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Future Potential of E-Nose Technology: A Review

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ABSTRACT

Electronic Nose (E-Nose) technology unlocks the fascinating world of electronic detection, identification, and analysis of scents and odors, paving the way for innovative research and promising applications. E-Nose mimics the human sense of smell and has gained significant attention and is applied in various fields, including the food, health and drug industries, safety and crime, and the environmental and agricultural sectors. This technology has the potential to improve quality control, medical diagnostics, and hazardous material detection processes. The E-Nose consists of a combination of gas sensors that mimic the olfactory receptors of the human nose. These sensors detect and respond to different scent molecules, resulting in unique response patterns that can be interpreted and analyzed. E-Nose has found application in the food industry to assess food quality, detect contamination, and monitor fermentation processes. In the health field, it has been used for disease diagnosis, monitoring patient health, and detecting cancerous tissue. In addition, E-Nose has been used for security purposes, such as detection of explosives and prohibited substances, as well as identification of counterfeit products. In addition, it has been used in environmental monitoring for air quality assessment and agriculture for disease detection in crops. Despite its promising potential, widespread adoption of E-Nose faces challenges related to sensor sensitivity, data analysis algorithms (complex data interpretation), response diversity, regulatory considerations, implementation complexity, and cost. This article reviews the latest developments in E-Nose technology, explores its applications and future potential, and highlights challenges that need to be addressed. This is considered important because E-Nose opens up a world of electronic scent identification and analysis with the potential to improve quality control, diagnosis, and detection.

1. Introduction

Electronic Nose (E-Nose) technology provides revolutionary capabilities in detecting, identifying and analyzing odors electronically, overcoming the limitations of traditional methods and opening up great opportunities in various fields [1], [2]. E-Nose can improve accuracy, efficiency, and reliability in food industry quality control, disease diagnosis in the health sector, detection of hazardous materials in safety, air quality evaluation in environmental monitoring, and disease detection in crops in agriculture. This makes E-nose one of the interesting and promising innovations in technology research today. The e-nose is designed to mimic the biological sense of smell and has been a challenge in the development of applied technologies in various fields of life sciences [3]. The E-Nose is formed from a combination of gas sensors that mimic the human nose [4]. In the natural world, the sense of smell plays an important role in the recognition and assessment of scents and smells. Humans and animals have the ability to recognize a variety of scents, ranging from pleasant to harmful. In addition, scents and smells can also provide information about the state of food [5], air quality, or even health conditions. The reproduction of this ability in the form of the E-Nose has been the focus of intensive research.

Based on its promising capabilities, E-Nose plays an important role in various fields, including the food industry [4]–[6], health [7], safety, and the environment [8]–[10]. With its ability to detect and distinguish various odors quickly and accurately, E-Nose has great potential to improve quality control, medical diagnosis, and hazardous material detection processes. Along with the advancement of sensors, computing, and artificial intelligence technology, the E-Nose has experienced rapid development in recent decades. More sensitive sensors, more sophisticated sensing devices, and more complex data analysis algorithms have been developed to improve E-Nose performance and applications. Through the integration of this technology, E-Nose is able to provide a fast, consistent, and reliable response to various smells and odors that exist.

In the food industry, E-Nose can be used to detect the quality, freshness, and acidity of food. E-Nose also helps in identifying contamination or damage to products, as well as monitoring fermentation or maturation processes. In the health sector, E-Nose can be used to diagnose diseases through analysis of breath or urine odor, as well as detect changes in body odor associated with certain health conditions. In the context of safety, E-Nose can assist in the detection of explosives, hazardous chemicals, or toxic gases quickly and accurately. In addition, E-Nose also has potential in the environmental and agricultural fields. This technology can be used for air quality monitoring, soil quality control, and pest and disease detection in plants. In the perfume and cosmetic industry, E-Nose can assist in the analysis and formulation of desired scents. Despite its promising potential, the widespread implementation of E-Nose is still faced with challenges that need to be overcome. Some of the challenges include increased sensitivity and selectivity of sensors, development of better data analysis algorithms, and regulatory and privacy aspects related to the use of E-Nose.

In terms of sensor sensitivity and selectivity, it is necessary to develop more sensitive sensors to detect scents in low concentrations and increase selectivity to distinguish similar scents. The challenges in data analysis algorithms involve developing algorithms that can interpret sensor response patterns with high accuracy, distinguish different scents, and overcome complex variations in sensor response. Meanwhile, regulatory and privacy aspects are important in regulating the use and protection of data generated by E-Nose, as well as ensuring that the information collected is not misused or accessed without permission. Addressing these challenges, further development will play an important role in driving widespread adoption of E-Nose technology and ensuring its success in various future applications.

