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Review

Advances in artificial olfaction: Sensors and applications

J. Gutiérrez, M.C. Horrillo*

Grupo de I+D en Sensores (GRIDSEN), Instituto de Tecnologías Electrónicas y de la Información (ITEFI), CSIC, C/Serrano 144, 28006 Madrid, Spain

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A B S T R A C T

The artificial olfaction, based on electronic systems (electronic noses), includes three basic functions that operate on an odorant: a sample handler, an array of gas sensors, and a signal-processing method. The response of these artificial systems can be the identity of the odorant, an estimate concentration of the odorant, or characteristic properties of the odour as might be perceived by a human. These electronic noses are bio inspired instruments that mimic the sense of smell.

The complexity of most odorants makes characterisation difficult with conventional analysis techniques, such as gas chromatography. Sensory analysis by a panel of experts is a costly process since it requires trained people who can work for only relatively short periods of time. The electronic noses are easy to build, provide short analysis times, in real time and on-line, and show high sensitivity and selectivity to the tested odorants. These systems are non-destructive techniques used to characterise odorants in diverse applications linked with the quality of life such as: control of foods, environmental quality, citizen security or clinical diagnostics.

However, there is much research still to be done especially with regard to new materials and sensors technology, data processing, interpretation and validation of results.

This work examines the main features of modern electronic noses and their most important applications in the environmental, and security fields. The above mentioned main components of an electronic nose (sample handling system, more advanced materials and methods for sensing, and data processing system) are described. Finally, some interesting remarks concerning the strengths and weaknesses of electronic noses in the different applications are also mentioned.

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* Corresponding author.
E-mail address: carmen.horrillo.guemes@csic.es (M.C. Horrillo).

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1. Introduction

The human nose is much more complicated than other human senses like the ear and the eye, at least regarding the mechanisms responsible for the primary reaction to an external stimulus. Therefore it has been much simpler to mimic the auditory and the visual senses. In olfaction hundreds of different classes of biological receptors are involved. Although several interesting developments have been made regarding so-called electronic noses, their performance is far from that of our olfactory sense. They are not as sensitive as our nose to many odorous compounds. The human nose contains approximately 50 million cells in the olfactory epithelium that act as primary receptors to odorous molecules. There are about 10,000 primary neurons associated with these primary receptors that link into a single secondary neuron which in turn feeds the olfactory cortex of the brain [1]. This parallel architecture suggests an arrangement that could lead to an analogous instrument capable of mimicking the biological system. Despite this difference, chemical sensor arrays combined with pattern recognition methods are very useful in many practical applications such as monotonous tasks in environment and food quality control and security. Electronic noses are thus emerging as a new type of instrumentation, which can be used to measure the quality or identify an aroma of a compound [2]. They work in a similar way and have, in that respect, a large similarity with the human nose [3,4].

The electronic nose is an electronic system that tries to imitate the structure of the human nose, so the first step is the interaction between volatile compounds (usually a complex mixture) with the appropriate receptors: olfactory receptors in the biological nose and a sensor array in the case of the electronic nose fulfilling the rule. “One odorant receptor is sensitive to multiple smells and one smell is detected by multiple odorant receptors”. The next step is the storage of the signal generated by the receptors in the brain or in a pattern recognition database (learning stage) and later the identification of one odour stored (classification stage).

Vertebrate olfactory systems can identify and distinguish volatile compounds (odorants) of diverse molecular structures with high accuracy. The mammalian nose can detect certain compounds in concentrations as low as a few parts per trillion [5]. Such performances are due to numerous olfactory receptors (ORs) expressed by olfactory sensory neurons and their subsequent neuronal processing.

Each of the ORs can bind to numerous odorants with specific affinities, although some receptors are relatively restricted to a set of few chemically related compounds in the process of sensing the smell, the binding of specific odorants to the OR proteins is the initiation step in odour recognition and the triggering of signal transduction in a cell. In [6] it is stated that “Given the fantastic odour space detected by the olfactory receptors, it is tempting to harness them to some generic electronic devices that could be endowed with some of the most prominent properties of animal olfaction: discrimination, specificity and sensitivity.” Recent studies have led to a more refined understanding of olfactory neurons and the mechanisms involving odorant detection [7].

The joint efforts of biologists and biochemists have revealed that olfactory receptor achieve odorant identification and signal transduction by employing molecular elements. An olfactory system plays an important role in identifying food and recognising environmental conditions. Olfactory sensing can be used for detecting human diseases [8–11], food contamination or hazardous agents [12–18]. Currently, olfactory research is focused on the discovery of potential commercial applications. Biomimetic design of an electronic nose on the principle of the mammalian olfactory system can aid in increased sensitivity and selectivity [19] for various trace level odorant detection applications. Different components of the biological olfactory system are being used for fabricating sensors.

This paper describes the state of the art of the use of electronic noses in: environmental quality monitoring, and citizen safety and security.

An electronic nose is a machine that is designed to detect and discriminate among complex odours using a sensor array. The sensor array consists of broadly-tuned (non-specific) sensors that are treated with a variety of odour-sensitive biological or chemical materials.

An odour stimulus generates a characteristic fingerprint (or “smellprint”) from the sensor array. 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 identified [2]. This is the classical concept of an e-nose; however, in recent years, as discussed below, the classical sensor types used for e-noses have been enhanced and complemented by other technologies introduced in this field.

An accepted definition of an electronic nose is: “an instrument which comprises an array of electronic chemical sensors with partial specificity and an appropriate pattern recognition system, capable of recognising simple or complex odours and tries to characterise different gas mixtures [3]. This definition restricts the term electronic nose to those types of sensor array systems that are specifically used to sense odorous molecules in an analogous manner to the human nose. However, the architecture of an electronic nose has much in common with the multisensor systems, designed for the detection and quantification of individual components in a simple gas or vapour mixture. A simple flow chart of the typical structure of an electronic nose consists of an aroma extraction technique or air flow system which switches the reference air and the tested air; an array of chemical sensors which transform the aroma into electrical signals; an instrumentation and control system to measure the sensors signal and a pattern recognition system to identify and classify the aroma of the measured samples in the classes previously learned when using supervised learning or perform by itself the classification in unknown classes. It uses currently a number of individual sensors (typically 5–100) whose selectivity towards different molecules overlaps. The response from a chemical sensor is usually measured as the change of some physical parameter, e.g. conductivity, frequency or current. The response times for these devices range from seconds up to a few minutes. By teaching a computer (or hardware) to recognise different patterns, it should now be