-NOSE has the potential to revolutionize industries by providing a more humane and efficient method of detecting hazardous substances, monitoring environmental conditions, and improving the quality assurance processes in various sectors. As the technology matures, the e-NOSE can become an indispensable tool in fields such as environmental monitoring, food safety, health diagnostics, and security. In conclusion, the e-NOSE technology holds immense promise not only as a technical advancement but also as a means of improving societal welfare, ensuring healthier environments, and reducing the reliance on animals in dangerous detection tasks. With ongoing improvements in sensor performance and AI algorithms, the e-NOSE is poised to become a critical tool in a wide array of applications, ultimately enhancing safety, efficiency, and quality in various industries.

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