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Electronic Nose: A Review

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Review Article

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ABSTRACT

The electronic nose was developed in order to mimic human olfaction that functions as a non-separative mechanism: i.e. an odor / flavor is perceived as a global fingerprint. In all industries, odor assessment is usually performed by human sensory analysis, by chemosensors, or by gas chromatography. Over the last decade, "electronic sensing" or "e-sensing" technologies have undergone important developments from a technical and commercial point of view. The "electronic nose" is a relatively new tool that may be used for safety, quality, or process monitoring, accomplishing in a few minutes procedures that may presently require days to complete. Electronic Nose is a smart instrument that is designed to detect and discriminate among complex odours using an array of sensors developed. This specialized field was born and became prominent in the mid 1980s, a smart instrument designed to detect and distinguish complex odours. Typical E-nose device includes, a sampling system, an array of chemical gas sensors, a analog to digital converter (ADC), a computer microprocessor with sample classification method (pattern-classification algorithm). E-nose finds application in industrial processes, environmental toxins and pollutants, space stations & space shuttle air quality, medicines body function, food processing, military environment and toxicology. Electronic noses have provided a plethora of benefits to a variety of commercial industries, including the agricultural, biomedical, cosmetics, environmental, food, manufacturing, military, pharmaceutical, regulatory, and various scientific research fields.

INTRODUCTION

For many years, scientists have recognized the power of including biological principles into the design of sensors. An example of this approach is the development of the Electronic Nose. Electronic Nose is an instrument which consists of an array of electronic chemical sensors with a partial specificity and an appropriate pattern-recognition system which is capable of recognizing simple or complex odours. The four main functional components of Electronic Nose system are as follows,

- A sample handler for odour vapour input
- An array of sensors
- A signal processing system
- A system for pattern recognition. Generally these operate serially on an odourant sample, and can be represented by a schematic diagram as follows.

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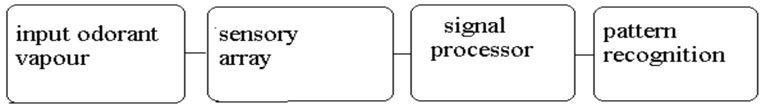

Fig (i) The output of the *Electronic Nose* may be the identity of the odourant, an estimate of the concentration of the odourant, or indeed some measure of the characteristic properties of the odour, as might be perceived by a human [1]. An electronic nose (e-nose), the Cyrano Sciences' Cyranose 320, comprising an array of thirty-two polymer carbon black composite sensors has been used to identify six species of bacteria responsible for eye infections when present at a range of concentrations in saline solutions [2]. An electronic nose (enose) is a device, which is composed of an array of gas sensors as well as a corresponding pattern recognition algorithm; it is able to imitate the olfaction system of humans and mammals, and is used for the recognition of gas and odor [3]. A typical electronic nose has two major components: a sensor that detects odors and a set of electronic components that interprets the resulting signals. The sensors incorporate different types of materials, including metal oxides or advanced polymers. When exposed to certain volatile compounds or combinations of them, the sensor materials change size, color, or their resistance to electricity [4]. Electronic nose is a new developed technology used to detect and to visualize flavors and odor. It is also known as excites sensory panelists because it works more like the human nose. The electronic nose is a valuable tool that creating it takes more than 10 years of research performed at Warwick and Southampton Universities in the United Kingdom and Toulouse University in France. This instrument is very efficient that in a few minutes it delivered objective, reproducible aroma discrimination with sensitivity comparable to the human nose for most functions. Electronic nose uses an array of sensors that responds to volatile and semi-volatile organic chemical in food material, similar to the way the human nose works [5].

Mechanism

Figure (i) shows the basic stages of signal processing in an electronic nose. Sample space Q is defined by either the chemical composition of the samples which may be a single compound (i.e. a simple odour), or more likely a number of compounds (e.g. a complex odour). The zero point represents odour-free air. The sensor array responds to the sample A and so maps one point in sample space onto sensor space !&. This is a crucial stage in the process and broadly determines the resolving power of the electronic nose. In the human olfactory system, the frontend processing is elaborate and manages to boost the sensor sensitivity to the sub-ppb level yet at the same time suppress the signal noise. The integrity of the output from the sensor array thus largely determines the performance of an electronic nose [6].

