Sensory Instruments and Its Application in Dairy and Food Industry

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Abstract

The demand for sensor arrays in the dairy and food industry is growing because the versatility and ease of operation of those instruments make them appropriate for fast and accurate analysis of various products or for monitoring quality in the production process. The commercial electronic tongue can be used for the evaluation of various products in the dairy industry. The concept of electronic tongue or taste sensor has been developed rapidly in the last decade due to their large potential in food quality control. The electronic tongue is based on electrochemical sensors combined with multivariate data analysis. The electronic tongue uses a sensor array with partially overlapping selectivity to get information on quality parameters such as sample condition, the state of a process, or expected human perception. Sensors forming the array should exhibit various selectivity patterns to minimize correlation between sensor responses, which provides more information about the sample. Millions of nonspecific olfactory receptors are located in the nose and tongue which respond to various substances in gas or liquid form. The signal is transmitted to the brain where olfactory neurons process the signal and the image of the sensed substance is formed. As the electronic tongue classifies particular properties in complex systems, the results are not necessarily compared to human sensation but with other quality properties in a sample. The use of sensor arrays in food analysis grew rapidly in the last decade. It has been used in wine analysis, honey classification, soy sauce analysis, water analysis and other beverages like soft drinks, beer, tea, coffee and milk. Other uses, which do not include food analysis, are microbial species detection, heavy metals detection, rare earth metal ion detection and ion detection. Sensor arrays combined with multivariate data analysis are a powerful tool for monitoring quality control in various fields of dairy industry. Both the electronic nose and electronic tongue were used in the assessment of dairy products.

1. Introduction

The taste or smell of end products manufactured in the food, beverage or dairy industries can be of vital importance to the commercial success of the product. The expectations of consumers regarding the quality of products in these fields are continually increasing as a result of greater range of choices in the marketplace, which emphasizes product quality. Competition for market share and the added emphasis on quality have increased pressure on product development and rigorous QA/QC to meet consumer expectations. Ideally taste analysis, both in the development of new products and their routine production, should be carried out by tasting panels composed of human experts. In practice such panels are extremely expensive and especially problematic when used for production control purposes. With rapid growth in electronic hardware technology and spurt of software-based computation and processing, standardized identification through artificial sensors like E-Nose, E- Tongue have been recently used. E- Nose & E-Tongue technology has generated a lot of interest recently because of its versatile applicability in terms of identification and classification of processed food and consumer items (Sujatha et al., 2012).

The emerging non destructive food quality analysis techniques are capable of evaluating the finished products quality by analyzing their sensory outputs which may be in the form of flavor, odor, color, texture and taste one of the signs of this care is development and optimization of monitoring and control methods of both, food materials and their processing. Valuable source of information about quality of the particular product is the analysis of volatile compounds based on either classic sensor analysis or application of instrumental methods. Food products flavour is mostly caused by many volatile compounds which appear in such product. Volatile compounds are mainly responsible for shaping the organoleptic quality of many kinds of food, even though they are found in relatively small quantities in such products. Sensing and perception through these organs are done through biological, physiological, chemical processes involving finally the brain as the Central Processing Unit (Bartlett et al., 1997).

2. Tasting Panels

For manufacturers, the quality of incoming raw materials and finished products are of the upmost importance to achieve maximum consumer satisfaction. The use of sensory panels in manufacturing plants is however significantly more difficult within an R & D environment. Typically, sensory panelists in the factory are staff with other main responsibilities so that their availability can be limited. In addition, the production environment is very

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hostile to sensory analysis with the noise, odours and pressure making it difficult to get objective and reproducible results. Unlike the typical sensory panelist in R&D, a panelist in a manufacturing environment needs continual motivation when faced with for repetitive QC tasks for evaluating new production batches. In practice, therefore, such problems make the sensory panel method of QC difficult to implement and maintain in terms of routine operation and costs. However, given that the end-consumer will judge the product on the basis of taste, it is vital that the QC process of verifying taste be maintained. Such conflicting pressures are the impetus behind the current trend to improve current sensory QC/QA methods by the introduction of alternative or complementary methods. Such methods must be fast, accurate and cost effective and of course must correlate with the results of sensory panel analyses.