Many studies have focused on the uses and potential applications of E-Nose in various fields. In that context, this article aims to review the latest developments in E-Nose technology and explore the potential and challenges of future applications. This is very important because the E-Nose has a significant contribution potential in improving quality control, diagnostics, and electronic odor detection. Through a better understanding of its potential and associated challenges, it is expected that E-Nose can be widely and effectively applied in various fields, making a significant contribution to quality control, medical diagnostics, and hazardous material detection in the future.

2. Working Principle of E-Nose

The E-Nose is designed to mimic the olfactory function of humans, which involves scent recognition as a complex global fingerprint. The instrument consists of several main components, namely a sensor array, a reorganization pattern module, and a headspace sampling system that work synergistically to produce signal patterns used to characterize odors. The headspace sampling system is responsible for forming the air space around the sample or volatile compound to be analyzed. This air chamber is then sent to an E-Nose detection system for further processing.

Basically, the human nose has receptors that can recognize and distinguish various scents. In the E-Nose, the receptor is replaced by a sensor consisting of several sets of gas sensors with different selectivity. Sensors that are often used in the development of E-Nose such as Metal oxide semiconductor (MOSFET) [11]–[13], Quartz Crystal Microbalance (QCM) [14]–[16], Metal Oxide Sensors (MOS) [17]–[19], Piezoelectric Sensors (PS) [20]–[22], and Conducting Polymers (CP) [23]–[25]. MOSFET are common sensors in E-Nose technology with high sensitivity and the ability to detect various aromatic compounds, although they are susceptible to environmental factors and require precise calibration. QCM has a fast response and high detection rate but cannot distinguish similar scents. PS has high sensitivity but is prone to interference, and it is difficult to distinguish similar scents. CP has a fast response and high sensitivity, but low stability and sensitivity can decrease over time. When the sensor interacts with volatile compounds, there is a change in the electrical characteristics of the sensor. In most E-noses, each sensor responds to various molecules in a specific way. However, there is also a type of E-Nose that uses receptor proteins that are specific to certain scent molecules, similar to receptors in the human nose. Each time the E-Nose sensor detects a scent, a specific response is recorded, and the electronic signal is converted into a digital value for further processing. This process involves a pattern reorganization module tasked with interpreting sensor response patterns and producing a more detailed characterization of the detected aroma [26]. An analogy of the working principle of the olfactory human system and E-Nose is shown in Fig. 1.

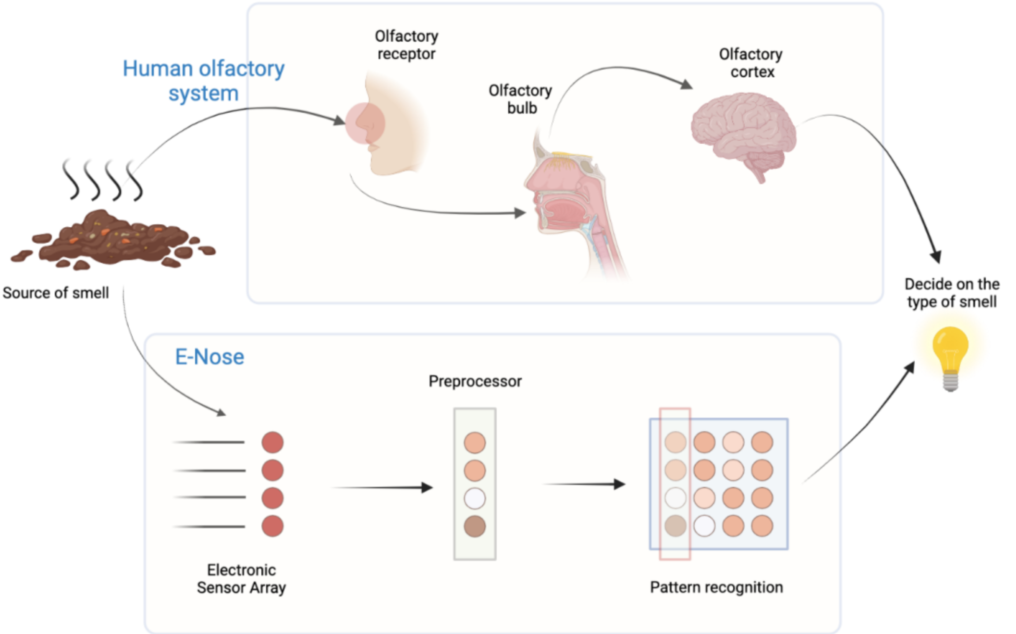

Fig. 1. An analogy of the working principle of the olfactory human system and E-Nose