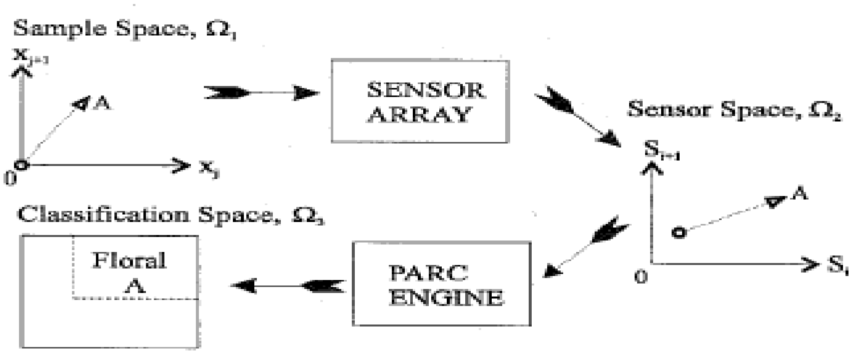

Figure i: Signal processing in an electronic nose.

Development of Electronic Nose

The Electronic Nose can be categorized into three generations starting from its development in the mid 80's.

The First Generatione E-Nose

The first generation of e-nose were based on Sensor Arrays (with different types of sensors). The 1st generation ENose Sensor Unit flight experiment, which flew aboard the STS-95 (1998), used an HP-200LX Palmtop Computer for device control and data acquisition; data were collected and analyzed after landing.

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Second Generation E-Nose

The second-generation ENose has the same functions as the first-generation device, but has been miniaturized to occupy less than 1000 cm3 with a mass ~800 g, not including the operating computer. Development of the second generation ENose for crew quarters air quality monitoring, focuses on optimizing the response of the array of conductometric sensors and on extensive ground testing.

Third Generation E-Nose

The 3rd generation ENose uses the basic sensing unit developed as the second generation device; it also includes an ISS interface unit, which conforms to electrical, data telemetry, display and data storage requirements for ISS. The ENose Sensor Unit consists of an anodized aluminum chassis which houses the Sensor array and pneumatic system. The ENose Sensor Unit also contains the electronics to route power, relay data and commands between the Sensor array and the ENose Interface Unit [7].

Olfactory Mechanisms-

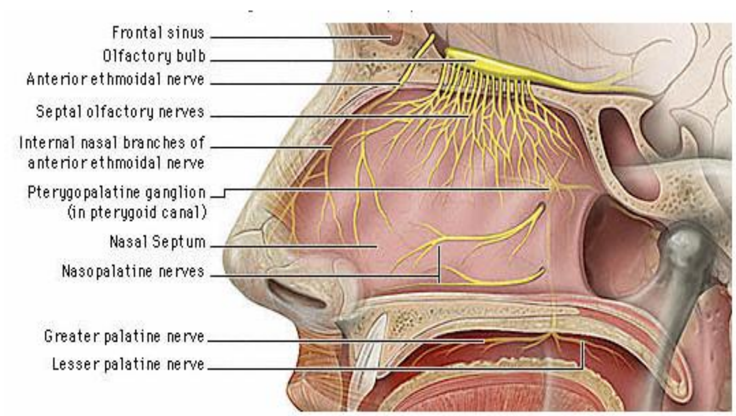

Figure ii: Cross section of nose [8]

Gas Chromatography

Although it is possible to separate mixtures by using the properties of their ions in electrical or magnetic fields, the most established and widely used technique in analytical chemistry is to separate them by chromatographic methods. In the case of volatiles, gas-liquid chromatography and gassolid chromatography are possible ways. The sample, transported by the mobile phase (gas), is directed over the stationary phase (liquid or solid) and interacts with it. Depending on physical and chemical properties, such as the boiling point, the polarity, H-bonding, polarizability, etc., the affinity of each single substance for the stationary phase is different. The partition behavior determines the retention time of the components and, consequently, the order of elution [9].

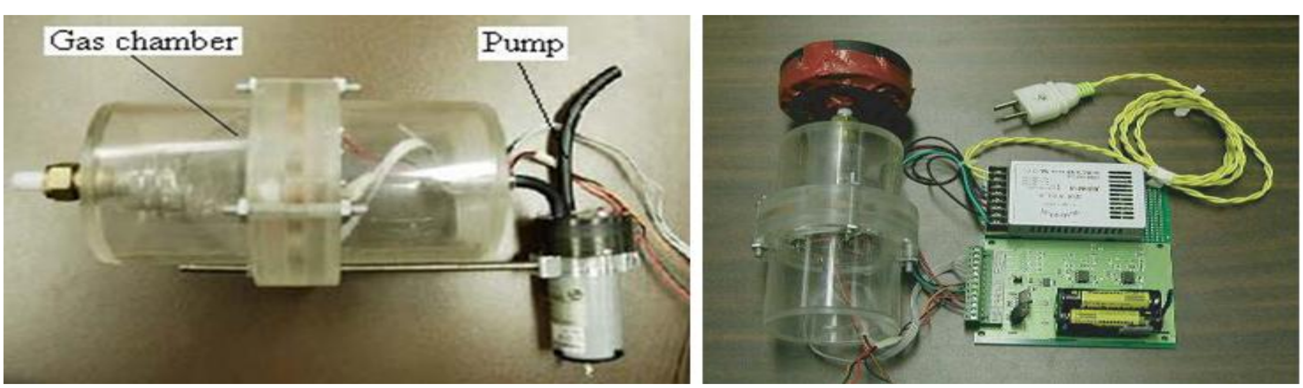

Figure iii: Gas chromatography instrument.

