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Electronic Nose

[1]Abdul Sayeed and [2]Mohammed Suhail Shameem
[1]*Lt. Haribai Warpudkar Colleg, SRTMU, Basmat Road, Parbhani, India*
[2]*MIT&M College, Anand Nagar, SRTMU, Nanded-431602 India*
e-mail: Sayeed002@rediffmail.com, Suhail_mca@rediffmail.com

Abstract—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. The array of sensors consists of a number of broadly tuned (non-specific) sensors that are treated with a variety of odour-sensitive biological or chemical materials. An odour stimulus generates a haracteristic fingerprint from this array of sensors. Patterns or fingerprints from known odours are used to construct a database and train a pattern recognition system so that unknown odours can subsequently be classified and/or identified. Over the last decade, "electronic sensing" or "e-sensing" technologies have undergone important developments from a technical and commercial point of view. The expression "electronic sensing" refers to the capability of reproducing human senses using sensor arrays and pattern recognition systems. For the last 15 years as of 2007, research has been conducted to develop technologies, commonly referred to as electronic noses, that could detect and recognize odors and flavors.

I. INTRODUCTION

An electronic nose is an array of non-specific chemical sensors, controlled and analyzed electronically, which mimics the action of the mammalian nose by recognizing patterns of response to vapors. The sensors used here are conduct metric chemical sensors which change resistance when exposed to vapors. The sensors are not specific to any one vapor; it is in the use of an array of sensors, each with a different sensing medium, that gases and gas mixtures can be identified by the pattern of response of the array. An electronic nose (e-nose) is a device that identifies the specific components of an odor and analyzes its chemical makeup to identify it. An electronic nose consists of a mechanism for chemical detection, such as an array of electronic sensors, and a mechanism for pattern recognition, such as a neural network. Electronic noses have been around for several years but have typically been large and expensive. Current research is focused on making the devices smaller, less expensive, and more sensitive. The smallest version, a nose-on-a-chip is a single computer chip containing both the sensors and the processing components. An odor is composed of molecules, each of which has a specific size and shape. Each of these molecules has a correspondingly sized and shaped receptor in the human nose. When a specific receptor receives a molecule, it sends a signal to the brain and the brain identifies the smell associated with that particular molecule. Electronic noses based on the biological model work in a similar manner, albeit substituting sensors for the receptors, and transmitting the signal to a program for processing, rather than to the brain. Electronic noses are one example of a growing research area called biomimetics, or biomimicry, which involves human-made applications patterned on natural phenomena.

Electronic noses were originally used for quality control applications in the food, beverage and cosmetics industries. Current applications include detection of odors specific to diseases for medical diagnosis, and detection of pollutants and gas leaks for environmental protection.

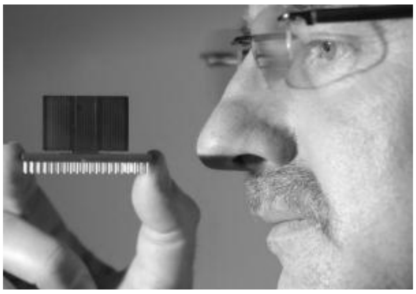

Fig. 1: Sensor Used by Odor-Sensing "Electronic Noses" That Mimic the Action of the Mucus in the Natural Nose.

II. WORKING PRINCIPLE

An electronic nose that uses an array of 32 polymer–carbon black composite sensors has been developed, trained, and tested. By selecting a variety of chemical functionalities in the polymers used to make sensors, it is possible to construct an array capable of identifying and quantifying a broad range of target compounds, such as alcohols and aromatics, and distinguishing isomers and enantiomers (mirror-image isomers). A model of the interaction between target molecules and the polymer–carbon black composite sensors is under development to aid in selecting the array members and to enable identification of compounds with responses not stored in the analysis library. The electronic nose was developed in order to mimic human olfaction that functions as a non-seperative mechanism: i.e. an odor / flavor is perceived as a global fingerprint. Electronic Noses include three major parts: a sample delivery system, a detection system, a computing system. The sample delivery system enables the generation of the headspace (volatile compounds) of a sample, which is the fraction analyzed. The system then injects this headspace into the detection system of the electronic nose. The sample delivery system is essential to guarantee constant operating conditions.

