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Detecting spoiled fruit in the house of the future

*Daniel L.A. Fernandes, João A.B.P. Oliveira, M. Teresa S.R. Gomes**

CESAM & Department of Chemistry, University of Aveiro, 3810-193 Aveiro, Portugal

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ABSTRACT

An electronic nose based on acoustic wave sensors has been developed to detect spoilt fruit. Different varieties of fruits, edible and rotten, were analysed. Starting from six sensors, the minimum number of sensors capable of discriminating between spoiled and unspoiled fruit was found. The discrimination capability of the sensor array was studied separately for each fruit variety, as well as for the whole set. Mathematical models were built to classify the fruits within a fruit variety, in an objective and clear way. The models were able to distinguish between edible and rotten fruits with 100% success for New Hall oranges, Golden apples, Kiwis and William pears, and with 97.2% of success for the Starking apples. Without forming fruit variety subsets, discrimination between edible and rotten fruit was achieved with 95% success.

1. Introduction

Comfort and technology are often interlinked. Recent advances in electronics and other sciences, such as chemistry, open up new possibilities for the development and marketing of novel machines that could make everyday life easier and more pleasant.

The house of the future, besides having architectural beauty, and mechanical resistance to earthquakes and other acts of nature, will require comfort and adaptability to human needs, desires and even to a state of mind. Automatic lightning, prevention of accidents, the creation of a legion of robots, which make domestic housework a thing of the past, and the capability of satisfying every whim of the owner now seem to be possible. Much of this new machinery must possess human capabilities that include the sensing of heat, smell, taste and of course will need “visual” and “touching” capacities.

One of the tasks of these robots in the house of the future would be the management of the kitchen storeroom. These tasks would involve keeping the stock and monitoring the spoilage of food. Spoiled food is associated with a bad smell and could have serious implications for the consumer’s health. The safety and quality of food is now one of the main concerns of the consumers, and the detection of spoilt food in a storeroom would be indispensable.

Several attempts to mimic the human nose have been made and instruments called electronic noses have been manufactured [1]. These devices employ various types of electronic chemical gas sensors to detect volatile compounds.

In this work, an electronic nose to detect rotten fruits has been developed and tested for a series of fruit varieties, common in Mediterranean houses. Several studies have been published dealing with electronic noses and fruits, most of them devoted to apple aroma measurement [2–8] and peaches aroma [3,9–12]. There are also a few studies involving melon aroma measurements [13], pears [3], tomatoes [14] and mandarins [15] aroma. The main purpose of these studies was to monitor the ripeness of fruit in order to find the optimum timing for harvest. Although several papers have been published on this subject, there is still no satisfactory methodology to classify the fruits in ripening groups; either the correct classification percentage is poor or it can be applied to only one or

* *Corresponding author*. Tel.: +351 234370722; fax: +351 234370084.
E-mail address: mtgomes@ua.pt (M.T.S.R. Gomes).
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two fruit varieties [17]. None of these studies has evaluated the possibility of using an electronic nose in a kitchen storeroom to alert the consumer to the presence of rotten fruit, although Moltó et al. [9] were capable of detecting a trend in the signals when 5% of rotten fruit was present. As most of these electronic noses operate in a steady state mode, equilibrium must be attained. In order to speed the analysis, a flow injection methodology will be used.

Acoustic wave sensors are inexpensive highly sensitive mass sensors. In order to detect volatile compounds, a sensitive layer must be applied onto the electrodes. This sensitive layer must be carefully chosen as it must be very stable and interact reversibly and selectively with the compound to be detected.

The sensor signal is caused by adsorption of aroma compounds on the sensor coating which produces a frequency change that is proportional to the adsorbed mass. This adsorption is ruled by physicochemical parameters of the volatile compounds and the applied film. The interaction between aroma compounds and coatings can be of several types, ranging from Van der Waals to hydrogen bonding, and depends upon polarity, steric hindrance and π-electron density [16]. However, a covalent bond cannot be present because it would impair the reversibility of the sensor.