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Applications

In the past two decades, the applicability of electronic noses has been tested in every imaginable field where odors or odorless volatiles and gases are thought to play a role [10]. A typical approach was to prove the ability of a given sensor array to discriminate a sample set in a desired manner (the black box approach). Consequently, researchers were frequently overly hasty in concluding that positive experimental results demonstrated success in the application. As a result one was considered to have reached the target and/or went ahead to the next challenge: the quantification of the sample property of interest. Taking the electronic nose as a black box, without having a feeling for the chemical processes going on and having no idea about the marker substances and interferents, one becomes critically dependent on the sample set. Accordingly, it is very important to be aware of the fact that one can sometimes have a limited or even a biased sample set, and as a consequence, the initial results can look much better than they are in reality. Typical examples have included the determination of the quality of complex food products, such as coffee, tea, olive oil, or wine [11]. Under laboratory conditions for a strongly restricted set of samples, the correlations may succeed: nevertheless, no commercial breakthrough to industry took place. There are many reasons for this approach to fail; one key factor is often a mismatch between the detector sensitivity and the components responsible for the odor [12].

Three application areas are as follows:

Plastic Industry

The plastic packaging industry is ubiquitous and part of our every day existence. Plastic is a wonderful material but if not prepared correctly it can produce a foul odor which has been responsible for tainting of products placed within the plastic container.

Food and Beverage Industries

Odors and fragrances are important for different reasons in the food and beverage industry. Here the freshness of ingredients becomes of primary concern. An example is the freshness of tomatoes which are the principal ingredient of spaghetti sauce and other well known recipes.

Onboard Sensors for Automobiles

Automobiles are well known for their smog producing vapors and everyone is familiar with ‘that new car smell’. Ever since automotive engineers began using microprocessors in automobiles there has been a demand for more and more on-board sensors to feed them. An on-board electronic nose has many uses such as monitoring the engine emissions and smog control system. Also, monitoring odors inside and outside the vehicle would provide warnings to the occupants when they were exposed to dangerous vapors such as benzene and toluene. An example of an auto exhaust chromatogram and the interior Vapor- Print™ of a new Oldsmobile Alero are shown in following Figure. Bloodhound’s BH 114 system uses tuned arrays of multiple gas sensors to measure and record fragrances, odors, and mixtures of volatiles as digital patterns [13].

Food industry, cosmetics/perfumes and aroma, chemistry, polymers, environmental, medical diagnostics and military applications are some of the areas where e-noses may be used effectively and profitably.

Food Industry

Food freshness, monitoring of fermentation, and spoilage and off-flavor are some possible applications of the e-nose. In other words e-noses may be used for QA in production, storage, and display. Fish storage measurement has been done. Identification of foodstuff, such as soy sauces and spices has been demonstrated. Off-flavoring of beers have been monitored. Citrus products have been classified. Recently, e-noses were used to supplement 19 humans in grading various cheeses. The Vieux Boulonge cheese made in Boulonge-sur-Mer, Northern France and aged for 7 – 9 weeks was the smelliest, followed by the English Cheddar cheese. The Material Science Labs of Sony Corp. in Europe is collaborating with European universities to make large nanotechnology memory chips [14].

Environmental Application

There are many important environmentally related applications for an Electronic Nose. Air pollution and many different types of odors are common pollutants which require monitoring and quantification. The exhaust from automobiles and trucks is a very good example of environmental air pollution. Environmental pollution in soil (solid

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matrices) is also an important application for electronic noses, particularly, when the nose is configured to detect semi-volatile compounds like pesticides, PCBs, and dioxins. Using direct desorption or liquid extraction techniques with soil based upon EPA methods provides techniques for evaluating this type of soil contamination [15].

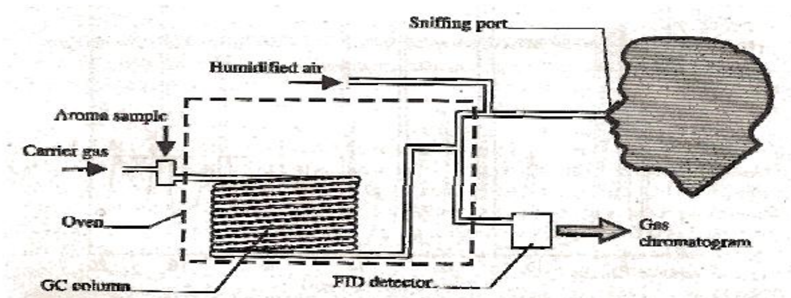

Figure 1. Gas chromatography olfactometry (GCO) configuration. The gas chromatographer accommodates a sniffing port for the human operator. Figure taken from ref [3].

