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Quality Control Through Electronic Nose System

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1. Introduction

Quality control is defined as: "a process selected to guarantee a certain level of quality in a product, service or process. It may include whatever actions a business considers as essential to provide for the control and verification of certain characteristics of its activity. The basic objective of quality control is to ensure that the products, services or processes provided meet particular requirements and are secure, sufficient, and fiscally sound"1 In order to apply Quality Control through the Electronic Nose System, all the stages involved in the process must be taken into account, this case refers to the use of electronic nose systems as a tool for quality control tasks. Therefore best practices must be implemented that will lead to obtaining good quality measures, which will later become good results (Badrick, 2008; Duran, 2005)

Section 2 of this chapter presents an overview of the parts or subsystems involved in an electronic nose system and the operating principle.

Section 3 deals with the issue of food quality control using electronic nose systems. This section discusses how to use the electronic nose system for these types of applications, and also presents some issues for consideration when analyzing products such as coffee, fruits and alcoholic beverages.

Section 4 covers other applications of electronic nose systems, especially applications in the medical field for detection and diagnosis of diseases. This section focuses more on viable alternatives for the detection of diseases, rather than on quality control.

It is important to note that quality control is mainly used to find errors in processes, so the deductions presented here have gone through a series of tests and experiments to obtain the desired results and thus facilitate further research and shed light on the question of how these types of applications should be addressed.

2. A look at the electronic nose systems

Existing systems for electronic olfaction (EOS), also commonly known as electronic noses, are basically arrays of chemical sensors, connected to a computer or processing systems

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[1] Applications and experiences of Quality Control. Preface. www.intechweb.org Copyright 2011 Intech.

which apply advanced techniques of digital signal processing and statistical pattern recognition. Their main objective is to enable the qualification of odours through classification tasks, discrimination, prediction, and even quantification of products, elements or components according to their organoleptic characteristics (Duran & Baldovino, 2009; Wilson & Baietto, 2009; Zhou et al., 2006).

2.1 Elements of an Electronic Nose System (EOS)

An electronic nose system can be seen as an instrument or measuring equipment of artificial olfaction, consisting of a series of modules that work together, which analyzes gas samples, vapours and odours. An instrument or equipment of this type has at least 4 parts, each with specific functions which are detailed below (Duran & Baldovino, 2009; Tian et al., 2005).

2.1.1 Matrix or array of gas sensors

In general, the gas sensors are devices that consist of two main parts, the first is an active element which changes its physical or chemical properties in the presence of that which it detects and the second part is a transducer, which converts the changes in the properties of the active element into an electrical signal. These sensors typically have a selective membrane, preventing passage of particles or unwanted material, acting as a first noise filter. In Figure 1 shows a simplified diagram of a device of this type, in which the main parts of a gas sensor and the nature of the inputs and outputs can be seen. (Grupo E-Nose, 2011, Tian et al., 2005).
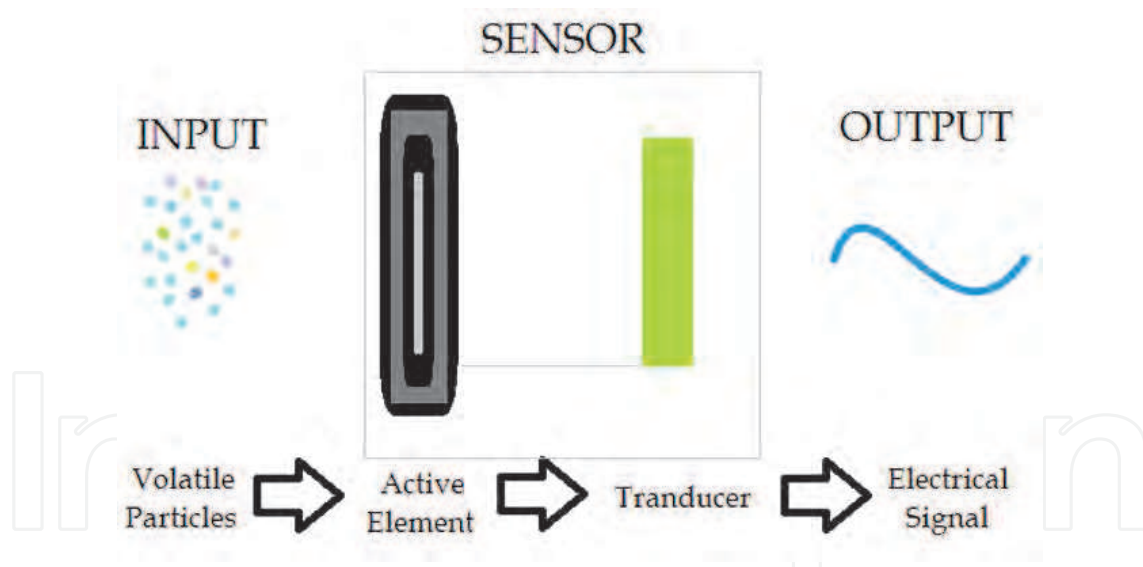

Fig. 1. Simplified schematic diagram of a gas sensor.

There are different types of gas sensors for use in EOS, the most common are: MOX (Metal Oxide Semiconductor), QCM (Quartz Crystal microbalance), SAW (Surface Acoustic Waves), MOSFET (Metal Oxide Semiconductor Field Effect Transistor), CP (Conducting Polymers), and FO (Fiber Optics). This chapter deals specifically with MOX sensors built with semiconductor materials such as Tin oxide (SnO_2), Zinc oxide (ZnO), Titanium oxide (TiO_2), among others. Their operating principle is based on the change of conductivity of a sensitive material when it absorbs or reacts with the gases in the environment, Figure 2 shows several commercial sensors of this type (Berna, 2010).

Fig. 2. Commercial gas sensors manufactured by Figaro and FIS, with different sizes and pin configuration.[2]

The majority of gas sensors are general purpose and usually have high sensitivity, detecting very low concentrations of volatile, but have disadvantages when trying to determine concentrations of a single component, because the output signal cannot be unambiguously assigned to the component by its generality (Duran, 2005, 2009).

Due to the fact that all EOS have a gas sensor array, it is desirable that the array be located in a special chamber or compartment in which the right conditions can be ensured for the proper operation. Mainly adequate insulation must be ensured to prevent pollutants from entering and the appropriate temperature and pressure must be maintained, these parameters are important or critical depending on the type of sensor used (Duran, 2005). Another advantage of using a chamber of sensors is that it facilitates the measurement process, because the volatiles will be in a higher concentration and they will have more contact with the active element of the sensor, which enables better and faster response from the sensors. It has also been experimentally determined that if the chamber of sensors is more hermetic, it can further exploit these advantages. Figure 3 shows a photograph of a chamber of sensors used in one of our projects with EOS (Velásquez et al., 2009).