3. Sensor Array Systems

Now a day, odour, aroma and taste control evaluation can be performed by gas and liquid sensor array system - the so called electronic nose and electronic tongues. Due to their simplicity, rapidity and objectivity, they have started to be extensively used by major food, cosmetic and packaging companies in various applications such as quality control, product matching, origin identification, spoilage detection, and flavour quantification. Without needing any prior fractionation, electronic noses and tongues can determine the fingerprint of a complex volatile or dissolved compound mixture by an array of semi-specific sensors coupled to a pattern recognition system. Just as humans do, an electronic nose operates by recognizing the overall pattern of components. In addition, the "odour/aroma and taste fingerprints" could then be stored in a data base in a way analogous to the memorization of olfaction perception in the human brain. Many optical sensors which could detect contamination invisible to human eyes to inspect by E-vision systems.

4. Electronic Noses and Electronic Tongues: A Comparison

Electronic nose and electronic tongues instruments analyze different aspects of the sensory perception. The electronic nose (E-nose) measures volatile components of aroma/ odour in the sample headspace while the electronic tongue measures dissolved organic and inorganic components i.e. Non-volatile molecule that remain in the food/beverage. For electronic noses, the final response can be described as R = f (SG, H (P)), where SG represents the sensitivity and selectivity of the gas sensor array sensitivity and selectivity and H (P) is a variable representing the properties of the sample headspace. Electronic tongue (E-tongue) sensors detect all chemical species present directly in the liquid samples. Only some of these species can be observed in the sample headspace generated. The response R can be described as R = f (SL, P), where SL represents the sensitivity and selectivity of the liquid sensors and P represents the properties of the liquid sample. Typically, E-tongue systems measure attributes like saltiness, sweetness, bitterness, sourness and metallic taste. In general, these attributes are fairly similar for each application area. The two instruments are thus complementary in most applications.

4.1 Benefits of E-Nose and E-Tongue

E-Tongues and E-Noses have the ability to perform sensory based analyses like odour/aroma and taste rapidly and in a cost-efficient manner. Not only are the systems more rapid and objective than human based tasting panels but they are much more amenable to routine use for example in production QC applications. Since they correlate well with human sensory panels, the instruments can be described as a 'consumer based instrumental test'. E-noses and tongues also correlate well with more classical analytical methods such as HPLC and GC/GCMS instruments which measure a specific analyte or group of analytes. E-noses and e-tongues are however much more rapid. For example the HPLC analysis of caffeine levels in a carbonated soft drink generally takes about 15 minutes. An E-tongue will give the result in approximately 3 minutes.

5. Electronic Nose (E- Nose)

Electronic Nose is a machine designed to detect complex odors using sensor arrays. The sensor array consists of broadly tuned (non-specific) sensors that are treated with a variety of odor-sensitive biological or chemical materials. An odor stimulus generates a characteristic fingerprint from the sensory array. The fingerprint (or smell-print) is classified and identified with suitable pattern recognition engine for declaration of odor. The system consisting of a set (matrix) of electrochemical sensors, selective for certain volatile compounds. The instrument is equipped with appropriate system of pattern recognition capable of identification of simple and complex odours (Labonique et al., 2002).

5.1 Electronic Nose Principles

The e-nose attempts to emulate the mammalian nose by using an array of sensors that can simulate mammalian olfactory responses to aromas. The odour molecules are drawn into the e-nose using sampling techniques such as headspace sampling, diffusion methods, bubblers or pre-concentrators (Pearce et al., 2003). The odour sample is drawn across the sensor array and induces a reversible physical and/or chemical change in the sensing material, which causes an associated change in electrical properties, such as conductivity (Harsa, 2000). Each “cell” in the array can behave like a receptor by responding to different odours to varying degrees (Shurmer et al., 1992). These changes are transduced into electrical signals, which are preprocessed and conditioned before identification by a pattern recognition system as shown in Fig.

