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Review

Fusion of artificial senses as a robust approach to food quality assessment

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ABSTRACT

Electronic nose (E-nose), Electronic tongue (E-tongue) and Computer Vision System (CVS) are three analytical systems which have been used separately in the food and pharmaceutical industries as quality evaluation methods. The E-nose and E-tongue are designed to mimic the mammalian olfactory and taste systems, both containing sensors that non-selectively interact with flavor molecules to produce some sort of electronic signals. The produced signals are related to the material quality or its main chemical components. The major aim in the use of CVS is to realize the mode of operation of human vision and is based on image analysis to extract some specific attributes as quality features. The extracted color and flavor features are analyzed in a computer using multivariate data analysis to recognize patterns in the data. Since these three systems are non-destructive, rapid, economic and consistent, their fusion can form a powerful and objective inspection tool able to out-perform the individual constituting techniques. The combined evaluation technique has a variety of applications replacing the systems that may not have sufficient performance individually for specific uses. Application of these three techniques are individually reviewed with emphasis on the fusion of the artificial senses. Spectroscopy methods which are also covered can be coupled with these artificial senses to enrich the extracted information from the food industry.

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1. Introduction

Quality assessment of food, pharmaceutical and medicinal plant products throughout all processes in the related industries is very important for both the consumer and the producers. With increased expectations of these products for high quality and safety standards, the need for accurate, fast and objective quality determination continues to grow and also is a challenging problem. Traditionally, panels of trained experts evaluate quality parameters, however, this suffers from a number of disadvantages such as being time consuming, expensive, discrepancies can occur due to human fatigue or stress and clearly cannot be used for online measurements. Also, conventional flavor analysis techniques including gas

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chromatography, spectroscopy and chemical analysis suffer from similar drawbacks such as high cost and not being suitable for on line quality control. Thus, the development of alternative methods for the objective, real-time assessment of food products in a reliable and cost-effective manner is highly desirable (Ghasemi-Varnamkhasti et al., 2010). In this regard, advances in sensor technology, electronics, biochemistry and artificial intelligence have made it possible to develop instruments such as E-nose, E-tongue and CVS capable of measuring and characterizing quality factors such as flavor, color, and chemical components of various products (Wilson and Baietto, 2009; Ghasemi-Varnamkhasti et al., 2011a; Cubero et al., 2011). Also, novel methods, combining the artificial senses, are presented in the recent years. These methods are combinations of artificial sensors (color, taste and smell) which have the potential to rapidly achieve more accurate results compared to the use of individual sensors (Apetrei et al., 2011). We are decided to review these novel methods in the following.

2. Use of artificial senses in food analysis

Computer or machine vision system as the integrated use of devices for non-contact optical sensing, computing and decision processes can receive and interpret the image of a real scene automatically (Dowlati et al., 2012). The application of CVS is quite widespread, particularly in the food industry. It has been widely used for quality inspection and grading of foods, fruits, and vegetables and has demonstrated the ability to provide objective assessment of some visual attributes of food quality (Narendra and Hareesh, 2010). Also, in combination with learning techniques it has been applied for the assessment of food quality such as prediction of some chemical parameters and color quantification (Shafiee et al., 2014a).

CVS includes subjects such as acquisition, processing, and analysis of images. It is a fast, precise, and noninvasive way of evaluating product quality in form of shape, size as well as color monitoring, and texture analysis (Domenico and Gary, 1994), but not in other senses. Poor working conditions such as improper illumination and observation and imperfections on the processing media can dramatically impress the image quality. Also the moisture content of the product surface can shift the reflective characteristics of the material and, accordingly, the quality of acquired image. Examples of work include: detection of color changes in beef samples and meat quality inspection (Larrain et al., 2008; Valous et al., 2009), fish quality assessment (Quevedo and Aguilera, 2010), inspection of fruits and vegetables (Ariana et al., 2006; Wang and Li, 2015), Tea grading (Wang et al., 2010; Laddi et al., 2012), analysis of morphological features or physical properties and spoiled grains in different grain varieties (Wan et al., 2000; Mendoza and Aguilera, 2004), monitoring of processed foods such as potato chips, pizza, sturgeon fillets, corn tortillas (Scanlon et al., 1994; Sun, 2000; Oliveira and Balaban, 2006; Mery et al., 2010), honey characterization based on color and its correlated chemical attributes (Shafiee et al., 2014b), and many other products as reported by Sliwinska et al. (2014) and Chen et al. (2015b).