2.1.2 Volatile delivery system

Basically it is a system that is responsible for transporting volatiles emitted by the samples or elements to be scanned into the chamber of sensor. Sometimes the sample is manually injected into the chamber of sensors, which results in error and delays; other times an automated system is responsible for transporting the volatile odorous molecules to the chamber of sensors, with the injection of a gas or air (Duran 2005, 2009).

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[2] Images of sensors were taken from different Internet pages.

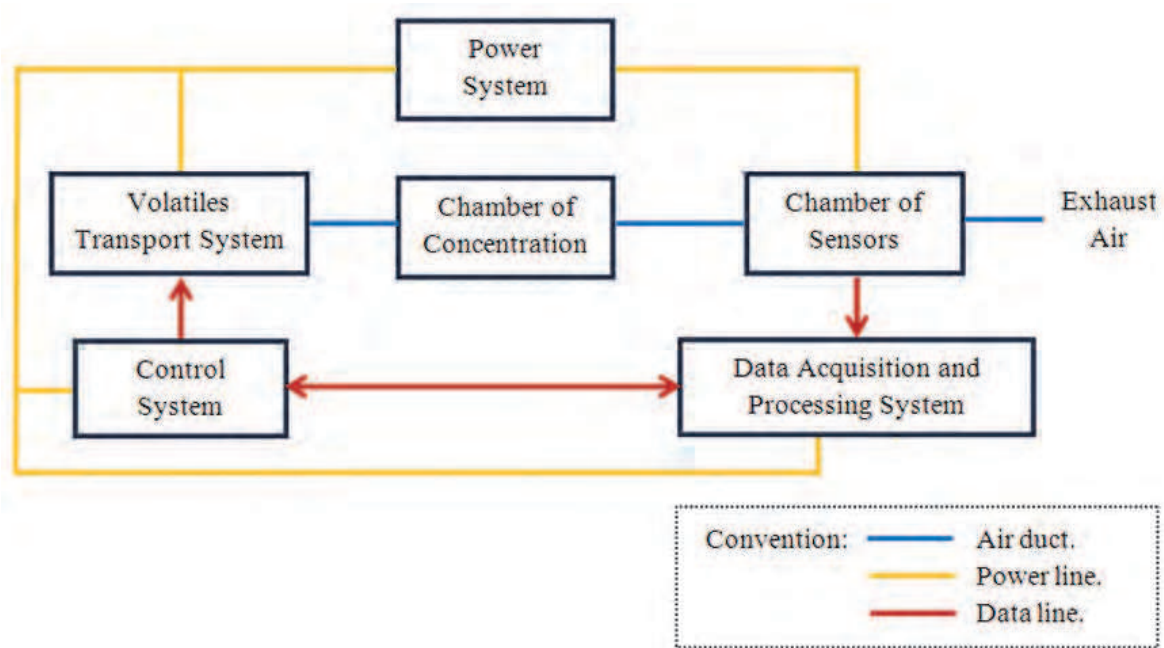Fig. 3. The chamber of sensors provides hermetic isolation and guarantees reliable measurements.

Fig. 4. Block diagram representing the electronic nose system.

Additionally most EOS have some kind of cleaning mechanism for the chamber of sensors, so that subsequent measures are made based on the same initial conditions and thus reproducibility of results is ensured. We recommend a different camera or hermetic compartment be used, called the "Chamber of Concentration", for containing the sample to be analyzed provided the environmental and physical conditions of the system allow it. Figure 4 shows the representation of an electronic nose system; note that the volatiles transport system is fundamental because it affects the operation of the EOS in the 3 different processes that can be carried out: concentration of volatiles, measurement and cleanup. (Rodriguez & Duran, 2008).

2.1.3 Control system and data acquisition

The control system takes care of proper handling of the Volatiles Transport System, for example: valves, air pump and other devices that are part of this system. It is also in charge of controlling additional subsystems or variables that the electronic nose system may have, such as temperature and humidity control, among others (Duran, 2005).

The data acquisition system is responsible for capturing the signals provided by the gas sensors and then delivering them to the process processing or computing system that has the appropriate software for processing such information (Rodriguez & Duran, 2008).

The control and data acquisition systems can be integrated into a single device, which can be a data acquisition card, a microcontroller, a DSP (Digital Signal Processor) or a computer; it must also have adequate power stage to handle the elements that consume more power and must have the proper memory settings to store large amounts of data obtained from the sensors.

We recommend working with a data acquisition card connected to a computer, to achieve good storage capacity, correct handling of information processing and graphical representation. Although in some cases when portability is required, a DSP or microcontroller can be used.

A significant part of the control system is the power source, which must be of a few amps, depending on the number of gas sensors and additional elements used; a source of 3 Amps is enough when working with an EOS that contains an array of 8 gas sensors.

2.1.4 Processing system

The processing system in most cases consists of a computer with an appropriate software for manipulating the data obtained by the sensors. Pre-processing techniques are applied to the data in order to extract the static parameters of the measures and reduce the amount of information to be analyzed. Subsequently multivariate analysis techniques and pattern recognition can be applied, such as PCA (Principal Component Analysis) and ANN (Artificial Neural Networks) to perform tasks such as: classification, discrimination, prediction, quantification of samples according to their organoleptic characteristics (Wilson & Baietto, 2009; Berna, 2010).

2.2 Operation of an electronic nose system

The operation of an electronic nose system depends on the component parts and the features of the equipment. In order to obtain measurements with a EOS the first step is to adjust the adequacy of the sample to be examined, this depends on the type of element to be analyzed, which sometimes must be heated, cut, mixed with other elements and simply placed near the sensors array or in the chamber of concentration ready to be analyzed. (Duran & Baldovino, 2009).

The concentration process begins when the sample is placed in the chamber of concentration. After this a few minutes should be given to allow the sample to release enough volatile particles, only then can the measurement process begin, for which the volatiles must be deposited or transported from then chamber of concentration to the chamber of sensors. During the measurement process, the data acquisition system records all the changes in the output signal of each of the gas sensors. When the measurement process is finished the cleaning process of chamber of sensors begins and the stored data can be processed and analyzed immediately (off-line processing), using the pre-processing software and signal processing, in order to obtain an olfactory footprint that represents the

sample, to perform the tasks of classification, discrimination and other (Berna, 2010; Wilson & Baietto, 2009).

