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A review on combined odor and taste sensor systems

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A B S T R A C T

When partaking of any food or beverage, we actually perceive its flavour, which is the combined effect of aroma and taste. This parallel processing of signals from our nose and tongue is possible due to the presence of large and complex biological neural networks in our brain. Artificial perception of odor and taste is attempted by the scientists using similar techniques, and is implemented with an array of sensors and an array of electrodes known as electronic nose and tongue, respectively. Fusion of electronic nose and tongue at various levels provides improved results for various applications This review article discusses different techniques of fusing electronic nose and tongue information as well as applications of the combined system in different fields.

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1. Introduction

Electronic nose and tongue systems have received considerable attention in the field of sensor technology during the last two decades because of numerous applications in diverse fields of applied sciences. In the mammalian olfactory system, signals from numerous biological sensors known as olfactory receptors are processed in the olfactory bulb and finally analyzed in the brain. The collective set of receptors combined with pattern recognition results in the detection and identification of each odor. Advancement in aroma-sensor technology, electronics, biochemistry and artificial intelligence has made it possible to develop devices capable of measuring and characterizing volatile aromas released from various sources and the device is termed as electronic nose. It has wide applications in agriculture, biomedical, automobile and aerospace, environmental, food, military, pharmaceutical, explosive and in various other fields (Bhattacharyya et al., 2008; Brezmes et al., 2001; Di Natale et al., 2001; Boilot et al., 2000; Young et al., 2003; Capua et al., 2009). It has already demonstrated its potential to be used as a complementary tool for the human tasters who are employed by the food and beverage industries for quality

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evaluation of the products. Even though human panel tasting is being used for centuries, the disadvantages are many. It is subjective, depends upon the professional acumen of the personnel involved and suffers from inconsistency and unpredictability due to various human factors like individual variability, decrease in sensitivity due to prolonged exposure, fatigue, and variable mental states. Electronic nose is generally free from the effect of such factors and it is based on the principle of identification or classification of odour in a mixture of compounds rather than identifying individual components. Electronic nose (Persaud and Dodd, 1982) technology includes arrays of gas sensors that respond to a wide range of compounds along with advanced pattern recognition systems and artificial intelligent systems so that the user can extract reliable and relevant information. Taste is another organoleptic property governing acceptance of product through the mouth. The primary method for taste analysis is also by a human panel of tasters. Here, too, the drawbacks related to the human taster are prevalent. Moreover, unapproved drug and food molecules cannot be tasted by a panel taster. Keeping these factors in mind, taste analysis can now be carried out using chemical taste sensor array known as electronic tongue (Toko, 1998). The electronic tongue also extracts a total signature from the complex mixture of liquids rather than analysing individual components. It has several applications in environment monitoring, food and beverages, medical diagnostics, herbal products, detection of endotoxin and pesticide and in pharmaceuticals (Winquist et al., 1997; Eckert et al., 2011; Alonso et al., 2013; Lvova et al., 2009). Among these areas, applications in quality estimation for food, beverages and pharmaceutical applications using electronic nose and tongue are more in number and are more advanced. In case of human sensory system, the brain receives signals from the olfactory sensors and the tongue receptors and integrates them to provide a final judgment. Electronic sensory panels have their own hardware and software which generate data from the signals of each sensory system. These datasets from electronic nose and electronic tongue may be combined either at the data (low) level or in the feature (intermediate) level or in the decision (high) level. While the data level fusion combines the responses of the sensors at the raw data level, feature level fusion is carried out by extracting certain features from the responses and combining the features. The decision level fusion is similar to the fusion mechanism in the human brain where the decisions from each sensory system are fused. Whenever we partake of food, the basic taste therein is combined with the information from the olfactory receptors (when aroma from the food enters the nasal cavities) and a combined perception of flavour is obtained rather than each of them individually. Unlike other human senses, the exact mechanisms that lead to our perception of flavour have not yet been specially elucidated. It is recognized that the process involves a wide range of stimuli (Taylor and Roberts, 2008) which are thought to interact in a complex way. Since the chemical compounds and physical structures that activate the flavour sensors change as the food is eaten, measurements of the changes in stimuli with time are essential to an understanding of the relationship between stimuli and perception. Thus, the sensations of smell and taste are not independent, and both of them are influenced by each other. Considerable research interest is visible now for the development of integrated human-like smell and taste sensing capabilities for various applications.

