Food Freshness Using Electronic Nose and Its Classification Method: A Review

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Abstract

Generally, E-nose mimics human olfactory sense to detect and distinguish an odor or gasses or volatile organic compound from a few objects such as food, chemicals, explosive etc. Thus, E-nose can be used to measure gas emitted from food due to its ability to measure gas and odor. Principally, the E-nose operates by using a number of sensors to response to the odorant molecules (aroma). Each sensor will respond to their specific gas respectively. These sensors are a major part of the electronic nose to detect gas or odor contained in a volatile component. Information about the gas detected by sensors will be recorded and transmitted to the signal processing unit to perform the analysis of volatile organic compound (VOC) pattern and stored in the database classification, in order to determine the type of odor. Classification is a way to distinguish a mixture odor/aroma obtained from gas sensors in an electric signal form. In this paper, we discussed briefly about electronic nose, its principle of work and classification method and in order to classify food freshness.

Keywords: Electronic Nose; Food Freshness; Food Classification; Food Quality.

1. Introduction

The main requirement for the food is fresh, unprocessed food, easily prepared and ready to eat, especially at room temperature [1]. For the past few years, food safety incidents often occur as a result of food poisoning from various food sources such as in schools, hospitals, night markets, street stalls and the like. According to [2], when the quality of food is reduced due to the low level of freshness, cleanliness factor, safety and nutrition, it can contribute to health risks. Hence, the freshness of food should be given priority because of the lack of food hygiene quality and freshness will give a risk to health. It is important to at least maintain the freshness of the food, especially for area of school and hospital.

There are many methods used to test the freshness of food such as visual appearance, also classical olfaction including normal olfactory and scentometer [3] which requires trained panels to taste or smell the food samples to ensure the quality or strength of the odor. However, this kind of method is rather subjective because the human sense of smell and taste is different and may be influenced by the weather and also sinus infection [4].

Electronic nose (e-nose) is one of the best choice of a sensible device that is used to identify and distinguish vaporous chemical compound [5, 6]. It is an electronic device that is intelligent of simulating human olfactory system [7], which contains an array of electrochemical sensors to detect and identify gasses/odor and will classify through a kind of pattern recognition method. It is extensively used in the food industry – for example in assessing the freshness of food in the food production [8], quality estimation of ground meat [9] mainly for export, estimation of food fish freshness for grading [10], fresh vegetables [11], beer production [12], also to predict the degree of musty odor in cereal [13] and many more. Besides widely used in food production, E-nose also useful in diagnosing disease [14]; water quality [15]; air pollution [16-17] as well as liquid chemical concentration [6].

E-nose contains of two main components i.e. the sensor part and classification part. The sensor part is using the gas sensor to detect an odor which can be used a market ready product such as MOS transistors, QMB, CP, piezoelectric crystal, QCM [18-20] and there are some of researchers developed their own gas sensors [21-23] for their research. While, classification part is to identify and distinguish types of gas in order to determine the quality of food. Food can be classified as bad or good from the activity of micro-organism in food that eventually will produce gas [24-25]. The higher the contents of microorganism, the more the activity of them, the higher the chances of spoilage. As e-nose is widely used in the food industry, especially in terms of determination the quality and freshness of food, thus determination process is crucial in order to sustain the quality of nutrition, avoiding the problem of poisoning, food wastage and the like [26]. This determination method is implemented by classification using a few methods towards gases/odor that has been yielded by gas sensors in electronic nose.

2. Electronic Nose

Electronic nose is a sensor that was first developed in 1982 by [27], followed by [28, 29] in 1985 and 1987 at Hitachi in Japan. It mimics human olfactory sense to detect and distinguish an odor or gasses or volatile organic compound from a few objects such as food, chemicals, explosive, etc. Conventionally, the resulting gas can only be identified by people based on past experience which is
stored in their brain memory. Data stored in this memory will be reused if they are faced with a similar smell and it is subjective between individuals. Hence, this concept is transformed electronically using a device called E-Nose. Figure 1 shows a comparison of biological nose to the E-Nose. E-Nose will receive input from a gaseous sample, then it will be converted into electric signal form to be processed through data processing i.e. data classification using certain algorithm in order to identify sample odor.

