Gas Sensing Techniques in Electronic Nose and its Applications: A Review

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Abstract

Electronic noses instruments were developed as systems for the discrimination of gases and odors. An electronic nose is a portable device which strives to sniff complex mixtures of volatile organic compounds. It consists of a large array of chemical sensors with associated signal conditioning and pattern recognition techniques. An electronic noses employs different types of gas sensors that uses a sensor array which results in partially overlapping sensitivity such that each sensor responds to a range of gases rather than to a specific one. Signals resulting from these arrays require to be examined by pattern recognition techniques such as artificial neural networks (ANNs). The gas sensing methods referred to the different types of sensors are mainly used for swift detection of gases in application. Each one of these sensors has its own kind of response in the sensor array. The electronic noses sensors are employed for the identification of gases/odors, such as volatile organic compounds (VOCs) to solve a broad variety of problems in food and beverages industry, chemical and biological hazards, wide area monitoring, environmental monitoring, process monitoring, flavors, fragrances, cosmetics productions, safety, security and military use. In this research paper, we study the operating principle of electronic nose technology, gas sensing sensor techniques and explain a range of applications of electronic noses in extensive areas.

1 Introduction

The growth of electronic nose has contributed considerably towards the progress of machine intelligence in the recent technological circumstances. An electronic noses uses various types of gas sensors methods that employs a sensor array which results in partially overlapping sensitivity such that each sensor responds to a range of gases rather than to a specific one. These gas sensor types’ displays physical and chemical relations with the volatile chemical compounds when they come in contact with the gas sensors. In the area of environmental quality monitoring consist of global air quality monitoring and local air monitoring and the requirement for the development and application of new machine intelligent system is required to sense the hint of chemical in the environment and also the determination of toxic and explosive gases more efficiently [1]. In medical and pharmaceuticals industry, new developments and application of new intelligent diagnostic systems are pioneered to control the human diseases health issues [2]. The use of electronic nose for food quality analysis is employed to discriminate various classes of identical odor emitting products [3, 4] to control the quality of food. The electronic nose strives to mimic human smell processing with the aim to detect the occurrence of gas/odor at very low concentration and also to discriminate them. The application of electronic nose for the classification and categorization of foodstuff, such as coffee [4], beverage [5], wine [6, 7], and milk [8] has obtained good results. The discrimination of complex odor compounds using electronic nose is an important task in many industry. During 1970’s gas chromatography techniques were adopted to study the identification of volatile organic compounds in medicine, food & flavors and environmental monitoring. In recent researches, advanced analytical techniques, such as mass spectrometry have been used in combination with soft computing techniques [9].

The first electronic nose was developed by Persaud and Dodd et al., in 1982 [10] and Ikegami et al., in 1985, 1987 at Hitachi in Japan [11, 12]. Since then a number of advanced sessions, workshops & conferences were held on the topics of machine olfaction [13] and a significant amount of consideration has been carried out in developing electronic nose systems in gas sensing of volatile organic compounds (VOC’s) without having to identify individual chemical components with the odors and avoid operator fatigue. Medical and food industry have employed electronic nose technology to determine the flavor and food quality, assessment of beverage container, classification of vintage of
wines examination of odor in the breath, infectious sinus problems and several other applications [14]. In this paper, we study and explain various gas sensing methods of electronic noses system and their applications for gas detection in the field of food and beverage industry, environmental monitoring and medical industry.

2 Electronic Nose Systems

An electronic nose is a portable device which contains an array of chemical sensors with partial specificity and a suitable pattern recognition method which are capable of discriminating simple and complex odors [15]. This instrument provides a rapid, simple and non-invasive sampling technique and a data analysis that can to certain extent discriminate between various ranges of gases [16]. The sensor array consists of broadly tuned non-specific sensors that are treated with a range of odor sensitive chemical materials. Each chemical vapor presented to the sensor array creates a pattern characteristic of the vapor. By producing various chemical sensors to the sensor array a database class is obtained. The lack of specificity and poor selectivity of multisensory arrays deliver the use of pattern recognition techniques (PARC) for classification of non-linear sensor responses for odor detection [17]. These electronic noses devices were engineered to mimic the mammalian olfactory system within an instrument designed to obtain repeatable measurements, allowing identification and classification of aroma mixture while eliminating operator fatigue [18]. Various prototypes of artificial nose devices have been developed to discriminate complex odor mixtures containing various different types of VOC’s. These prototypes correspond to different aroma detection technology that employs different sensory material currently used in artificial nose technology including metal oxide sensors, conductive polymers, surface acoustic and fiber optic sensor [19].

An electronic nose consists of a sensing system and the automated pattern recognition system. The output from the sensor array may be understood by numerous pattern recognition algorithms, fourier transform techniques, principal components analysis, discriminant function analysis, transformed cluster analysis and artificial neural networks (ANN's) [20]. Artificial neural networks are used to analyze the data set and to identify patterns that display promising results in discrimination of gas detection. The ANN's are usually considered most significant pattern recognition methods to process the signals from a chemical sensor array of electronic noses which makes the system more bionics [21]. The prototype of electronic nose is shown in Fig. 1. [22], is composed of an array of sensors coupled with ANN. Fig. 2. [23], demonstrates the structure of back propagation multilayer feed-forward neural network which learns to discriminate various chemicals.