The data processing and pattern recognition stages of E-Nose technology involve the use of various special techniques and methodologies. In pattern analysis, E-Nose sensor response data is processed and analyzed using multivariate statistical methods such as Principal Component Analysis (PCA) [27]–[29], Linear Discriminant Analysis (LDA) [30]–[32], and Discriminant Factor Analysis (DFA) [33]–[35]. This method helps identify unique patterns relating to specific scents or odors, as well as differentiate and classify samples based on their aromatic characteristics. In addition, E-Nose technology uses Artificial Neural Network (ANN) as a machine learning method for pattern recognition [33], [35]–[37]. ANN is trained using E-Nose sensor response data to recognize patterns associated with a particular scent or odor. This allows the E-Nose to perform tasks such as scent recognition, sample classification, and detection of deviations from normal response patterns. The classifier is an important component in E-Nose data processing. Classifying algorithms such as Support Vector Machines (SVM) [4], [38], [39], k-Nearest Neighbors (k-NN) [40]–[42], and Decision Trees [40] are used to classify sensor response patterns into predefined scent or odor categories. These algorithms help in quick and accurate decision-making based on sensor response patterns.

In addition, E-Nose technology also uses a Decision Support System (DSS) to assist in decision-making. DSS provides relevant information and recommendations based on data analysis conducted by E-Nose. This information can be used in quality control, medical diagnosis, or hazardous material detection. Data processing and pattern recognition in E-Nose technology utilize these various techniques and methodologies to analyze sensor responses, identify scent or odor patterns, and classify samples. The selection of the right method depends on the purpose of the application and the characteristics of the data at hand, as well as allowing E-Nose to provide accurate and useful results in various fields.

3. Current Applications and Future Potential of E-Nose Technology

3.1. Food Industry

The latest technology of E-Nose in the field of food has made a significant contribution to the evaluation and quality control of food products [4], [5], [43], [44]. Industries engaged in food have tried to use E-Nose as an alternative to help the production process. The industries in question are the meat industry [45], [46], the oil industry [47], the alcohol industry [48], the tea industry [49], and others. Furthermore, E-nose is also used in various food industry applications such as shelf life determination [46], [50]–[52], identification [19], counterfeit detection [53], assessment [54], [55], freshness assessment [48], and authentication [56]. In addition, the industrial world also uses E-Nose to detect contamination [6], [57], allergens [17], [58], and harmful substances in food [59]. In addition, E-Nose is used in the determination of sensory qualities of food products, providing objective information regarding aroma, taste, and texture [60]. In its development, E-Nose technology continues to improve sensitivity, selectivity, and analytical capabilities. With the integration of artificial intelligence, E-Nose provides accurate and fast information to improve quality, safety, and consumer satisfaction in the food industry [55], [61].

Previously, Roy Mrinmoy and Yadav, B. K has reviewed the application of E-Nose in the food industry. They say the technique has proven effective in identifying food scams. In an effort to ensure the authenticity of food products, the contribution of gas sensor-based e-nose systems is very potential and benefits the food industry [44]. In addition, Yu Thazin et al. have also researched related to the detection of formalin adulteration in food. This research aims to develop E-Nose to detect formaldehyde in formalin-contaminated food. Nanocomposite gas sensors using OPDs and f-SWCNTs are used and show a high response to formaldehyde. Through testing on chicken, shrimp, and tofu contaminated with formalin, e-nose can distinguish odors related to these conditions. The results of this study support the use of e-nose with nanocomposite gas sensors as a useful tool in food safety [6]. Then, in another study, Yuan Huang et al. also implemented an E-Nose based on the ZYNQ7000 hardware platform for fruit freshness classification. Transient feature extraction methods are used for faster recognition, and PCA-KFDA models are used for feature dimensionality. The results showed higher classification accuracy than traditional methods, with 92.9% accuracy in fruit freshness [62]. The results of these three studies show that E-Nose is effective to be applied in the food industry.