3. Quality control of food using electronic nose systems

A great part of electronic nose system applications are used in the food industry, where studies can be found with meat, milk and dairy products, eggs, different grains, fruits, oils, alcoholic and non alcoholic beverages, among others (Berna, 2010).

a)   b)

Fig. 5. a) Growing Coffee.[3]. b) Image of green coffee beans.[4]

Food quality control is one of the many applications that can benefit from the use of electronic nose (EOS). E.g., it can determine the type of product that is being analyzed, it can be classified by region, quality, time of ripening or storage, the food life span can be determined or predicted, as well as the level of deterioration or decomposition, the food life span can be determined or predicted and can determine flavors (Berna, 2010; El Barbri et al., 2008).

This chapter discusses the use of EOS in the quality control of foodstuffs such as coffee, fruits and alcoholic beverages.

3.1 Quality control of coffee with an electronic nose system

In the quality control of coffee, the organoleptic characteristics are a determinant of its quality and therefore, they are significant to locating the predominant defects of coffee beans, as they negatively affect its flavor and odor (Rodriguez et al., 2010; Pardo et al., 2000).

It is important to keep in mind that coffee production (Fig. 5. a.) is such an artisan process, that its control is somewhat complex and highly dependent on the historical traditions and cultural knowledge of those involved in the process, the lack of modernization of coffee farms, the incidence of fungal and other diseases in the crops and the need for chemicals sometimes influences the product quality (Rodriguez et al., 2010).

Another important factor to take into consideration in the quality of coffee is the climatic and edaphological conditions or nature of the soil. The Colombian coffee zone is located on

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[3] Photo owned by FNC, by Patricia Rincon Mautner. http://www.colombia.travel/es/turista-internacional/actividad/590-clima-y-ubicacion-geografica-del-cafe

[4] Taken from the website of Herbolario Esencia.
http://herboesencia.es/a-e/cafe-verde-coffea-arabica/

hillsides between 1000 m and 2000 m above sea level, with temperatures between 17ºC (290ºK) and 23ºC (296ºK) and relative humidities between 70% and 85%. The Table 1, show other data associated with optimal climatic conditions for growing coffee ([CENICAFE], 2011).

Average Solar Radiation	Solar Brightness	Temperature	Rainfall	Relative Humidity	Daily evaporation	Winds
Between 300 and 450 cal/cm² per day.	Between 4 to 5 hours daily.	Between 17 and 23 ° C or 290ºK and 296ºK	Between 1800 and 2800 mm annually.	Between 70 and 85%	Between 3 to 4 mm.	Below 5 km/h.

Table 1. Average Climatic conditions in coffee growing regions ([CENICAFE], 2011).

The CENICAFE web page (2011) states that: "The soils of the Colombian coffee region are relatively young, e.g. they are still under development and the nature of the material which is derived from petrographic material is grouped into the following classes: Metamorphic, igneous and sedimentary, which occur on different levels and patterns of coverage with volcanic ash. These soils are highly variable in their characteristics and their distribution throughout the coffee zone, its location in reliefs from flat or gently undulating to steep with 75% slope, and the variety of their physical (from rocky and sandy to loam and clay) and chemical conditions (low to high content of organic matter and minerals)".

3.1.1 What should be taken into account when considering a product such as coffee?

Coffee is a product that is collected manually and subjected at certain processes before obtaining the green coffee beans (Fig. 5. b.), in this condition it is more difficult to make an organoleptic analysis of coffee; therefore the best way to analyze coffee is the same way as tasters do, who perform tests on toasted and ground coffee, therefore the coffee must be subjected to a process of roasting and grinding in order to obtain a powder which is mixed with water at an average temperature of 60ºC (333ºK), which enables the emission of volatile particles. This mixture is introduced into the chamber of concentration (Fig. 6) in order to cluster the volatile particles which are then carried to the chamber of sensors for the measurement process. Figure 7 shows in detail the procedure used for the preparation of the mixture before the measurements (Falasconi et al., 2005).

Fig. 6. Chamber of concentration, container for the different samples to be analyzed.

3.1.2 Some results obtained with the coffee

There have been several tests of different varieties of export quality "Excelso" coffee, with "regular" coffee and coffee with marked defects in the grains. Tests have been accompanied by personnel trained in coffee tasting, who issued their concept based on their personal perception of each coffee sample, helping in the designation of various patterns for facilitating subsequent classification tasks with different measures (Rodriguez et al., 2010).

In one of the tests measures were taken from samples of export quality coffee of two different varieties, Excelso Europe and Excelso UGQ-10%, which are classified as good quality cafes. These measurements were compared to those of regular coffee (for domestic consumption, commonly known as "Pasillas"), in which the experts detected some defects such as traces of fermentation, chemical contamination and signs of "Repose" (caused by prolonged storage or storage in unfavorable conditions). It is noteworthy that the defects mentioned are those most commonly found in coffee, influenced by poor product handling techniques (Rodriguez et al., 2010).
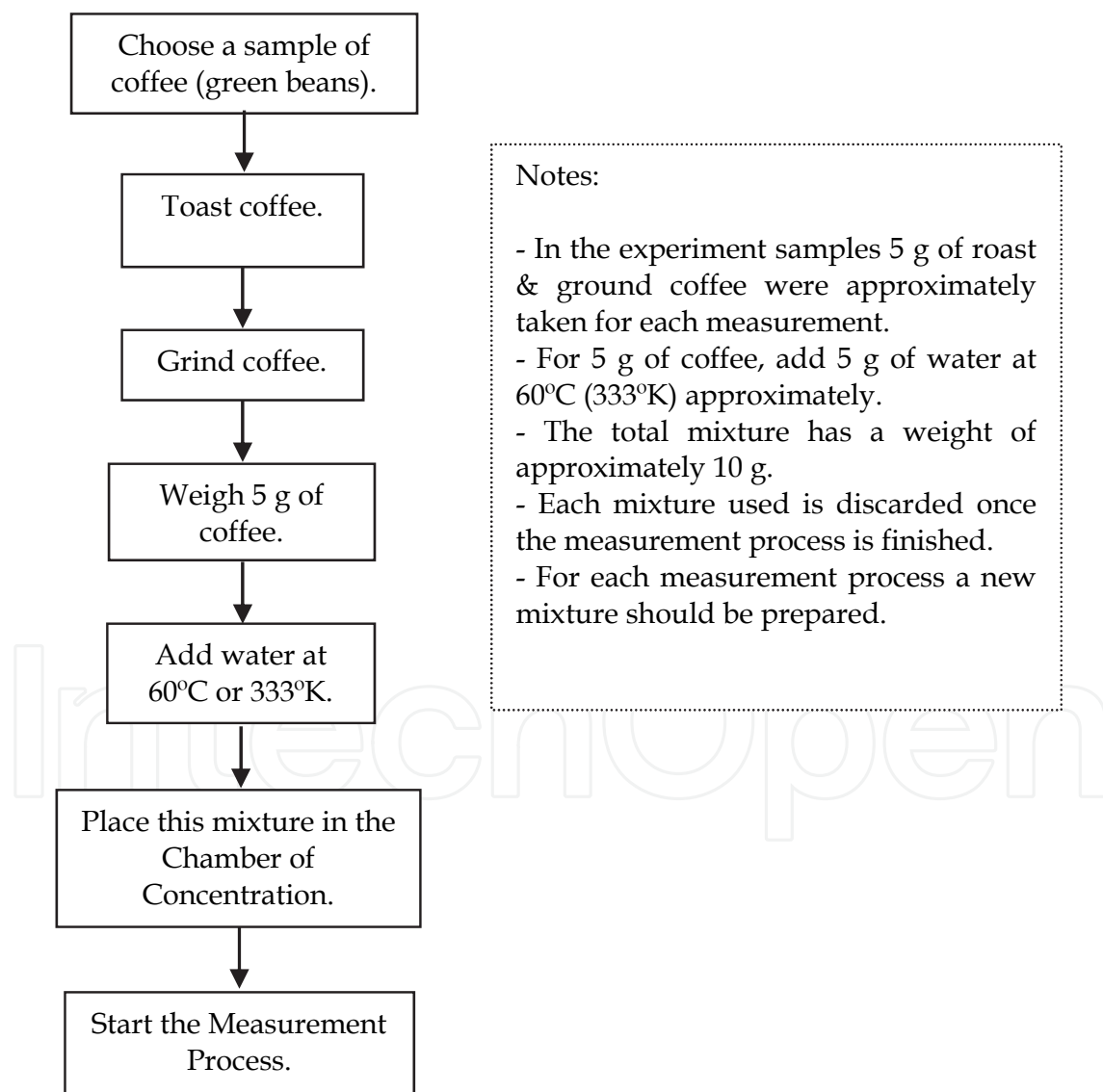