Fig. 1: Electronic nose prototype

![Fig. 1: Electronic nose prototype](image1)

Fig. 2: Structure of the back propagation ANN

![Fig. 2: Structure of the back propagation ANN](image2)

3 Gas Sensing Techniques in E-nose

Different varieties of sensors are obtainable in the market that is designed by the researchers. These sensor types exhibits physical and chemical interactions with the chemical compounds when they flow or come in contact with the sensors [24].

3.1 Metal Oxide Sensors

The sensing systems based on metal oxide sensors (MOS) reached the food industry more than a decade ago and it was presented as a non-critical technique for food odor analysis that could contend with panel test. Gas sensors based on the chemical sensitivity of metal oxide semiconductors sensors (MOS), are readily available. They have been more extensively used to make arrays for odor measurement than any other type of gas sensors. Although the oxides of many metals show gas sensitivity under healthy conditions, the most widely used material is tin dioxide (SnO2) doped with a small amount of a catalytic metal such as palladium or platinum. By varying the selection of catalyst and working conditions, tin dioxide resistive sensors have been developed for a group of applications. Materials with enhanced performance with respect to relative humidity differences have been found by observed testing. Titanium-substituted
chromium oxide (CTO) is an example of such a material. Other available oxide-based gas sensors include zinc oxide (ZnO), titanium dioxide (TiO2) and tungsten oxide (WO3) [25].

The metal oxide sensors are based on the change in conductance of the oxide on interaction with a gas and the change is proportional to the concentration of the gas. There are two types of metal oxide sensors, n-type (zinc oxide, tin oxide, titanium dioxide) which respond to reducing gases and p-type (nickel oxide, cobalt oxide) which respond to oxidizing gases [26]. The main advantage of metal oxide sensor is fast response and recovery times, which mainly depend on the temperature and the level of the interaction between the sensor and the gas.

3.2 Optical Sensors

Optical fiber sensor arrays are one more approach to odor identification in e-nose systems. The sides or tips of the optic fibers (thickness, 2mm) are coated with a fluorescent dye encapsulated in a polymer matrix. Polarity alterations in the fluorescent dye, on contact with the vapor, changes the dye’s optical properties such as intensity change, spectrum change, lifetime change or wavelength shift in fluorescence. These optical changes are employed as the response mechanism for odor detection [27]. For high temperature applications, the outer coating is a protective layer, while for in vivo uses it is a biocompatible material. The active material includes chemically active fluorescent dyes immobilized in an organic polymer matrix. As VOCs interact with it, the polarity of the fluorescent dyes is changed and they react by shifting their fluorescent emission spectrum. When a pulse of light from an outside source interrogates the sensor, the fluorescent dye responds by emitting light at a dissimilar frequency. As the source intensity is much larger than the sensor response, enormous concern to be taken to make certain that the response photo detectors are protected from the source emissions. Arrays of these devices with various dye mixtures can be used as sensors for an electronic nose [28].

3.3 Conductivity Sensors

Conducting polymer composites, intrinsically conducting polymers and metal oxides are three of the most commonly utilized classes of sensing materials in conductivity sensors. Conductive polymer gas sensors operate based on changes in electrical resistance caused by adsorption of gases onto the sensor surface. Conductive electro active polymers have fascinated much interest for use as electronic noses since the early 1980s [29], mostly because they have high sensitivities, short response times, are effortlessly synthesized, have good mechanical properties and are typically useful because they operate at room temperature [30]. Conductive polymer gas sensors consist of a substrate, usually silicon, a pair of gold-plated electrodes and a conducting organic polymer coating as the sensing element [31]. The sensitivity of conductive polymers to VOCs is measured as changes in electrical resistance. The first commercial E-nose system used conducting polymer based sensors and they have been utilized in much subsequent sensor array research [32]. Conducting polymer can be used as sensors as the polymer conductivity is changed in response to organic vapors. The mechanism of the intrinsic conducting polymer response is unknown but many theories have been suggested. The major drawbacks are the effect of humidity and sensor drift due to oxidation of the polymers over time [33].

3.4 Surface Acoustic Wave Sensors

The surface acoustic wave sensor device is composed of a piezoelectric substrate with an input (transmitting) and output (receiving) interdigital transducer deposited on top of the substrate. The sensitive membrane is placed between the transducers and an AC signal is applied across the input transducer generating an acoustic two-dimensional wave that propagates along the surface of the crystal at a depth of one wavelength at operating frequencies between 100 and 400MHz [34].

3.5 Piezoelectric Sensors

In piezoelectric sensors, the phenomenon is that after certain anisotropic crystals, when subjected to mechanical stress generates electric dipoles. Piezoelectric crystals have varied usage which includes optoelectronics, electronics, radio frequency filters and liquid and gas sensing devices. Quartz is the most commonly utilized crystals for gas sensing. Many different forms of piezoelectric sensor exist, including bulk acoustic wave (BAW), surface acoustic wave (SAW). The two major types of piezoelectric sensors used in electronic nose sensing are BAW and SAW. In BAW devices, the wave propagates through the substrate. In SAW devices, the wave propagates on the surface of the substrate [35]. In both cases, the waves are at ultrasonic frequencies, particularly 1 to 500 MHz.