2.1. Principal of Electronic Nose

The e-nose operates a sensor to response to the odorant molecules (aroma). Figure 2 shows the general architecture of E-Nose to detect gas, which later need to be analyzed. The basic important requirement of E-Nose is sampling chamber for gas sample, sensor chamber which contain a number of gas sensors, a software-based of gas acquisition and analyzer. Sampling and sensor chamber will communicate to each other in order to produced output in a specific form (recorded through data acquisition system) and after that will be analyzed using classification method.

2.2. Gas Sensor Array

The sensor array is a main component of the electronic nose to detect gas / odor contained in volatile component. Each sensor will respond to their specific gas respectively. Examples of gases that can be detected by E-nose are CO, CH₄, H₂, SO₂, NOₓ, O₃ (to name a few), while Table 1 summarized the involved gas and gas sensors used by commercial product gas sensors [30-31] for the specific purpose. In order to use E-Nose to detect food freshness, researchers need to know the specific gas that will be produced by food through some findings, i.e. information from literature or through experts. Researchers have to find the specific commercial E-Nose or specific gas sensors if they want to develop their own E-Nose.

There are several gas sensors available in the market such as metal-oxide semiconductor sensors (MOS) which can detect more than 20 odors [32], Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), Piezoelectric sensors, Intrinsically Conducting Polymers (ICPs) Optical sensors [33-37], to name a few. Sensors to detect gas involved with this type of sensing material as well as way of detection can be summarized by Table 2.

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Sensitive Material</th>
<th>Detection Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic sensors</td>
<td>Organic or inorganic film layers</td>
<td>Mass change (frequency shift)</td>
</tr>
<tr>
<td>Quartz crystal microbalance (QMB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(QMB); surface acoustic</td>
<td></td>
<td></td>
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<tr>
<td>(SAW)</td>
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<tr>
<td>Calorimetric, catalytic</td>
<td>Pellistor</td>
<td>Temperature or heat change</td>
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<td>head</td>
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<tr>
<td>Metal-oxide semiconductor field</td>
<td>Catalytic metals</td>
<td>Electric field change</td>
</tr>
<tr>
<td>effect transistors (MOSFET)</td>
<td></td>
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</tr>
<tr>
<td>Conducting polymer sensors</td>
<td>Modified conducting polymers</td>
<td>Resistance change</td>
</tr>
<tr>
<td>sensors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal-oxide semiconductor</td>
<td>Solid or liquid electrolytes</td>
<td>Current or voltage change</td>
</tr>
<tr>
<td>(MOS)</td>
<td></td>
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<tr>
<td>Electrochemical sensors</td>
<td>Fluorescence-sensitive detector</td>
<td>Fluorescent-light emissions</td>
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<td></td>
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<tr>
<td>Infrared sensors</td>
<td>IR-sensitive detector</td>
<td>Infrared-radiation absorption</td>
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<tr>
<td>Metal-oxide semiconductor (MOS)</td>
<td>Doped semi-conducting metal oxides</td>
<td>Resistance change</td>
</tr>
<tr>
<td></td>
<td>(SnO₂, GaO)</td>
<td></td>
</tr>
<tr>
<td>Optical sensors</td>
<td>photodiode, light-sensitive</td>
<td>Light modulation, 510 optical</td>
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The example of market ready of E-Nose were used in the previous research, i.e. Znose, Cyranose and FOX. However, the market ready E-Nose devices are expensive (between US $ 10,000 to US 33,000) with limited and specific sampling procedures which some of that not meet the requirement of research target [23]. Weaknesses and advantages of the market ready E-Nose have been discussed in detail in [38-42]. Due to that, there are many research done previously has developed their own fabricated E-Nose to fulfill their own research requirement.
3. Classification Method

Classification is a way to analyzed electrical signal obtained from gas sensors in order distinguish a mixture odor/aroma. This distinguishes are further can determine the level of food freshness. Most of them using machine learning algorithm as shown in Figure 3.