Figure iv: G.C.O configuration [16]

The number of successful applications is expanding rapidly and with considerable diversity. Because chromatography is an accepted analytical technique, GC/SAW technology is able to satisfy and follow accepted testing methodology. The ability to perform these methods with precision, speed, and accuracy is unique to the GC/SAW enose. Olfactory imaging is proving more useful than at first expected because of the human ability to recognize subtle visual changes in Vapor Print™ images [17].

Disease Diagnosis

Smell has been used to diagnose disease since ancient times and is directly linked to traditional medicine in different cultures. ("You can learn a lot just by smelling your patients with the unaided nose." -Hippocrates, 430 B.C.) However, as modern diagnostic techniques provide more precise information with physical, chemical, and microbiological methods observation of odors fades into the background and is used only in some obvious cases as a disease indicator. The subjective odor perception of the physician is no longer required, although this ignores a lot of information on the health condition of the patients [18].

Early use of Aroma-Detection in Evaluating Health Conditions

Medical doctors have utilized the sense of smell to facilitate determinations of the physical state and general health of their patients for centuries. The application of smell as useful sensory clues used by physicians to identify the causes of human ailments resulted in the development of qualitatively descriptive odors (or aromas) and specialized terms used to describe and identify odors associated with specific human diseases and physiological disorders. Some descriptive aromas found to be associated with some common humandiseases are presented in following Table [19].

Table 1: Descriptive aromas previously used for diagnosing human diseases

Disease / Disorder	Body source	Descriptive aroma
Anaerobic infection	Skin, sweat	Rotten apples [20]
Congestive heart failure	Heart	Dimethyl sulfide [21]
Fetor hepaticus	Breath	Newly-mown clover [22]
Gout	Skin	Gouty odor [23]

Discovery of Bioindicators of Disease

The discovery and recognition of particular volatile organic compounds (VOCs), released from various diseased human body parts or fluids derived from these tissues, have been found to be associated with specific human diseases through the use of specialized modern analytical instruments. These instruments have included such analytical machines as gas chromatographs working in tandem with mass spectrometers (GC-MS) and other such technical instruments used in analytical chemistry. The results of intense chemical analyses from numerous research studies have been the identification of many volatile biomarkers of disease and their associated chemical structures. The identification of unique molecular markers (volatile metabolites) associated with particular diseases has become an extremely effective and powerful tool for the early detection of diseased tissues and infectious agents in the human body. For example, the analysis of patients' breath odors has had a long history of application for the detection of various human diseases, not only respiratory diseases. Even though the human breath contains hundreds of volatile organic compounds at low concentrations, relatively few (less than fifty) of these are detected in the majority of healthy humans under normal physiological conditions [24].

Table 2: Molecular biomarker VOCs of specific human diseases and disorders

Disease / Disorder	Volatile chemical biomarkers
Allograft rejection	Carbonyl sulfide [25]
Breast cancer	C4-C20 alkanes [26]
Cholera	p-menth-1-en-8-ol, dimethyl disulphide [27]
Chronic hepatitis	Methyl-mercaptan, dimethyl sulfide [28]
Cirrhosis	Dimethyl sulfide, mercaptans [29]
Cystic fibrosis	Leukotriene B4, interleukin-6, carbonyl sulfide, alkanes [30]
Hepatic encephalopathy	3-methylbutanal [31]

Working e-nose Applications in Current Medical Practice

E-noses in general have the advantages of providing patient laboratory results much faster than standard cultures or wet chemistry tests and the capability of providing early detections of diseases before symptoms appear. These characteristics have been compelling reasons for the development of e-nose systems for clinical medicine. Some recent uses of electronic noses in hospitals and universities around the world are presented in following Table.

Table 3: Electronic-nose uses in hospitals and universities around the world

Country	Hospital, University or Research Facility	E-nose utilized	Application
USA	University of Pennsylvania	Experimental model	Distinguish Cerebrospinal fluid [32]
Tanzania	National Institute of Medical Research	Bloodhound EN	Diagnosis of Tuberculosis [33]
United Kingdom	Birmingham Heartlands Hospital	Cyranose 320	Identify *Staphylococcus* [34]
Germany	University of Applied Sciences	DE 101	Detect renal Dysfunction [35]
Belgium	University of Antwerp	PEN 2	Clinical diagnoses of bacteria [36]
Australia	Prince Charles Hospital	unspecified	Detect chronic lung disease [37]

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