3.2. Health and Medicine

The latest technology E-Nose has shown exciting potential in the health and medical fields [63]–[66]. The use of E-Nose in medical diagnosis has been a promising focus of research. In this field, E-Nose can be used to detect and identify diseases based on characteristic aroma patterns associated with specific health conditions. For example, E-Nose has been used to detect respiratory diseases such as asthma [18], [67]–[69], pneumonia [70]–[72], and COPD (Chronic Obstructive Pulmonary Disease) [18], [37], [73], and others [58], [65], [73]. In addition, E-Nose is also used in the field of surveillance and patient monitoring [74]–[76], with its ability to detect scent changes associated with infection, inflammation, or the body's reaction to medications [59]. In addition to diagnostic applications, E-Nose has also been developed in the field of drug research and development. With its ability to distinguish molecular scents, E-Nose can assist in the identification of active compounds in drugs and monitor the quality and stability of pharmaceutical products. It can also be used in detecting illegal drugs [77]–[79]. Later in the surgical field, E-Nose is also used to detect scents associated with cancerous tissue or tumors [65], [66], [80], [81], helping in the identification of healthy tissue boundaries and disease-affected tissues.

During the Covid-19 pandemic, E-Nose also plays an important role in distinguishing infected and uninfected people. Jing Li et al. researched about E-Nose nano sensor developed for rapid screening of COVID-19 infection by detecting volatile compounds in human breath. Early clinical trials successfully distinguished between positive and negative COVID-19 patient breath with an identification rate of 79%. This technology has the potential to be used to rapidly screen for active COVID-19 infections [82]. This research was also supported by Steven Laird et al., who said in their research related to the detection of chemical components in the breath of Covid-19 patients. The results showed a significant difference between the Covid-positive patient group and the Covid-negative control group, with higher outcomes in asymptomatic patients. Some chemicals, such as ethanol, methanol, and acetaldehyde, have higher concentrations in Covid-19 patients, especially in patients with symptoms. This breath analysis can provide significant results in distinguishing patients with or without Covid-19 [83]. In addition, in another study, Bilal Ahmad et al. said that E-Nose is an electrical device that can detect odors efficiently. Its use has increased in health and biology. E-Nose has the potential to support early detection of diseases and development of better technologies in the future [59].

In the analysis of E-Nose development efforts, Wang Li et al. combined e-nose with 10 gas sensors of 4 types developed to detect lung cancer. Feature extraction methods and clustering algorithms, and classification strategies were used to analyze sample data from healthy participants and lung cancer patients. The results suggest that the use of a combination of gas sensors and optimized analysis techniques can produce "breath-prints" that can distinguish between the two groups. The random forest algorithm with 3-fold cross-validation showed the best performance in classification, with good accuracy and AUC. This study suggests that sensor diversity may improve e-nose performance in detecting lung cancer, although further evaluation is still needed [84]. With continued research and development, E-Nose technology has the potential to become a more integrated tool in health systems, providing valuable information in disease diagnosis, monitoring, and treatment.

3.3. Security and Crime

E-Nose technology also has promising potential in the areas of security and crime [77], [85]–[87]. In terms of safety, the E-Nose can be used to detect explosives and other hazardous materials [88]–[90]. With its ability to detect unique scent patterns, E-Nose can assist in early detection of security threats and prevention of terrorist attacks. In addition, E-Nose can be used in the detection of drugs and illicit substances [77]. Different scent patterns of drugs can be identified by the E-Nose, thus assisting law enforcement officials in efforts to combat drug trafficking and related crimes. The scent information collected by E-Nose can be strong evidence in the process of criminal investigation. Another potential is the use of E-Nose in the field of product authenticity testing, such as identifying counterfeit products. Different scent patterns on genuine and fake products can be identified by E-Nose, thus helping in maintaining the authenticity and safety of the product [44].

Related to the application and development of E-Nose in the field of safety, Zhiyuan Wu et al. researched E-Nose system with metal oxide sensors (MOS) developed to monitor 5 flammable liquids. Temperature control proved important in improving E-nose performance. Qualitative analysis showed that reverse propagation artificial neural networks (BP-ANN) are more efficient than principal component analysis (PCA) in differentiating samples. Quantitative analysis shows an average error between 9.1% and 18.4%. Through anti-interference training, E-nose can avoid false alarms caused by mosquito repellents [91]. In another study, Cheng-Chun Wu et al. researched about developing an electronic nose system to detect and identify ketamine cigarette gas. This gas can endanger not only health but also a factor of safety and comfort of the general public. The study used standard operating procedures and sensor signal analysis. This system managed to achieve a classification accuracy of 95.92%. It provides an effective and easy method to detect ketamine cigarette odors that are harmful to health and occupancy quality [92].