3.1. Statistical Analysis and Neural Network

There are several methods to classify data from E-nose as explained earlier such as classical computational techniques based on statistical and factorial analysis such as Principal Component Analysis (PCA), Corresponding Analysis (CA) and Generalized Canonical Analysis (GCA) [43]. Another method is Artificial Neural Network (ANN) which was introduced in 1943, for food classification through learning process. It is an interconnected network of neurons that capable to classify a complex vaporous data. In e-nose, the ANN learns to identify the various chemicals or odors by example as well as can rapidly identify unknown chemical in vaporous object.

Both ANN and statistical based classification method contributed to the improvement of sensitivity and accuracy of food classification and air quality control. In [44], a fusion method of gas sensor array with neural network improve the sensor selectivity and accuracy. PCA and ANN also were used to evaluate the signals from multisensory as in [45 - 46] while in [47], GA was used to determine air pollution and air quality control. A reliable result obtained in [48 - 49] by applying ANN and PCA for detection and classification of apples ripeness.

However, some weakness of non-probabilistic character in statistical analysis (PCA, CA, GA) is not efficient for uncertainty information especially for data obtained through olfactory based sensor as it contains a sampling biases [50].

A few other methods have been explored by researchers to improve performance parameters in food classification. For example, in [51], neural network is applied to analyze data from gas sensors in order to improve selectivity and accuracy. While [23] approached an integrated Multi-Layer Perceptron Neural Network to increase repeatability and reproducibility towards three kind of beverages i.e. blackcurrant juice, mango juice and orange juice. In this research, PCA was used in order to test the capability of E-Nose in extricating different substance. Another algorithm in ANN is back-propagation algorithm (BP) was used by [52] to classify tea aroma.

BP algorithm was also used in [23] to determine gas contained in a few samples of teas and coffees. ANN’s ability to classify odor has been proved in [53] by combining ANN algorithm with General algorithm (GA) to improve the selectivity of the gas sensor arrays, which has been tested on decay and fresh meat and fish. In [54] analyzed data using PCA and Artificial Neural Network (ANN) using Backpropagation algorithm. Based on result, honey classification using electronic nose with ANN and Backpropagation algorithm had produced good classification.

Another hybrid method has been studied by [55] to improve performance in the training phase of the food classification by combining artificial bee colony algorithm (ABC) and BP algorithm. In their experiment, tests were carried out on four kinds of fruit aroma of strawberry, lemon, cherry and melon. Good result achieved in terms of performance after a comparative study between BP algorithm only and ABC algorithm with BP were done.

3.2. Fuzzy Logic

Fuzzy logic is one of the method that also can be used to identify food freshness. This is because food is considered as uncertainty object, where its attribute is complex to be specified as good, somewhat good, poor and so forth. While, the most machine learning method can only specify a crisp data such as good or poor. As such, a fuzzy logic based classification can be applied in order to tackle the problem of uncertainty condition of food. Fuzzy sets were first introduced by in [56] as a way to express degrees of membership to a set in imprecise, rather than crisp, terms. Generally, the theory of fuzzy logic allows machines deal with imprecise language used by human to describe data that may not be exact or crisp. Fuzzy logic has been found appropriate for various practical classification problems for food quality evaluation since most food quality attributes rather difficult to specify whether poor, worst, good, very good and so on. Using the fuzzy membership functions, a more realistic knowledge base can be created. Due to that, more studies were done by researchers to improve classification performance as well as for food quality determina-
tion since it has been studied has ability to identify the uncertainty in food classification. In literatures, research done by [57] applied Sugeno-based fuzzy logic to increase an accuracy in identifying odor towards a few gases yielded by food i.e. butanol, acetic acid, acetone, benzene, chloroform, di-chloromethane, ethyl-acetate and sulfuric acid. Fuzzy Inference System (FIS) method was proposed by [58] to evaluate a grading of dates based on water contents since dates can be graded as moist, dry, somewhat dry and solid dry. Another achievement has been proven by [59-64], which approached fuzzy logic for apple grading based on color defect and sizes.

4. Conclusion

In this paper, we present electronic nose and component involved, and specific methods that can be used to perform the classification. Each gas sensor array has their own capability depends on the type of gas that would be detected. There are many classification algorithms that generates promising results to identify the freshness of food, have been discussed briefly in this paper.

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