Many review articles (Varadan and Gardner, 1999; Krantz-Rülcker et al., 2001; García-González and Aparicio, 2002; Deisingh et al., 2002; Gouma and Sberveglieri, 2004; Logrieco et al., 2005; Wang et al., 2007; Rudnitskaya and Legin, 2008; Escuder-Gilabert and Peris, 2010; Peris and Escuder-Gilabert, 2009; Ghasemi-Varnamkhasti et al., 2010; Tuantranont et al., 2011; Baldwin et al., 2011; Peris and Escuder-Gilabert, 2013) have been published on various sensor types for electronic nose and electronic tongue and several application areas of these sensor systems. The motivation for preparing this paper originated while studying the research reports in the area of combined odor and taste systems, wherein it is reported that the combined system, in general, outperforms the individual systems in terms of classification or quality evaluation. It is thus envisaged that wherever possible, the signals from these artificial sensor array based systems should be combined using suitable fusion algorithms to obtain results closer to the mammalian sensory systems. This review presents a compilation of the research reports with the combined system using electronic nose and tongue and future research directions in this field.

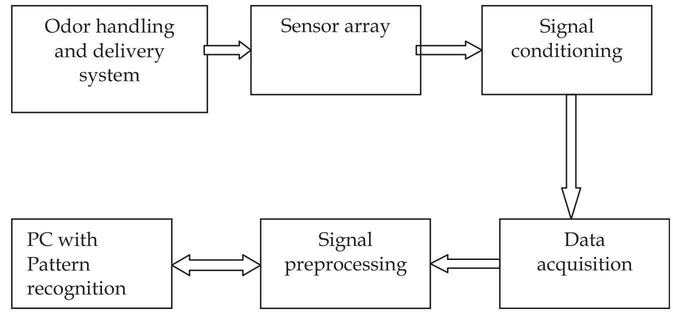

Fig. 1. Block diagram for electronic nose system.

2. Brief description of the sensing techniques of electronic nose and electronic tongue

Electronic nose detects the odour of the test sample whereas electronic tongue identifies the sample on the basis of taste. An electronic nose consists of an array of sensors for chemical detection and a pattern recognition unit. The odour recognition process is similar to human olfaction and is performed to identify, compare, quantify odors. The block diagram for electronic nose system is given in Fig. 1. The functioning of electronic tongue is similar to that of human taste buds. Unlike other conventional chemical sensors, which selectively detect specific chemical substances, a taste sensor is non-selective and broadly tuned. So, the taste sensors do not distinguish the individual chemical constituents but responds globally to the non-volatile compounds present in test sample. Finally, the signals are analyzed in a pattern recognition unit to discriminate between the samples. Fig. 2 describes the block diagram of an electronic tongue system.

3. Sensor &instrumentation system for the combined electronic sensing

The term “electronic nose” was coined in 1994 by Gardner and Bartlett (Gardner and Bartlett, 1994). Most of the electronic nose systems, whether developed for laboratory uses or available

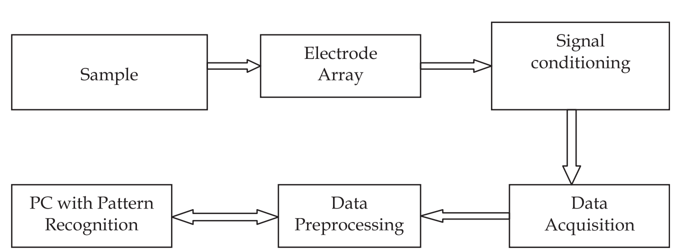

Fig. 2. Block diagram for electronic tongue system.