The detection system, which consists of a sensor set, is the “reactive” part of the instrument. When in contact with volatile compounds, the sensors react, which means they experience a change of electrical properties. Each sensor is sensitive to all volatile molecules but each in their specific way. Most electronic noses use sensor-arrays that react to volatile compounds on contact: the adsorption of volatile compounds on the sensor surface causes a physical change of the sensor. A specific response is recorded by the electronic interface transforming the signal into a digital value.

Recorded data are then computed based on statistical models. The more commonly used sensors include metal oxide semiconductors (MOS), conducting polymers (CP), quartz crystal microbalance, surface acoustic wave (SAW), and field effect transistors (MOSFET).In recent years, other types of electronic noses have been developed that utilize mass spectrometry or ultra fast gas chromatography as a detection system. The computing system works to combine the responses of all of the sensors, which represents the input for the data treatment. This part of the instrument performs global fingerprint analysis and provides results and representations that can be easily interpreted. Moreover, the electronic nose results can be correlated to those obtained from other techniques (sensory panel, GC, GC/MS).

III. DEVELOPMENT OF ELECTRONIC NOSE

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

A. The First Generatione-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.

Fig. 2: First Generation E-Nose.

B. Second Generation E-Nose

The second-generation ENose (Figure 5) 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. The power requirements of the 2nd -generation ENose are similar to those of the 1st generation device. The body and flow system of the 2nd generation device are made from a single block of hard-anodized aluminum; this design was chosen to eliminate fittings and to ensure that there are no leaks in the flow system. 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. The sensors are films of polymers which have been loaded with carbon to make them conductive. After the ENose Flight Experiment on STS-95, it was clear that confidence in the ability of ENose to identify and quantify compounds cannot be developed during flight. Such confidence must be developed on the ground, with an optimized device and test conditions which will challenge the sensors and the identification software. Sensor optimization work has included studies of noise, reaction time, and sensor recovery by studies of conductive medium, film thickness and sensor size. Data acquisition work has focused on the use of AC measurements of the sensor response to ppm levels of contaminant. AC methods may allow the use of very thin films and thus increase sensitivity while decreasing noise.

Figure 3 shows plot of sensor response as change in impedance (I/I0) vs. time, at several frequencies. Change in impedance is normalized to initial impedance, I0. The sensor, a film of carbon-loaded polyethylene oxide, responds to an injection of 4700 ppm ethanol. Figure 4 shows how frequency dependent measurements can be used to turn a single sensor into a virtual array. For a particular polymer film, the response at different frequencies to different compounds will result in a pattern such as can be made from Figure 4.

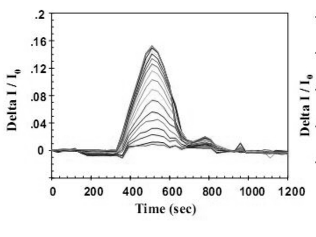

Fig. 3: Response as I/I0of a film of carbon-loaded Polyethylene oxide to an injection of 4700 ppm ethanol at 325 sec.

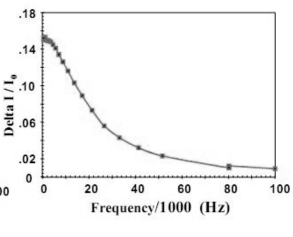

Fig. 4: Response as I/I0 vs. Frequency at 510 Seconds in the Plot Shown in Figure 1.

In the 2nd Generation ENose Sensor Unit, the unit was coupled with a desktop and/or laptop computer for lab experiments. A Personal Data Assistant (PDA), as shown in the photograph, may be used for device

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control and data collection, with the data analyzed later. The objective of this project is to prepare the ENose Sensor Unit as a technology demonstration on board the International Space Station (ISS). A modified 2nd Generation ENose Sensor Unit coupled with an Interface Unit will become the 3rd Generation ENose.

