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ELECTRONIC NOSE (draft)

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1. Introduction

Across a wide range of applications there is a need to rapidly detect, identify, and quantify complex volatile mixtures. Food manufacturers need to monitor the quality of incoming raw products and evaluate the perceptual properties of their products; environmental agencies seek to regulate the emission of malodors from waste treatment and other industrial plants. Humans readily accomplish these tasks through the sense of smell. Could an instrument be developed to mimic these capabilities? This entry describes the technology of electronic noses, discusses the challenges associated with mimicking human olfaction, and reviews past and current application areas of electronic noses.

2. Definition of an electronic nose

Electronic noses (or e-noses for short) are scientific instruments that detect, recognize, and quantify volatile chemicals in a manner that is loosely reminiscent of the sense of smell. The concept of an e-nose dates back to a 1982 article by Krishna Persaud and George Dodd, which showed that fine discrimination between odorants is possible without highly selective sensors. Instead, and much like the human nose, e-noses rely on cross-selective sensors; that is, sensors that respond to many different odorants, though the strength of the response varies with each odorant. To discriminate odorants, e-noses (and human noses as well) use an array of sensors with different cross-selectivities. In this way, the response pattern across sensors becomes a fingerprint for each particular odorant. In addition to chemical sensors, e-noses require a pattern-recognition system and an odor-delivery system, as described next.

Chemical sensors consist of two elements: a sensing layer and a transducer. The sensing layer is made of a material whose properties change when odorant molecules are adsorbed on its surface; as an example, the sensing material may change its electrical resistance or its mass. In turn, the transducer converts these changes into an output signal; as an example, a transducer may convert mass changes in the sensing layer into frequency changes of an output signal, which then can be easily recorded with a computer. Sensing materials for e-noses can be inorganic (metal oxides are typical), organic (e.g., conducting polymers), and biological (e.g., proteins). Typical transducers for e-noses are based on conductivity or mass changes, though other transduction principles can be used as well (e.g., capacitive, calorimetric, optical, field effect), sometimes simultaneously.

Most e-noses operate under two basic forms of odor delivery: static headspace and dynamic headspace. In static headspace analysis, a sample is placed inside a closed container along with the sensor array, and the headspace above the sample is allowed to equilibrate before recording the sensor array response. In the dynamic headspace method, an effluent (e.g., filtered room air) flows through the sample continuously, carrying odorant molecules to the sensor array located in a separate chamber. Several techniques (e.g., preconcentration, separation) can also be used to condition odorant samples before they are delivered to the sensors.

Once an odorant sample has been delivered to the sensor array and the corresponding response has been recorded, the signals are analyzed with a pattern-recognition system. Depending on the application, the goal of the analysis may be to classify the sample into one of several potential categories (e.g., fresh vs. spoiled milk), predict a set of properties for the sample (e.g., concentration, quality), or find samples that are similar (e.g., clustering).

3. Mimicking human olfaction

The term "electronic nose" suggests that the instrument could be used to predict the perceptual properties of an odorant. Prediction of perceived intensity is straightforward since both chemical sensors and olfactory receptors have monotonic concentration-response curves. However, prediction of qualitative descriptors is more challenging, unless the problem is constrained to specific applications (e.g., rating the freshness of particular foods). Unlike vision and hearing, in which the properties of rods/cones and hair cells can be explained in terms of light wavelengths and sound frequencies, respectively, the primary dimensions of olfaction are still unknown. Findings by Linda Buck and Richard Axel, which led to the 2004 Nobel Prize in Physiology or Medicine, indicate that olfaction is high dimensional (about 350 olfactory receptors in humans). However, the precise odorant properties detected by each olfactory receptor are yet unknown, which makes it difficult to develop chemical sensors with response properties similar to those of olfactory receptors. In addition, olfactory stimuli can contain many individual chemicals (e.g., over 800 different volatile compounds in coffee), and the perception of odor mixtures is poorly understood. Finally, current chemical sensors have detection thresholds that are several orders of magnitude higher than those in the olfactory system.

4. Applications and outlook

E-noses represent a trade-off between high-end analytical instruments, such as mass spectrometers or gas chromatographs, and sensory analysis with human panels. Like analytical instruments, e-noses can provide objective results; like human panels, e-noses provide an overall response (a gestalt), rather than a fine analysis of a smell into its individual constituents. Early commercial e-noses were marketed as general-purpose instruments that could be calibrated to any application by "retraining" their pattern-recognition model on the odorants of interest. Experience has shown that this is not possible with current chemical sensors. As a result, current commercial efforts are moving towards application-specific chemical sensor systems. In the food and beverage industry, e-noses can be used to inspect raw ingredients (e.g., olive oil quality), monitor production processes (e.g., fermentation and roasting), and estimate the shelf life of products (e.g., fish spoilage), to name a few scenarios. E-noses also have application in environmental problems, where they could be used to monitor emissions (e.g., waste disposal sites) and indoor air quality (e.g., ventilation systems in hospitals). Finally, e-noses have shown potential for the rapid diagnosis of disease by analyzing odors from skin (e.g., yellow fever), breath (e.g., diabetes), sweat (e.g., diphtheria), as well as odors from waste products and excretions. Thus, while e-nose systems are yet unable to describe a Marqués de Murrieta 1989 Ygay Rioja as having "intense black fruit and vanilla aromas with a lovely scent of something surprising like toasted coconut," a variety of applications can benefit from specialized e-noses that can rapidly recognize and quantify volatile compounds.

See also: Ageing and chemical senses; Air quality; Olfactometry; Olfactory quality; Olfactory receptors and transduction; Olfactory stimulus; Transduction.

5. Further readings

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