Fig. 7. Procedure used for preparing samples of coffee before starting the measurement process.

Figure 8 shows the analysis of these measurements, using the technique PCA (Principal Component Analysis). The different measurement groups can be seen, clearly differentiated in samples of regular and export type coffee. The measurements taken from export quality coffee are highlighted in green circles, while the measurements taken from regular coffee are in red circles.
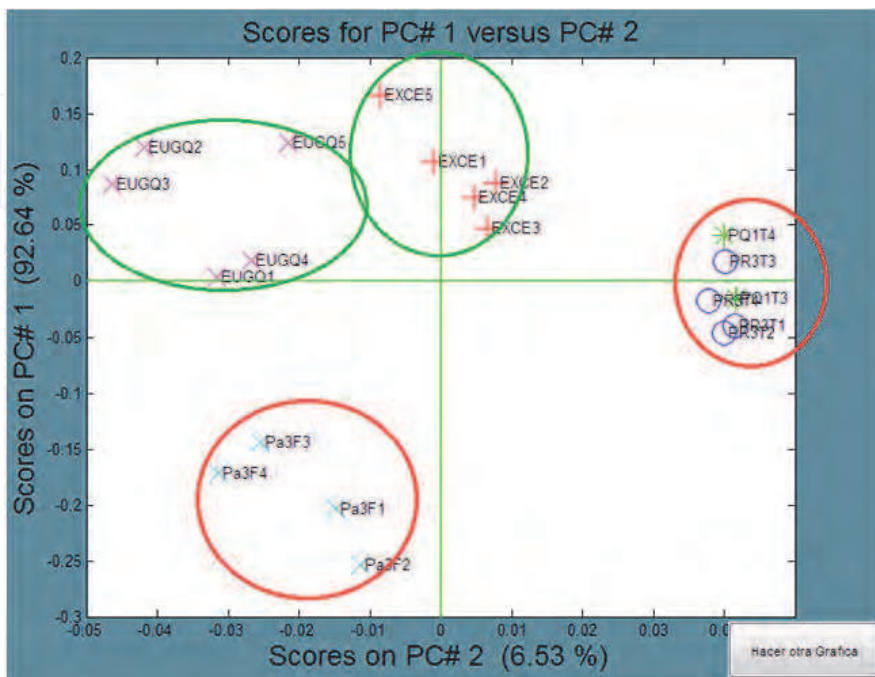

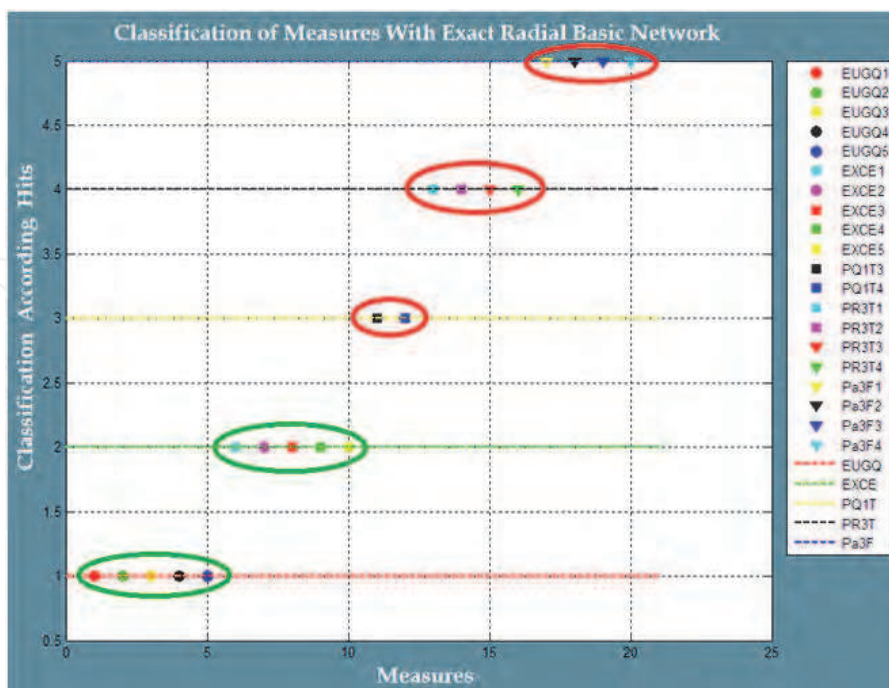Fig. 8. Results of PCA analysis between measures of good quality coffee (green circles) and coffee with defects (red circles).

Fig. 9. Classification results of the measurements with a radial basis neural network, between good quality coffee (green circles) and coffee with defects (red circles).

This group of measurements was classified using a radial basis neural network (Figure 9). It can be seen how the various measurements of the same type are located within a horizontal axis, forming 5 different subgroups, which belong to two major groups of export type coffee (green circles) and regular coffee (red circles).