E-nose is an analytical device which is usually made up of an array of sensors to respond to gases and vapors generated by the sample. The sensor array consists of non-specific sensors treated with a variety of chemical materials, each element measuring a different property of the sensed chemical (Bhattacharyya and Bandhopadhyay, 2010). As soon as the sensor array is exposed to the volatile molecules, smell prints are generated from the sensors. Patterns from known odors are used to construct the database and train a pattern recognition system so that unknown odors can be classified and identified. Applications of E-nose have been growing in different fields of research; attention being paid to quality control and process monitoring for the food industries. For example, the E-nose has been successfully applied for purposes of food process analysis such as monitoring postharvest processing of grapes (Pinheiro et al., 2002; Santonico et al., 2010), classification and quality evaluation of black tea (Bhattacharyya et al., 2008; Borah et al., 2008; Yu et al., 2009; Yang et al., 2009; Chen et al., 2013), saffron (Carmona et al., 2005), coffee (Falasconi et al., 2005; Rodriguez et al., 2009), ripeness and quality evaluation of pears (Oshita et al., 2000), oranges (Steine et al., 2001), apples (Echeverria et al., 2004; Saevels et al., 2003), mangos (Lebrun et al., 2008), pineapples (Torri et al., 2010), apricots (Parpinello et al., 2007), brewery (Ghasemi-Varnamkhasti et al., 2011b), peaches (Brezmes et al., 2000; Natale et al., 2001), Meat Quality Assessment (Ghasemi-Varnamkhasti et al., 2009), fish freshness (Huang et al., 2011), rice wine (Ouyang et al., 2013a), quality status of mandarin (Qiu et al., 2015b; Chen et al., 2016) and many others that have been reported (Sliwinska et al., 2014; Chen et al., 2015b; Loutfi et al., 2015). Unfortunately, the E-nose can sometimes lack the required sensitivity or can be disturbed by major compounds not relevant to the aroma (Rodriguez-Méndez et al., 2004). Quality evaluation of some beverages by E-nose has been known to be physically challenging due to the influence of water vapor and temperature drift (Ghasemi-Varnamkhasti et al., 2012).

In the case of E-tongue, it closely mimics the organization of human taste buds using sensor arrays with the appropriate pattern recognition methods and it can be defined as a multisensory system for liquid analysis based on chemical sensor arrays. Distinct signals are obtained by each sensor from different samples similar to an E-nose system. These signals can be used as "taste print" information to detect substances with different chemical properties. Several authors have applied E-tongue for identification of changes in taste and quality of different kinds of foods and beverages and indicated positive results. For example, in the field of food process monitoring, identification of the origin of raw milk (Winquist et al., 2005; Ciosek and Wroblewski, 2008), monitoring of wine aging (Parra et al., 2004, 2006a, b), classification of black tea taste (Ivarsson et al., 2001; Palit et al., 2009), taste changes of apricots during storage (Kantor et al., 2008), quality monitoring of orange juices (Medeiros et al., 2009), classification of mineral water (Men et al., 2009), classification of soy sauce (Ouyang et al., 2011), and many others that have been reported in the literature (Ghasemi-Varnamkhasti et al., 2010; Sliwinska et al., 2014). One of the most important drawbacks of the E-tongue is its make-up, based on the same type of sensors, i.e., potentiometric, voltammetric sensors, or inter digitated electrodes (IDEs) which restrict the amount of useful information obtainable from the samples (Haddi et al., 2014).

While E-nose and E-tongue present a number of advantages over traditional analyses, the sensors also involve a number of shortcomings which have yet to be solved (Ghasemi-Varnamkhasti and Aghbashlo, 2014). These include issues such as sensor poisoning, drift, and sensitivity. Recent trends to overcome these shortcomings include combining semiconductor chemical sensors with other types of gas sensors which use more than one type of sensor in the array systems. These systems are known as hybrid E-nose or E-tongue. While this complicates the sampling system (requiring more bulk and electronics), this hybrid technology is able to compensate for the shortcomings in current chemical sensor technology (Loutfi et al., 2015).

3. Hybrid E-nose and E-tongue technologies

Various kinds of gas sensors are available, but only four technologies i.e. Metal Oxide Semiconductor (MOS), Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFET), Quartz Crystal Microbalance (QCM) and Bulk acoustic wave (BAW) sensors