In another case, Vijay S. Palaparthy et al. developed the E-Nose, which is cost-effective and portable, sensitive to resistive and capacitive changes, and effective in detecting explosives such as TNT, RDX, and PETN. The system has high sensitivity, low measurement error, and can accommodate different types of sensors. However, it is necessary to make further improvements to address environmental factors. The study successfully classified explosives with 77% accuracy. Its use as a commercial detector requires further development, including better algorithms [93]. This statement is also supported by the statements of Tomasz Wasilewski and Jacek Gębicki in their article, who say that the use of E-nose in explosives detection continues to face challenges and requires continuous development [90].

3.4. Environment and Agriculture

The latest technology of E-Nose in the field of environment and agriculture has shown great potential [8], [10], [94]–[97]. In the environment, E-Nose can be used to detect and monitor air quality, including pollution by toxic gases or unwanted odors [98], [99]. It can assist in environmental surveillance, monitoring of air quality around factories or industries, and early detection of environmental disasters such as gas leaks or air pollution caused by waste [8], [10]. In agriculture, E-Nose can be used to identify the quality and presence of disease in plants [2], [100], [101]. The sensitive E-Nose sensor can detect volatile organic compounds (VOCs) produced by disease-infected plants so that early prevention or treatment can be taken [102]–[104]. In addition, E-Nose can also help in quality control and identification of acidity in agricultural products such as fruits, vegetables, or processed products.

In the environmental field, Magdalena Piłat-Rożek et al. researched E-Nose, which combines gas sensors and machine learning methods used to improve the classification of stages of the wastewater treatment process. The t-SNE method is used to reduce the dimensions of gas sensor data, while the k-median method is used to analyze chemical patterns. The classification model based on the random forest algorithm showed good quality and was able to classify observations perfectly. These results show the potential of E-Nose in monitoring and classifying wastewater treatment stages [10]. This research is also supported by another research by Javier Burgués et al. [9].

While in the agricultural sector, Jinyong Xu et al. conducted research related to VOC characteristics that contribute to the aroma of rice. They say the use of E-nose has great potential as a reliable measuring tool for assessing rice quality based on aroma profiles. Comparison with traditional methods also shows the superiority of E-nose in routine analysis. Future challenges and trends of the E-nose were also identified, including reduced working temperatures, better pattern recognition, and the development of new predictive models [96]. In addition to reviewing the quality of the harvest, E-Nose also plays an important role in helping the plant care process. As researched by Alireza Makarichian et al. about the use of E-Nose to detect fungal infections in garlic. E-nose can quickly and non-destructively detect fungal infections with scent analysis. Results showed that infected garlic degrades faster, and the sensor's response to the scent differs depending on the type of infection. E-nose can be a practical and useful tool for early detection of fungal infections in garlic [101].

3.5. Perfume Industry

The latest technology E-Nose has had a significant impact on the perfume industry [105]–[109]. In the perfume industry, E-Nose can be used for scent characterization and development of new perfumes [108], [110]. The sensitive E-Nose sensor can identify scent components in perfumes with high precision, allowing manufacturers to create unique and interesting scent blends. With the help of E-Nose, the scent testing process can also be accelerated and simplified.

Related to the application of E-Nose in the perfume industry, the Scientific Committee of Cosmetic and Non-Food Products identified 26 compounds that can cause contact allergies in cosmetic products. GC-MS and e-nose are used to identify and distinguish volatile compounds in original and imitation perfumes. GC-MS revealed 10 allergens in the samples, some found only in fake fragrances. E-nose manages to distinguish between real and imitation fragrances well. PCA shows that the first three main components account for 98.09% of the information in the database [109]. Other studies have shown that E-nose can also group accessions well using Principal Component Analysis (PCA). Partial Least Squares (PLS) indicate that specific sensors are very sensitive to terpenoids. E-nose can distinguish different Hedychium volatile profiles accurately and quickly [107]. The results of these two studies show that E-Nose provides convenience and a good role in the recognition of floral or perfume scents.

Then, E-Nose can also be developed in the cosmetic industry (other than perfume) to test the quality and stability of cosmetic/beauty products. There are still very few and almost no previous studies examining cosmetics using E-Nose. We gave this statement because of the difficulty in finding references related to the application of E-Nose in cosmetics/beauty products.

4. Challenges and Opportunities

Every new and advanced technology will never be free from challenges and opportunities [111], [112]. Challenges and opportunities usually arise from a variety of factors that include market needs, technical limitations, rules and regulations, and response and acceptance from the public [113], [114]. In market needs, challenges arise due to the complex demand and needs of the market. The demand for more efficient, reliable and innovative solutions is driving the development of new technologies. However, achieving the expected level of satisfaction from the market can be a challenge that requires further research and development. In addition, fundamental obstacles such as technical limitations can also be a challenge. New technology developments often face technical limitations such as reliability, stability, sensitivity, selectivity, and complexity of hardware and software integration. The development of more sensitive and selective sensors, as well as improved sensor reliability and stability, are key challenges. In addition, complex hardware and software integration is also a thing that needs to be addressed. Then technical matters such as the supply of representative data covering different types of scents and reference materials are also needed to effectively train and test the E-Nose model. Similar to market needs, technical limitations also require further efforts and research to overcome technical barriers and ensure optimal performance [90], [93].