4 Electronic Nose Applications

The Electronic nose technology has been employed in various applications. The electronic nose technology has been applied to a range of food & beverage applications, medical field and environmental application [36]. In addition this technology presents promising applications. The reported application is their use to classify the aroma of various foods & beverages.
The machine olfaction with chemical sensor arrays has been an advanced research from past few decades to achieve better classification rate in sensing the odors in various industries.

4.1 Electronic Nose for the Food & Beverage Industry

The applications of electronic noses in the food industry include quality assessment in food production [37], inspection of food quality by odor/gas, control of food cooking processes, inspection of fish, monitoring the fermentation process, checking rancidity of mayonnaise, verifying whether orange juice is natural, monitoring food and beverage odors [38], grading wine, inspection of beverage containers and automated wine flavor control [39] to name a few. In the food processing industry qualitative assessment of food spoilage is made by human sensory panels that evaluate air samples and discriminate good food products. Meat is a best growth medium for numerous groups of pathogenic bacteria. Estimation of meat safety and quality is generally based on microbial cultures. Bacterial strain identification needs a number of different growth conditions and biochemical tests with overnight or large incubation periods and skilled personnel, which mean that testing may not be frequently performed. The electronic nose is appropriate instruments for measuring fish freshness since a huge number of volatile compounds are related to “offness” [40]. The areas of research have deviated in finding adulteration / contamination of milk to determining the geographical origins of cheese [41]. The E-nose was able to discriminate among different ripeness stages of fruits and vegetables that are either formed during ripening or upon tissue disruption, which occurs after maceration, blending or homogenization. The E-nose has been employed for classification of wines which is an economically important application because of high value of wines from specific geographical regions and also the need to avoid illegal substitution or adulteration [42]. In few illustrations electronic noses can be used to expand or replace panels of human experts. In other cases, electronic noses can be used to reduce the amount of analytical chemistry that is performed in food production for qualitative results.

4.2 Electronic nose for the Environmental Monitoring

The laboratory of many industries are exploring the technologies of E-nose are required to perform environmental restoration and waste management in a cost effective manner. This effort includes the development of portable, inexpensive E-nose systems capable of real time identification of contaminants in the field. The electronic noses are employed in environmental applications that comprise the testing ground water for odors, identification of household odors [43], the analysis of fuel mixtures [44], and detection of oil leaks [45]. Many potential applications comprises of identification of toxic wastes, air quality monitoring, and monitoring factory emissions.

4.3 Electronic Nose for the Medicine

The sense of smell is an important sense to the physician; as electronic nose has applicability as a diagnostic tool. An electronic nose can test odors from the body (e.g., breath, wounds, body fluids, etc.) and identify possible problems. Odors in the breath can be indicative of gastrointestinal problems, sinus problems, infections, and diabetes and liver problems. Infected wounds and tissues emit distinctive odors that can be detected by an electronic nose. Odors coming from body fluids can indicate liver and bladder problems [46]. A more futuristic application of electronic noses has been recently proposed for telesurgery [47]. While the inclusion of visual, aural, and tactile senses into telepresent systems is widespread, the sense of smell has been largely ignored. An electronic nose will potentially be a key component in an olfactory input to telepresent virtual reality systems including telesurgery. The electronic nose would discriminate odors in the remote surgical environment. These identified odors would then be electronically transmitted to another site where an odor generation system would recreate them.

4.4 Electronic nose for the Military Use

Military applications of electronic noses include personnel and population security, civilian and military safety, biological & chemical weapons and explosive materials detections. The electronic nose is more than a bomb detector because it detects all chemical compounds in an odor, fragrance or vapor [48]. Electronic noses have the ability to recognize an almost limitless number of chemical vapor threats while bomb/chemical agent detectors provide the ability to detect specific target chemicals at trace levels while not being affected by high ambient concentrations of non-target compounds. Electronic noses provide a different screening capability with inherently more information gathering power than bomb detectors and help to resolve ambiguities by using a library of aroma signatures [49].

5 Conclusions

In this paper study, we presented the electronic nose gas sensing sensor methods and its applications such as food, beverages, environmental monitoring, medical & military use. The electronic nose identifies & recognizes odors/vapors i.e. a machine olfaction device coupled with an array of sensors and pattern recognition system. The different types of sensor array are available that take the advantage of different
responses of different sensors to many volatile organic compounds and produces a unique data set which can be analyzed using various types of pattern recognition techniques. The differences between an electronic nose and analytical chemistry equipment are that an electronic nose produces a qualitative output and can be used in real-time analysis. This study presents few gases sensing sensor techniques & promising applications of electronic noses for real-world applications for better identification of gases/vapors. The development of electronic nose technology with pattern recognition techniques and machine intelligence can advance the possible use of electronic nose for different fields of applications.

References