The E-Nose system is designed so that the overall response pattern from the array is unique for a given odour in a family of odours to be considered by the system. In effect, the electronic nose can create odor-exposure profiles beyond the capabilities of the human panel or GC/MS measurement techniques. The electronic nose is a system consisting of three functional components that operate serially on an odorant sample--a sample handler, an array of gas sensors, and a signal-processing system. The output of the electronic nose can be the identity of the odorant, an estimate of the concentration of the odorant, or the characteristic properties of the odor as might be perceived by a human.

5.2 Applications of Electronic Noses

Currently, the biggest market for electronic noses is the food industry. Applications of electronic noses in the food industry include quality assessment in food production, inspection of food quality by odor, control of food cooking processes, inspection of fish, monitoring the fermentation process, checking rancidity of mayonnaise, verifying if orange juice is natural, monitoring food and beverage odors, grading whiskey, inspection of beverage containers, checking plastic wrap for containment of onion odor, and automated flavor control.

5.2.1 Food Freshness, Quality, Ripeness and Shelf-Life

Electronic-nose systems have been designed specifically to be used for numerous applications in many different industrial production processes. A wide variety of industries based on specific product types and categories, such as the automobile, food, packaging, cosmetic, drug, analytical chemistry and biomedical industries utilize e-noses for a broad and diverse range of applications including quality control of raw and manufactured products, process design, freshness and maturity (ripeness) monitoring, shelf-life investigations, authenticity assessments of premium products, classification of scents and perfumes, microbial pathogen detection and environmental assessment studies.

The age of fruits (ripeness or maturity level) determines the shelf life and future rate of quality loss due to changes in flavor, firmness and color. Harvesting fruits at an optimal physiological condition ensures good quality at a later stage (when evaluated by the consumer) by enhancing a number of quality characteristics that extend the shelf-life, slow the rate of decline in firmness or texture, and maintain a preferred level of flavor and overall appearance. Several studies have demonstrated that the aroma emitted by fruits can indicate the maturity level and thus quality and shelf-life of the marketed product. Pathange et al. (20007) used maturity indices such as starch index and puncture strength to categorize fruit of the “Gala” apple variety into three maturity groups referred to as immature, mature and over-mature fruits. Gòmez et al. (2006) studied volatile production of unripe, half-ripe, full-ripe and over-ripe tomatoes using the PEN 2 E-nose (10 different metal oxide sensors) with principal component analysis (PCA) and linear discriminant analysis (LDA). The results demonstrated that the electronic nose could differentiate among the ripeness states of tomatoes and classify them with 100% reliability in each ripeness group.

The process of coffee production has been widely investigated by e-nose technologies to distinguish different types of coffee beans (Aishima, 1991), to identify various brands and mixtures, to classify commercial coffee blends [109] and separate samples with different roasting levels. Falascon et al. (2005) provided evidence for the efficacy of predicting the perfect ripening moment by analyzing roasted coffee with a new thin film semiconductor metal oxide gas sensor e-nose (Electronic Olfactory System EOS835). The human panel expert-taster assessment indicated that the best coffee quality resulted when samples lots were ripened for 96h. The electronic nose effectively recognized ripening progression and allowed the determination of necessary coffee quantity and operating condition needed to detect samples at the perfect 96-h ripening times Other studies involved in predictions of fruit maturity level and shelf life have been done on various fruits. For example, fried mango chips were evaluated for the presence of deteriorative aromas (Niruntasuk et al., 2006). Fuji apples were evaluated for the effects of different storage conditions, storage periods and days o shelf-life on ripening and condition (Echeverria et al., 2005). Supriyadi et al. (2004) investigated the specific aroma of a pentane extract in snake fruit. Others have examined the pre- and post-harvest characteristics of kiwifruit (Costa et al., 2003) and fresh-cut vegetables like chicory (Riva et al., 2002). Utilizing e-noses as a means of monitoring fruit freshness and shelf-life prior to marketing can have a number of benefits that maximize corporate profits and optimize customer satisfaction.