In addition to market needs and technical limitations, the rules and regulations of a region are also obstacles. The development of new technologies often faces regulatory and regulatory challenges. Creating a clear framework, meeting security, privacy, and ethical standards, and complying with legal requirements are challenges that need to be overcome in order for technology to be effectively and securely applied to a given region and globally. It also supports other factors, such as public trust. The more obedient a technology is to applicable regulations and rules, the greater public trust in the technology applied. The public is one of the important factors in the density of new technology, especially if the target user of the technology is the public (not just a certain government, agency, or organization). Misunderstanding, privacy concerns, mistrust, or fear of change can hinder technology adoption. Therefore, it is important to communicate well, provide proper understanding, and build public trust.

However, despite the challenges to overcome, E-Nose technology has great opportunities. Innovative new product development can be done by utilizing E-Nose's ability to detect and distinguish scents. In the security and crime industries, the E-Nose can be used to detect harmful odors and assist in forensic investigations. In agriculture and the environment, E-Nose can be used to monitor air quality, detect pollution, and assist in environment-related decision-making. In addition, there are also many scientific fields that can utilize E-Nose technology in facilitating work and overcoming problems experienced, both small and problems with a high level of complexity. By addressing technical challenges, ensuring adequate data supply, complying with regulations and privacy, and building public trust, E-Nose technology has great potential to deliver significant benefits in a variety of fields. This technology can improve safety, product quality, and understanding of the environment, making it a useful tool in responding to the challenges faced by modern society.

5. E-Nose Development Potential in the Future

As a technology that has high utilization in various fields, E-Nose allows it to be developed again, both in optimizing the accuracy and capabilities of existing systems and by integrating them with some of the latest technologies, such as the Internet of Things (IoT) [115]–[119], Blockchain [120]–[122], Artificial Intelligence (AI), Big Data [123], [124], Augmented Reality (AR) [125]–[127], and Virtual Reality (VR) [128]–[130]. All of these technologies have enormous potential to contribute to expanding the use of E-Nose in the real world. However, some of these technologies have begun to be developed by some researchers, such as integrating them with IoT [98].

IoT is a concept that refers to a network of physical devices that are interconnected via the internet [131]–[135]. In IoT, these devices can communicate and share data automatically without human intervention [136]–[138]. IoT devices can include different types, such as sensors, electronic devices, vehicles, home appliances, and more [139]–[142]. The goal of IoT is to create extensive connectivity between these devices, enabling seamless data exchange and cooperation between different devices [143]–[145]. With IoT, these devices can collect data, share information, and take action automatically based on detected conditions [146]–[148].

In the context of E-Nose, integration with IoT refers to connecting E-Nose to the internet network and allowing it to communicate with other devices in a wider system. This enables real-time data exchange, remote control, and interoperability between the E-Nose and other devices [149]–[151]. With IoT integration, E-Nose can collect scent data continuously and send it to a cloud platform or central server. The data can then be accessed and analyzed in real-time by authorized users via smart devices such as smartphones or computers [152]. This real-time receipt of information enables early detection of unwanted or harmful odor changes, allowing users to make faster, more informed decisions in terms of quality control, identification of hazardous chemicals, or optimization of production processes. In this case, E-Nose can also be integrated with sophisticated analytical algorithms, such as machine learning techniques or big data analytics, to provide more detailed and accurate information about the scent being observed. In addition, IoT-connected E-Nose can receive instructions from centralized systems, such as commands to start or stop scent monitoring, send notifications when certain scent detections occur, or activate other response actions. Illustration of the E-Nose concept integrated with IoT, such as Fig. 2.