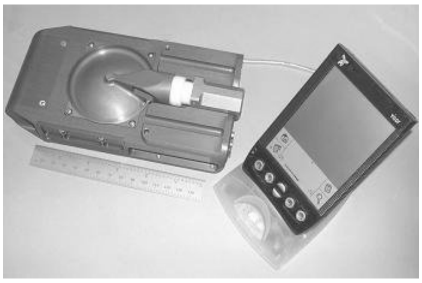

Fig. 5: 2nd Generation E-Nose

C. *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.

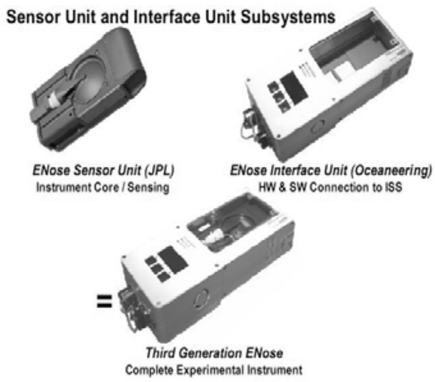

Fig. 6: 3rd Generation E Nose.

The ISS computer system manages data collection from the ENose Sensor Unit and communication between the ISS and the ENose Unit. A data analysis computer will also be incorporated inside the ENose Interface Unit. The ENose Interface Unit will control the thermal environment of the ENose Sensor Unit.

IV. APPLICATIONS

A. *Electronic Nose for Space Missions*

The ability to monitor the constituents of the breathing air in a closed chamber in which air is recycled is important to NASA for use in closed environments such as the space shuttle, the space station, and planned human habitats on Mars or the Moon. The best real time, broad band air quality monitor now available in space habitats is the human nose. It is limited by human factors such as fatigue, exposure to toxins, and inability to detect some compounds. At present, air quality from the space shuttle is determined on the ground after a flight by collecting samples and analyzing them in laboratory analytical instruments such as a gas chromatograph-mass spectrometer (GC-MS). The availability of a miniature, portable instrument capable of identifying contaminants in the breathing environment at levels which have the potential to be harmful to crew health would greatly enhance the capability for monitoring the quality of recycled air as well as providing notification of the presence of potentially dangerous substances from spills and leaks.

B. *Electronic Nose for Environmental Momitoring*

Enormous amounts of hazardous waste (nuclear, chemical, and mixed wastes) were generated by more than 40 years of weapons production. The Pacific Northwest National Laboratory is exploring the technologies required to perform environmental restoration and waste management in a cost effective manner. This effort includes the development of portable, inexpensive systems capable of real-time identification of contaminants in the field. Electronic noses fit this category. Environmental applications of electronic noses include analysis of fuel mixtures, detection of oil leaks, testing ground water for odors, and identification of household odors. Potential applications include identification of toxic wastes, air quality monitoring, and monitoring factory emissions.

C. *Electronic Nose for Medicine*

Because the sense of smell is an important sense to the physician, an electronic nose has applicability as a diagnostic tool. An electronic nose can examine 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, 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. Currently, an electronic nose for examining wound infections is being tested at South Manchester University Hospital.

V. CONCLUSION

E-Noses can be used to identify and differentiate complex mixtures and individual chemicals. Eventual deployment of the ENose as one part of a fully automated environmental monitoring and control system is envisioned. In this scenario, activities such as remediation of spills and leaks would be actuated through a logic system and would be done robotically. Work continues in developing a model of sensor-analyte interaction to optimize selection of materials for a sensing array as well as for possible future use to identify array responses from untrained-for compounds. Further work will involve comparing neural network sensor analysis to more conventional techniques, exploring other neural network paradigms, and evolving the preliminary prototypes to field systems.

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