5.2.2 Milk and Dairy Products

Dairy products contain off-flavor compounds created by a variety of mechanisms such as through the action of natural and microbial enzymes and chemical changes catalyzed by light or heavy metals. In cheeses, quality, flavor and taste are closely connected to the ripening process which depends on the growth of bacteria, lipid degradation and oxidation, and proteolysis. Traditionally, sensory analysis was used to determine the product identity of cheese. However, detection of aroma compounds using electronic noses has become more and more important.

Russell (1995) first focused on the classification of Parmesan cheeses with differing rates of maturity. The Aromascan e-nose successfully distinguished the two types. They also were able to characterized Gorgonzola and Cottage cheese using polypyrrole semi-conductor sensors. Zondevan et al. (1999) used the electronic nose to classify block milk products, subjected to various heating processes, in order to predict the most favorable heating method. In this case, the results were moderate to good. Ampuero et al. (2002) found the electronic nose has a lower detection limit (0.5 mg/kg) and better precision compared to dynamic headspace gas chromatography (GC) for determining the presence of trimethylamine in Swedish milk samples.

Compared with near-infrared spectroscopy (NIRS), the electronic nose has shown better results.

Riva et al. (2005) demonstrated that NIR spectra (NIRS) collected from Crescenza cheese were influenced both by raw material and by its high moisture content. NIRS, like the classical measures such as acidity and texture chances, was able to detect only chemical modifications that occurred during the first stages of storage, whereas the results obtained by spectroscopy and electronic nose analyses were more useful because they could be used to monitor the shelf-life of these products as online

The shelf-life of milk also has been studied (Labreche et al., 2005). A Fox 4000 electronic nose equipped with 18 sensors and an auto sampler was used to evaluate the growth of total bacteria in milk stored at ambient temperature and 5 °C. The results showed that measurements generated by the electronic nose could be used to detect both bacterial growth in milk and shelf-life. Other studies that have focused on the feasibility of the electronic nose in evaluating the shelf-life of several other dairy products including yogurts (Navràtil et al., 2004), Taleggio cheese (Benedetti et al., 2002), Danish Blue Cheese (Trihaas et al., 2002), seasonal changes in whole milk powder aromas (Biolatto et al, 2007) and the selection of bacterial strains of Lactobacillus casei as flavor-producing adjunct cultures (Irmler et al., 2006).

5.2.3 Meat Products

Much work has been done in the electronic detection of quality characteristics of meat products within the food industry. Rajamäki et al. (2004) studied the applicability of an electronic nose for the quality control of modified-atmosphere packaged broiler chicken cuts with different temperature regimes. The electronic nose results were compared with those obtained by microbiological, sensory, and headspace GC analyses. The e-nose could clearly distinguish broiler chicken packages with deterioration from fresh packages either earlier or at the same time that sensory changes indicated significant deterioration. Counts of Enterobacteriaceae and hydrogen sulphide-producing bacteria were most consistently associated with the electronic nose results indicating that the electronic nose was capable of detecting even early signs of spoilage in modified atmosphere packed poultry meat. Vestergaard et al. (2007) found the storage time of a pork-meat pizza topping product was predictable using an electronic nose. The study included two independent test sets composed of "known" production samples and "unknown" production samples. The results showed that storage time of "known" samples was very well predicted, while the "unknown" storage time was fairly well predicted. This provided evidence that the electronic nose system was a relevant and useful device for on-line implementation in quality control of pork meat products.

5.2.4 Fish and Seafood Products

Haugen et al. (2005) confirmed the feasibility of the Fish Nose on direct quality measurements of smoked salmon. Quality changes were monitored by the Fish Nose and compared with results of traditional sensory, chemical and microbial measurements. In this case, gas-sensor selection was optimized for the detecting of changes in the highly volatile compounds mainly representing microbial metabolism during spoilage. The system was further tested on-site in a smoked salmon production plant. Due to varying ambient air conditions at the production plant during the measurements, the sensor readings had to be corrected by subtracting the background ambient air signal from the sensor readings. High rates of correct sample discrimination were obtained for fresh (95%) and tainted (93%) meat samples, respectively. Chantarachoti et al. (2006) evaluated the capability of a portable electronic nose in detecting spoilage of whole Alaskan pink salmon stored at 14 °C and in slush ice. In 92% of the samples, the instrument could correctly classify the fish as either fresh or spoiled.