3.2 Quality control of fruits

For the analysis of fruits invasive and noninvasive techniques can be used. Invasive techniques involve damaging the fruit to take a sample, in order to perform various tests with the same fruit at the same moment and also facilitate extraction of volatile particles, as manipulation helps to release more volatile particles, which facilitates the measurement process. A drawback of this technique is that once the product is handled it can only serve in the measurement process, because handling accelerates the decomposition process. Meanwhile, the noninvasive techniques, just take the fruit for testing without inflicting damage therefore the same fruit can be used for further testing in order to analyze maturity stages and study the processes of decomposition. (Rodriguez & Duran, 2008; Duran & Baldovino, 2009; Berna, 2010).

Figure 10 shows the results of the analysis of some measurements made on samples of passion fruit, peaches and apples, using the PCA technique. The 2 measurement groups can be seen, which can be clearly differentiated in samples of passion fruit and peaches, in addition 2 measurements of apple were introduced as a test (Creole apple and Chilean apple), in order to test the classification accuracy of the system and the similarity that may exist between different varieties of a fruit. Also Figure 11 shows the validation of the measurements using an Artificial Neural Network Feed Forward Back Propagation, applying the technique "Leave one out", it can be seen how the system responds to the eventual absence of a measure in the training of neural network, the most significant result occurs with measurements of apples which are classified successfully despite having so few measures.
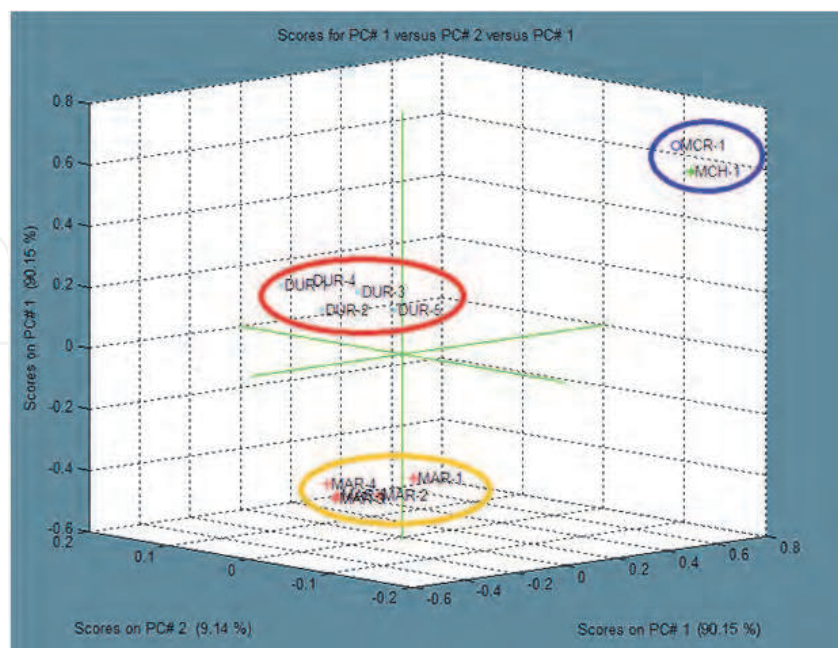

Fig. 10. Results of PCA analysis between passion fruit (yellow circle), peaches (red circle) and apples (blue circle).
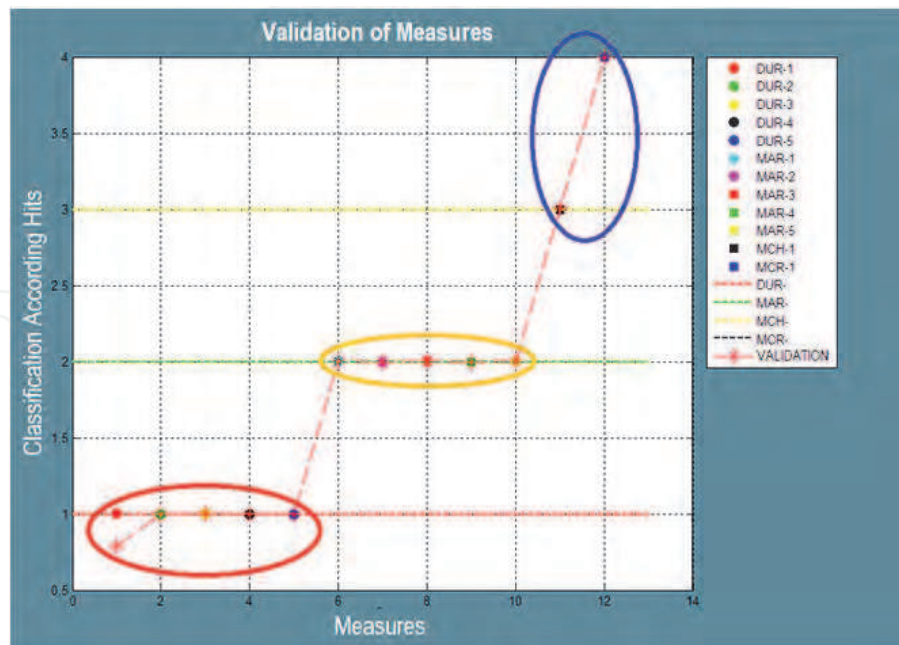
Fig. 11. Validation Results of measurements with passion fruit (yellow circle), peaches (red circle) and apples (blue circle) using a neural network Feed Forward Back Propagation.

3.3 Quality control of alcoholic beverages

Electronic nose systems have been widely used for classification, discrimination of characteristics and detection of different elements or compounds considering the organoleptic characteristics, but its application in quantification tasks has not been widely explored.   In some of these studies the least square regression method is used to consider the gas concentration (Khalaf et al., 2009) and for the quantification of mixed contaminants in the air (Zhou et al., 2006), also the new technologies have been used as systems based on micro-electromechanical sensors for the quantification of components in vapor mixtures (Zhao et al, 2007).

Below is a study with an electronic nose system, where a digital signal processor DSP was adapted and artificial neural network "Feed-forward back propagation" was implemented, which was trained with the aim of identifying and quantifying levels of Ethanol and Methanol in different samples. As result the percentage of Ethanol and Methanol of the samples were obtained, and the electronic nose system was improved, called "A-NOSE" (Rodriguez et al., 2010), when the processing software was implemented in a different device from the personal computer.

The artificial neural network that was used to perform the identification and quantification of Ethanol and Methanol was Multi Layer Perceptron (MLP) Feed-forward back propagation network, which was trained and tried in R2006a Matlab software; as a result of training of the artificial neuronal network the weight matrices and bias vectors were obtained, that were used to codify the artificial neural network program in C++ language with software CodeWarrior and subsequently downloaded this program in the digital signal processor DSP56F801 of Motorola.