Integration with IoT enables the use of E-Nose on a larger scale, such as the use of multiple E-Nose sensors distributed over a large area or the use of E-Nose in complex supply chain networks. However, integration with IoT also has challenges that need to be addressed, such as data security, interoperability between devices, and the need for a reliable network infrastructure. In addressing this, blockchain can be applied to provide a secure, transparent, and immutable system for recording and sharing scent data collected by E-Nose. Using Blockchain technology, scent data can be verified for authenticity and can be clearly traced, thus increasing confidence in scent testing results [153], [154]. This can be beneficial in the cosmetics and perfume industry, where the authenticity of the scent is very important. In addition, by utilizing the security and privacy features built into the Blockchain, confidential and sensitive information regarding fragrance formulas can be better protected. The application of blockchain in the E-Nose system also allows it to be integrated with IoT [155]–[158]. The working concept of E-Nose integrated with IoT Blockchain is shown in Fig. 3. In addition to IoT and Blockchain, E-Nose's integration with other technologies such as AR and VR also has potential. For example, the use of AR and VR can aid in interactive visualization of scent data, allowing users to see and sniff scents virtually. This can be useful in the perfume industry, where customers can try different scents through a virtual experience before deciding to buy.

Not only integration with the latest technology, but E-Nose can also be combined with other sensory functions, such as vision (E-Eyes) [159], [160], touch (E-Skin) [161]–[164], taste (E-Tongue)

[4], [160], [165], [166], and hearing (E-Ears) [167]–[169]. The combination of E-Nose, E-Eyes, E-Ears, E-Skin, and E-Tongue at one time is an exciting idea to develop in the future with complex multi-sensor sensory technology. When used together, these sensors are capable of detecting and monitoring a variety of different sensory aspects, such as smell, visual, sound, texture, and taste.