6. Electronic Tongue (E- Tongue)

An Electronic Tongue is an instrument which comprises of electrochemical cell, sensor array and appropriate pattern recognition system, capable of recognizing simple or complex soluble non-volatile molecules which forms a taste of a sample.

An electronic tongue is a system for automatic analysis and recognition (classification) of liquids, including arrays of non-specific sensors, data collectors and data analysis tools. The result of an electronic tongue can be the identification of the sample, an estimation of its concentration or its characteristic properties. This technology has many advantages. Problems associated with human senses, like individual variability, impossibility of on-line monitoring, subjectivity, adaptation, infections, harmful exposure to hazardous compounds, mental state, are no concern of it (Winquist et al., 1997).

The electronic tongue uses a sensor array with partially overlapping selectivity to get information on quality parameters such as sample condition, the state of a process, or expected human percep-tion (Winquist et al., 2004). Sensors forming the array should exhibit various selectivity patterns to minimize correlation between sensor responses, which provides more information about the sample (Ciosek et al., 2006). The logic behind the applica¬tion of low-selectivity sensors is based on an analogy to biological organization of the olfactory and taste systems in mammals. Millions of nonspecific olfac¬tory receptors are located in the nose and tongue which respond to various substances in gas or liquid form. The signal is transmitted to the brain where olfactory neurons process the signal and the image of the sensed substance is formed. As the electronic tongue classifies particular properties in complex systems, the results are not necessarily compared to human sensation but with other quality properties in a sample (Winquist et al., 2004).

6.1 Principle of E- Tongue

Human have long been thought to detect four basic taste types viz. sweet, salty, sour and bitter. Very recently, a fifth candidate basic taste was identified: unami, the taste of monosodium glutamate (MSG), characteristic of protein rich foods. Taste buds are believed to contain receptor molecules that trigger nerve signals when they encounter flavor imparting molecules. The details of this system are still not understood. Each taste sensation may correspond to a fingerprint signal induced by the differential activation of the various taste receptors. E- Tongue works on this principle. It works by measuring dissolved compounds and taste substances in liquid samples (Giese, 2001).

It contains four different chemical sensors. The sensor comprises very thin films of three polymers and a small molecule containing ruthenium ions. These materials are deposited onto gold electrodes hooked up to an electrical circuit. In a solution of flavor some substances, such as sugar, salt quinine (bitter) and hydrochloric acid (sour), the thin sensing films absorb the dissolved substances. This alters the electrical behaviour of the electrodes in a measurable way. Each sensor responds differently to different tastes. A composite sensor that incorporates all four there four there four produces an electronic fingerprint of the taste. The researchers combine these responses into a single data point on a graph. The position on the graph reflects the type of taste: sweet lies towards the top left. For example sour towards the top right (Riul et al., 2002).

Various recognition techniques are ap¬plied in electronic tongues; potentiometry, voltam¬metry and conductometry being most commonly used (Winquist et al., 2004). The data obtained from the electronic tongue is processed by multi¬variate data analysis (MVDA), primarily by principal components analysis (PCA) which explains the vari¬ance in the experimental data. Potentiometric elec¬tronic tongues using lipid/polymer membranes have a concept of global selectivity which implies the ability to classify vast kinds of chemical substances into several groups, as really found in the taste reception in biological systems. The measur¬ing principle is based on the potential of electrodes across an ion-sensitive membrane with zero current flow (Winquist et al., 2004). Voltammetric elec¬tronic tongues are based on metal electrodes with different selectivity and sensitivity patterns. Through these electrodes a varying potential is applied to change the current/ voltage characteristics of an electrolytic solution which is then measured. Conductometry is the di¬rect measurement of the conductance between two inert identical electrodes, so that most specific ef¬fects due to electrodes are eliminated.