The initial samples were 95% Ethanol and 95% Methanol, which were diluted with distilled water to obtain 50%, 25% and 10% concentrations. Different measurements with the Ethanol and Methanol were realized in their different concentrations to realize the training of the

artificial neuronal network and additionally other measures with wines (red, white, fruity, orange wine) and Aguardiente (national drink) were performed. The percentages of wine were close to 10% Ethanol and 0% Methanol and Aguardiente was close to 30% Ethanol and 0% Methanol, values in accordance to the values specified on the product labels.
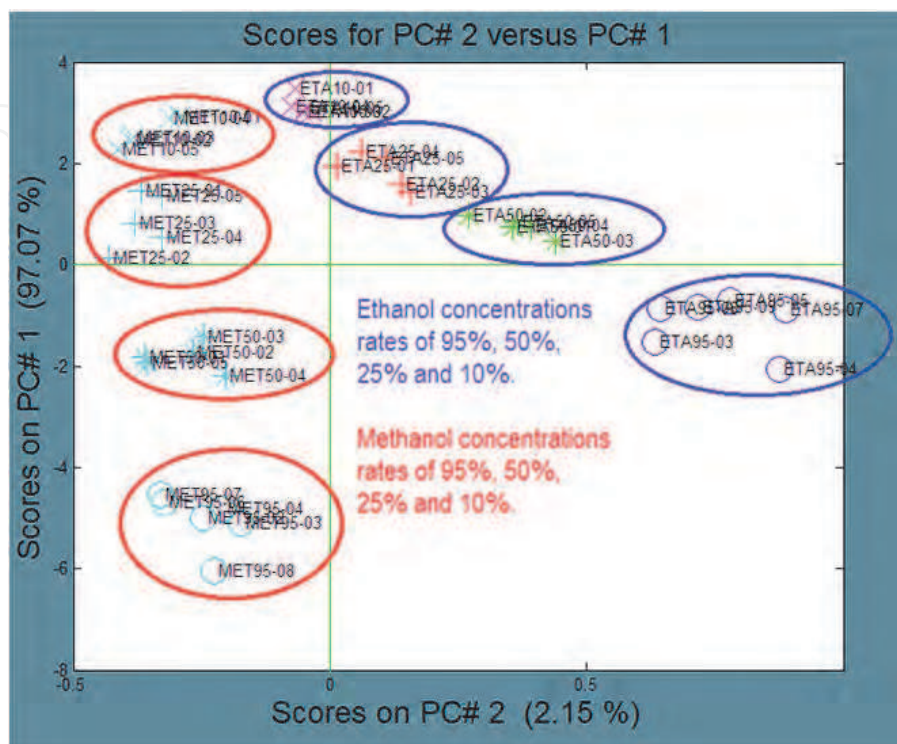

Fig. 12. Results of PCA analysis between Ethanol measurements (blue circles) and Methanol measurements (red circles).

Figure 12 the results of PCA analysis can be seen applied to measurements of different ethanol and methanol concentrations. It can be inferred that the measurements follow a trend, which yield a characteristic equation that models the behavior for different concentrations of Ethanol and Methanol. It can also be seen that as the concentration of Ethanol and Methanol is lower measurements tend to find a common point, this may be because they have are both alcohol.

Another test analyzed samples of different kinds of wines (e.g.: red wine, white wine, orange wine) and Aguardiente (national drink), the results are shown in Figures 13 and 14. It can be seen that wine measurements are close to 10% Ethanol, the results obtained by the neural network (feed-forward back propagation) that was trained for this purpose showed results very close to 10% and 0% Ethanol Methanol.   It should be clarified that the neural network was trained with data from measurements of different ethanol and methanol concentrations and were then tested with data from measurements of different drinks.

4. Other applications of electronic nose systems

The applications of electronic nose systems are very diverse. The previous sections have covered some of the possible applications in the agro-food industry, but there are many other still to be mentioned, for example: The identification and diagnosis of respiratory
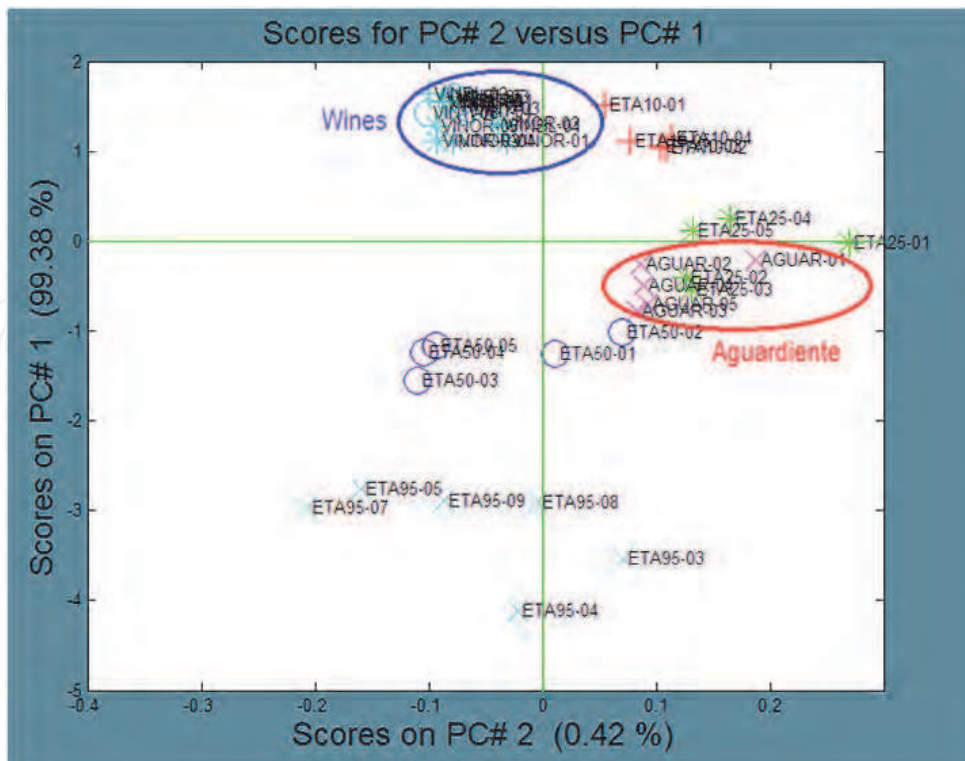
Fig. 13. Results of PCA analysis for the classification of wines and Aguardiente, according to the concentration of Ethanol.
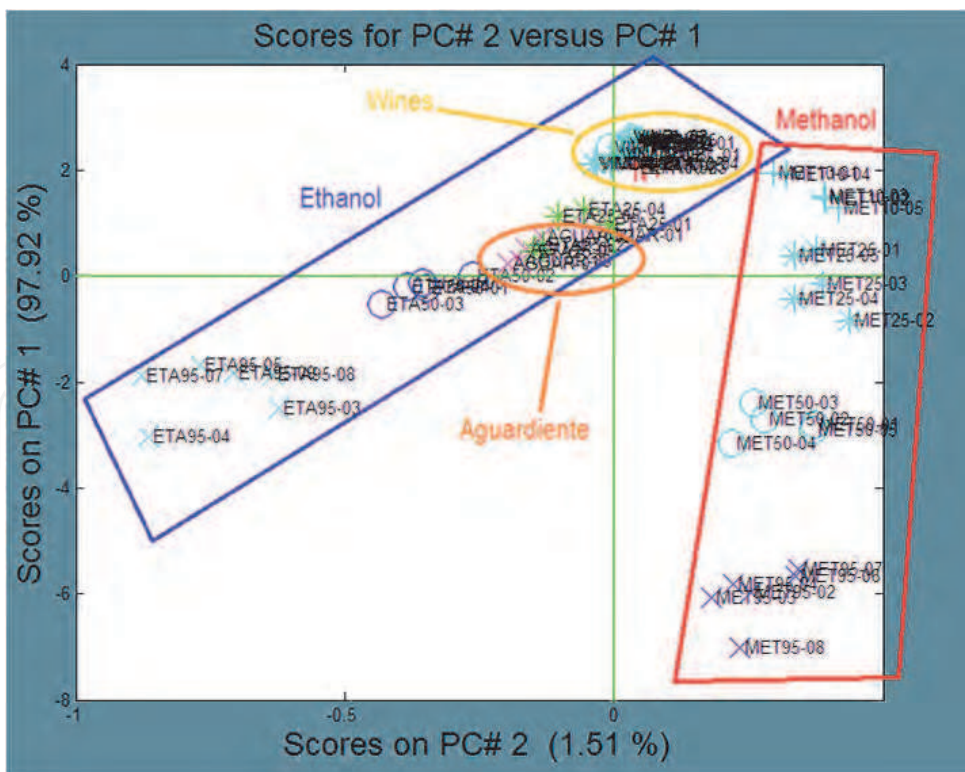