Fruit aroma is a complex mixture of alcohols, aldehydes, terpenes and mainly C1–C6 esters, and ethylene [6,9,17]. A previous study found that the concentration of alcohols decreases with the increase in ester concentration, which is maximum in mature pears and apples [3,5,18]. A range of coating compounds were selected to interact with these fruit aroma compounds and the sensors were later evaluated according to their discriminating capabilities.

The major goal in this study was to evaluate the potential of an electronic nose to detect spoiled fruit. Five different species of fruit were employed in this study, including climacteric fruits (Starking apples, Golden apples, Kiwi and William pear) and non-climacteric fruits (New Hall orange).

Mathematical models have been used to classify fruits in two categories, edible fruit and rotten fruit, in a clear and simple way, using the electronic nose.

Supervised pattern recognition was conducted and a linear discriminant function based on a normal distribution and the theorem of Bayes was obtained.

Classification was performed within each fruit variety, but also for the whole set of fruits, without any variety sorting.

2. Experimental

2.1. Reagents

The sensors were coated with: poly-vinylidene fluoride (Kynar, Fluka 81432), Nafion 117 solution (Nafion, Fluka 70160), manganese(II) phthalocyanine (Mn_pht, Aldrich 379557), polydimethylsiloxane (PDMS, ABCR 76189), Tenax TA 80/100 (Tenax, Supelco 21009), and triethanolamine (TEA, Merck 8377). Nitrogen and AIR were Alphagaz from ArLíquido.

Different species of fruits, New Hall orange, Starking apples, Golden apples, William pears and Kiwis were bought at a local supermarket.

2.2. Apparatus

Fig. 1 shows the experimental layout. Each coated quartz crystal was housed in a cell and a stream of nitrogen, controlled by a flowmeter, was split and passed through each one of the crystal cells. Each piezoelectric crystal was driven by an oscillator and the frequency of the six sensors were monitored simultaneously and stored on a PC every 1 s and displayed numerically, as well as in a graphically, on the PC monitor.

Oscillators and cells were home-made and the frequencies of oscillation of the crystals were monitored with a Counter/Timer Device PXI 6608 from National Instruments. Data acquisition software was written in Lab View. Software and oscillators were specifically designed for this work, in order to achieve the best possible precision for the frequency measurements.

In ordinary frequency measurements, the frequency counter uses its clock (time base) to generate a signal of 1 s, and the counter determines the number of signals over that period. With the counter device used here an extra CMOS divider device (74HC292) was added to the oscillator circuit board, which divides the frequency from 2^2 to 2^{31}. The divider generates a signal whose frequency is 2^{-20} of the original signal, and the internal time base of the PXI 6608 was used to count this signal. The advantage of this methodology is to

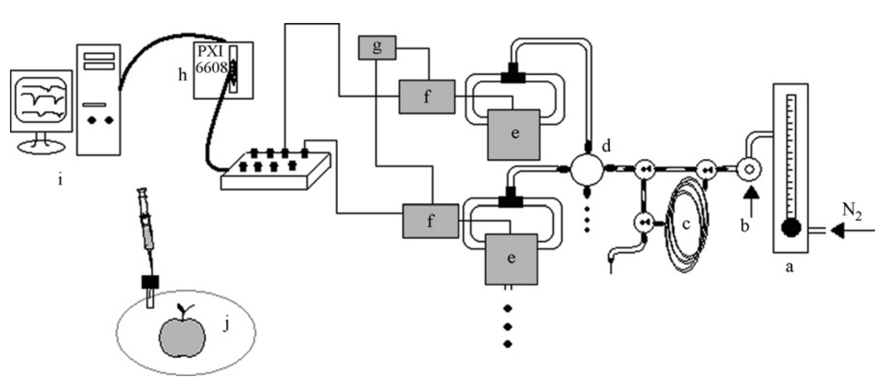

Fig. 1 – Experimental layout: (a) flowmeter; (b) injection port; (c) sample loop; (d) distribution valve; (e) crystal cell; (f) oscillators; (g) power supply; (h) Counter/Timer PXI 6608; (i) computer; (j) sample bag with a septum to withdraw the sample.