The use of sensor arrays in food analysis grew rapidly in the last decade. It has been used in wine analysis, honey classification, soy sauce analysis, water analy¬sis and other beverages like soft drinks, beer, tea, coffee and milk. Other uses, which do not include food analysis, are microbial species detection, heavy metals detection etc. Sensor arrays combined with multivariate data analysis are a powerful tool for monitoring quality control in various fields of dairy industry. Both the electronic nose (and electronic tongue were used in the assessment of dairy products. Winquist et al. (1998) started to use the voltammetric electronic tongue to monitor the deterioration of milk quality due to mi¬crobial growth. Winquist et al. (2005) also imple¬mented the voltammetric electronic tongue into the production line to follow different sources of milk coming into the process and to monitor the cleaning process after pasteurization. Dias et al. (2009) de¬veloped a potentiometric electronic tongue and used it in the detection of goat milk adulteration with bo¬vine milk. Paixão and Bertotti (2009) developed a disposable voltammetric electronic tongue and it was used to differentiate among milks with different pasteurization processes and adulterated milk with hydrogen peroxide. The use of voltammetric electronic tongue to monitor yoghurt production in a pilot facility also been observed.

6.2 Applications of E- Tongue

E- Tongue has a multitude potential application, which includes its uses in quality control laboratory. The E-Tongue has been designed to replace human tasters. E-Tongue can also taste cholesterol levels in blood and toxins in water.

In brewing industry, E- Tongue can be used to monitor batch to batch variation of the beers following the brewing process. E- Tongue allows product conformity testing, taste default detection, origin identification (Giese, 2001). The objective of the instrument is to complement the E- Nose and more important, allow the food and beverages industry to cover a large proportion of the sensory perception of consumers in essence, covering both aroma/ odour and taste (Tan et al., 2001). For orange juice and apple juice, E-Tongue will more typically measure the non volatile components, including chemical molecules, responsible for sweetness, bitterness, saltiness and sourness (Tan et al., 2001). This instrument has also been used to detect off flavor in beer, as in a pale ale lager containing too high a concentration of dimethyl sulfide (DMS), formed from a malt derived precursor during worth production or by contaminant bacteria during fermentation (Tan et al., 2001). An extremely important taste attribute of beer is its bitterness. A range of beers has also been analyzed using E-Tongue. Result shows the good linearity of quantification of BU (Bitterness Unit) using PLS.

E- Tongue has also been used for analysis of quality of high fructose corn syrup to detect some taint compounds responsible for the off flavors, such as fish taste/flavor formed by microbiological oxidation of protein residue and other taste/ odour descriptors including fruity, astringent, So2, salty, corn- caramel and moldy. Bleibaunm et al. (2001) tested a series of nine 100 % apple juices, including a three apple blend, vitamin C fortified apple/ pear juice and apple cider using E- Tongue.

Application of E- Tongue would allow the taste quality of a food to be monitored continuously from the raw material stage right through to final product. In recent years, E- Tongue finds food and beverage industry as the challenging environment for its routinely application in taste control and analysis.

7. Conclusion

E- Nose and E- Tongue technologies for measurement of quality are particularly suitable for the carrying out, mainly within a QC/QA environment, of rapid and objective sensory measurements, that are important in the food and beverage industries. Systems exist for either quantitative or qualitative analyses and have been shown to be useful in a wide variety of applications. When operated correctly, and calibration, validation and training process, the technology has been shown to be able to contribute significantly to the maintenance or improvement of quality for products destined for both the consumer market and the industrial market and to improve quality for both consumer and industrial products in these domains.

8. Future Developments

Future developments in the use of hybrid micro sensor arrays and the development of adaptive artificial neural networking techniques will lead to superior electronic noses. The major areas of research being carried out in this field are: Improved sensitivity for use with water quality and sensitive microorganism detection applications, Identification of microorganisms to the strain level in a number of matrices, including food, Improvement in sensitivity of the E-Nose for lower levels of organisms or smaller samples, Identification of infections such as tuberculosis in noninvasive specimens (sputum, breath) and Development of sensors suitable for electronic nose use, and evaluation of unexploited sensors (Alam et al., 2013).

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