Fig. 14. Results of PCA analysis for the classification of wines and Aguardiente, according to the concentration of Ethanol and Methanol.

diseases (Xu et al., 2008, Velasquez et al ., 2009), the detection of narcotics and explosive substances (Oakes, L.; Dobrokhotov, V., 2010), determination of air quality and the environment (Zhou et al., 2006), among others, although there are still many possible applications to be explored.

4.1 Detection of diseases using electronic nose systems

There are a variety of respiratory diseases, which in some cases are caused by smoking and exposure to contaminated environments. This is the case of Chronic Obstructive Pulmonary Disease COPD, which has a mortality rate exceeding 15.9% (Velásquez et al., 2009; Velásquez, 2008).

COPD is a chronic lung disease characterized by airflow limitation that is not fully reversible, with progressive deterioration and is associated with abnormal lung inflammatory response to noxious particles or gases (Velásquez et al., 2009; Velásquez, 2008). The main cause of COPD is prolonged consumption of cigarettes, it is said that up to 20% of smokers have COPD.

This disease is more common in:
- White people.
- People over 60 years of age.
- People who work in environments polluted by chemical vapors and harmful dust that can damage the lungs.
- People who suffer from chronic asthma.
- People with a family history of emphysema.

Other COPD risk factors include:
- Passive smoking.
- Air pollution.
- Low birth weight and other lung infections (Velásquez, 2008).

4.1.1 Analysis of measurements taken from people with COPD and healthy controls

Below are some results of the analysis of measurements taken from healthy controls, nonsmokers and patients diagnosed with COPD. All patients diagnosed with COPD were long time smokers from 16 years up to even 50 years and most of them have already quit smoking, due to the fact that many receive medical treatment. (Velásquez et al., 2009; Velásquez, 2008).

Figure 15 shows the results of PCA analysis of samples of healthy controls and patients with COPD. The low dispersion of measurements of healthy controls and high dispersion of measurements of patients with COPD can be seen; due the fact that to not all patients have the disease at the same level.

Figure 16 has separated the samples from different patients with COPD, from these results it can be inferred that according to the health of the person the different patients can be classified. Future research should conduct more measurements on patients at different stages of the disease and could also be extended to other respiratory diseases and even gastric related diseases.

A study that deserves attention is (Xu et al., 2008) who developed a solid trap/thermal desorption-based odorant gas condensation system designed and implemented for measuring low concentration odorant gas. The results showed that the technique was successfully applied to a medical electronic nose system. The developed system consists of a