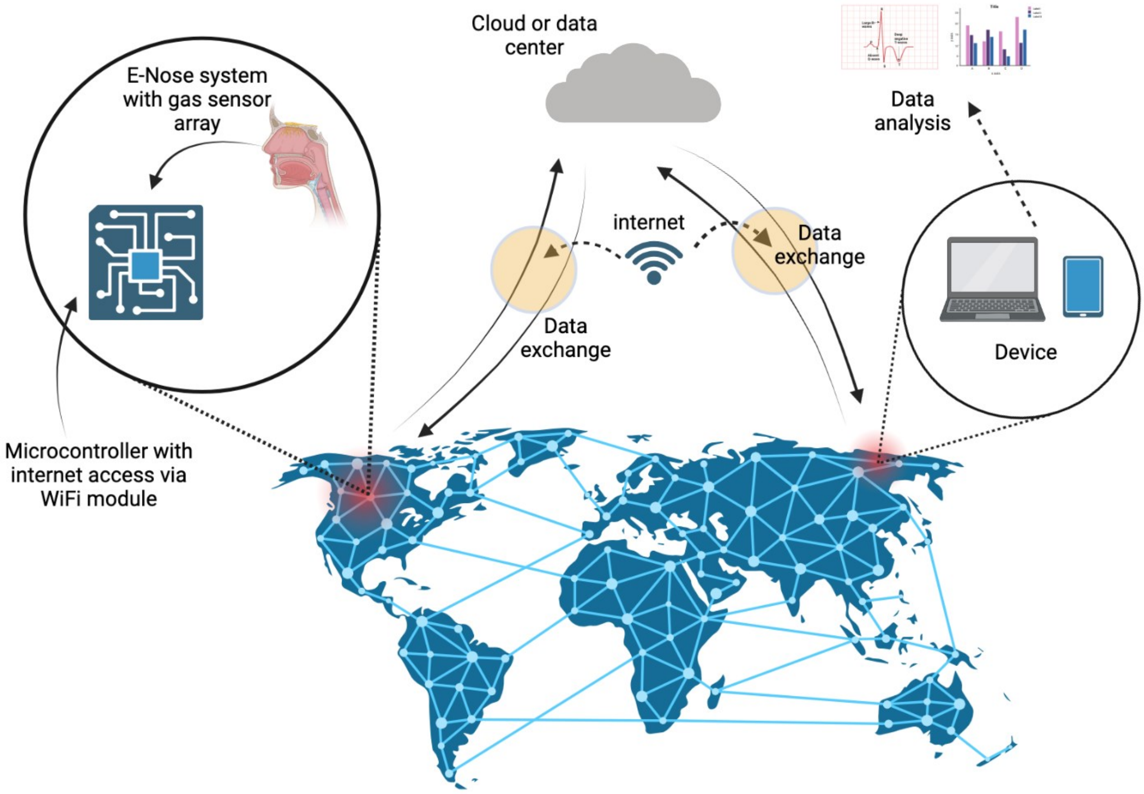

Fig. 2. Illustration of the concept of E-Nose integrated with IoT

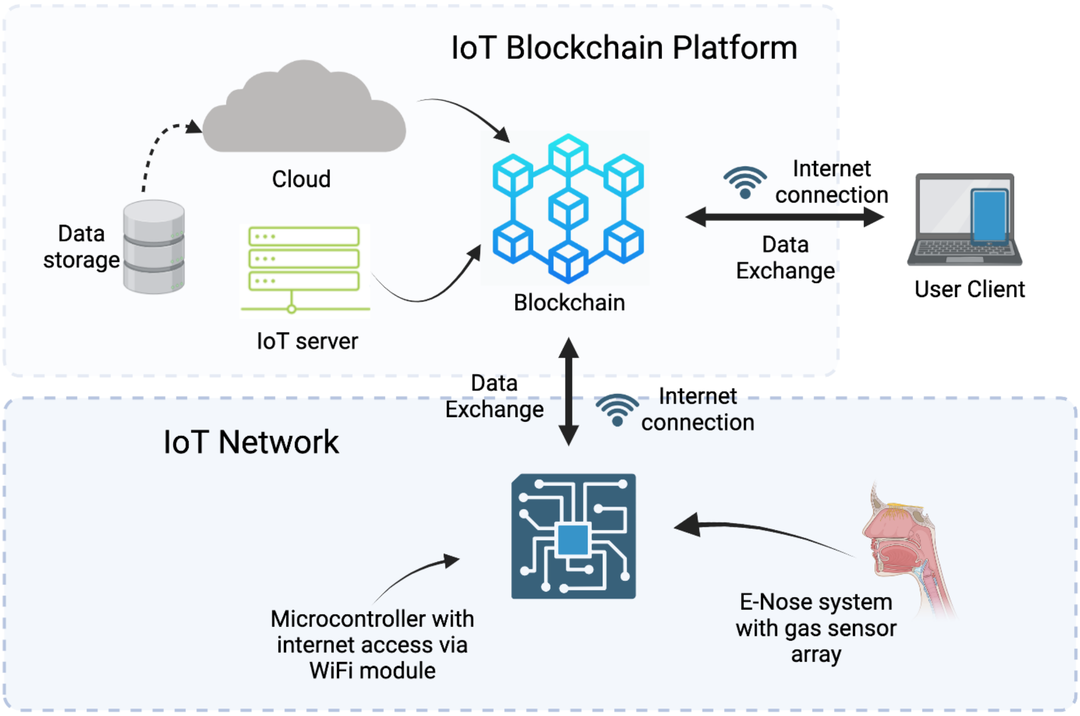

Fig. 3. E-Nose working concept integrated with IoT Blockchain

E-Nose, which measures odor components, can work together with E-Eyes, which focuses on visual analysis to provide complete information about the characteristics of a particular food, beverage, or chemical [170]. This combination can identify not only the scent but also the look and color associated with it. E-Ears, which are capable of detecting sound and frequency, can provide additional information about sounds and vibrations produced by certain materials or objects. Thus, the combination of E-Nose, E-Eyes, and E-Ears can provide a more thorough understanding of the sensory characteristics of an object. Then E-Skins, which are designed to understand texture and softness, can play a role in this combination by providing information about the surface texture of an object. This can complement the information provided by other sensors, such as E-Nose and E-Eyes, to provide a more complete understanding of the sensory of a product. Lastly, E-Tongue, which measures taste and chemical components, can complement this combination by providing an understanding of the flavor profile and chemical composition of an ingredient or product. With the E-Tongue, information about taste can be combined with information from other sensors to provide a more comprehensive analysis.

The combination of E-Nose, E-Eyes, E-Ears, E-Skin, and E-Tongue together can provide a more complete and in-depth sensory understanding of an object or material. It can be used in a variety of applications, such as food quality assessment, safety surveillance, cosmetic product development, and chemical quality testing. The incorporation of these sensors opens up opportunities for the development of more complex and accurate sensory systems, as well as improved understanding and decision-making in various industrial fields.

6. Conclusion

E-Nose's integration with various cutting-edge technologies such as IoT, Blockchain, AI, Big Data, AR, and VR has great potential to expand its applications in various industries. Through IoT integration, E-Nose can connect to the internet, enabling real-time data exchange, remote monitoring, and interoperability with other devices. This enables large-scale deployment and more informed decision-making in sectors such as quality control, identification of hazardous chemicals, and optimization of production. Blockchain technology improves the security and traceability of scent data, which is especially important for industries that prioritize authenticity, such as the cosmetics and perfume industries. In addition, the combination of E-Nose with other sensory technologies such as E-Eyes, E-Ears, E-Skin, and E-Tongue can lead to more comprehensive sensory analysis. By exploring this integration, E-Nose opens up new possibilities for highly accurate and advanced sensor systems with extensive applications in various industrial domains.

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