flow control unit, a temperature control unit and a sorbent tube. The theoretical analysis and experimental results indicate that gas condensation, together with the medical electronic nose system can significantly reduce the detection limit of the nose system and increase the system's ability to distinguish low concentration gas samples.
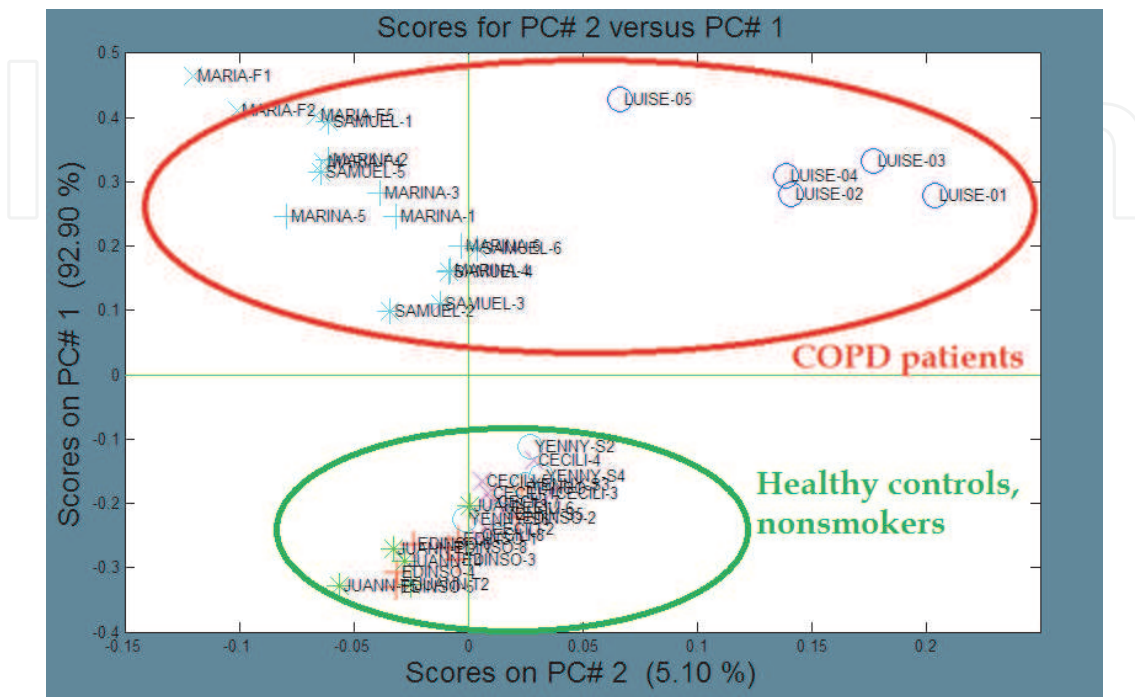
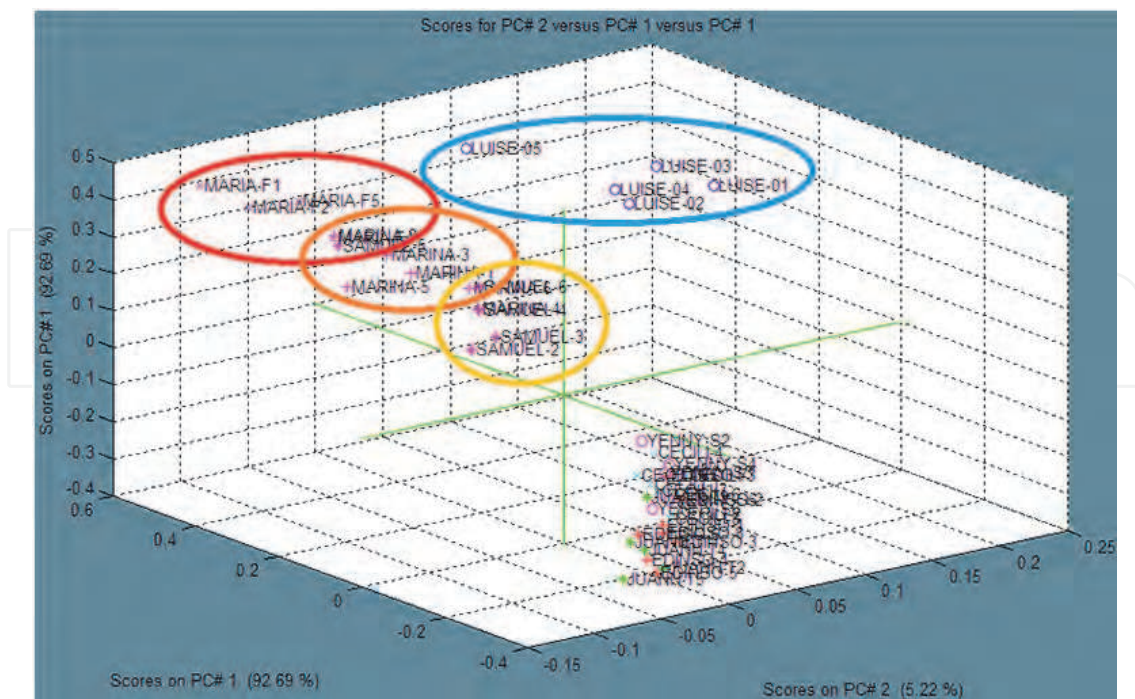Fig. 15. Results of PCA analysis for the classification of COPD patients and non-smokers.

Fig. 16. Results of PCA analysis with emphasis on measurements of patients with COPD. Using DGN (Center), displaying the first 2 components.

4.2 Determination of air quality using electronic nose systems

Such applications have a bright future in the industry, because the environment is very susceptible to leakage and contamination by gases, which in many cases can be harmful and even lethal to humans.

NASA has done some work on this issue, for example (Ryan et al., 2009), Whom Developed an Electronic Nose to be used in Environmental Monitoring in the International Space Station, the Electronic Nose (Enose) is an array of 32 polymer sensors, the pattern of response may identify contaminants in the environment. An engineering test model of the ENose was used to monitor the air of the Early Human Test experiment at Johnson Space Center for 49 days. Examination of the data recorded by the ENose shows that major excursions in the resistance recorded in the sensor array may be correlated with events recorded in the Test Logs of the Test Chamber. The ability to monitor the constituents of breathing air in a closed chamber in which air is recycled is important to NASA for use in closed environments such as the space shuttle and the space station.

In the same way an electronic nose system could be developed for places such as airports or customs, in order to detect narcotics or prohibited hallucinogenic substances and in hostile or war environment to detect explosives or mines planted in the soil.

5. Conclusions

The operation of the electronic nose system depends on the component parts and the features of the equipment. Inside we find the gas sensor array, the volatile particle delivery system, control system, data acquisition and data processing system.

We recommend a different chamber or hermetic compartment be used for containing the sample to be analyzed, called "Chamber of Concentration", provided the environmental and physical conditions of the system allow it.

The volatile particle transport system is fundamental because it affects the operation of the electronic nose system in the 3 different processes: concentration of volatile particles, measurement and cleanup.

Measurements with electronic nose systems begin by ensuring the adequacy of the sample to be examined, this depends on the type of element to be analyzed, which sometimes must be heated, cut, mixed with other elements or simply placed near the sensor array or in the chamber of concentration.

During the measurement process, the data acquisition system records all the changes in the output signal of each of the gas sensors. When the measurement process is finished the cleaning of the chamber of sensors begins, which is very important to restore the initial conditions of the system and to ensure the reproducibility of the measurements.

Once the measurement process is finished the stored data is processed and analyzed using the pre-processing software which allows to extraction of static parameters from the measurements and reduces the amount of information to be analyzed. Subsequently the processing software is applied, in order to obtain an olfactory footprint that represents the sample, to perform classification, discrimination and other tasks.

Coffee is preferably analyzed in the same way as by tasters, who perform tests on toasted and ground coffee, therefore the coffee must be roasted and ground in order to obtain a powder which is mixed with hot water, to facilitate the emission of volatile particles and this mixture is introduced into the chamber of concentration for the measurement process. This procedure for the preparation of the mixture can be applied similarly to other elements before the start of the measurements.

To identify measurement patterns or to carry out the training applications using computational intelligence it is very important to have expert staff on hand, as in the case of coffee quality control which had the support of trained coffee tasters, who issued their concept based on personal perception of each coffee sample, helping in the designation of the various patterns to facilitate subsequent classification tasks with different measurements.

Electronic nose systems have been widely used for classification, discrimination of characteristics and detection of different elements or compounds considering the organoleptic characteristics, and even for quantification tasks. This can be carried out with tools like multivariate analysis techniques and pattern recognition, such as PCA (Principal Component Analysis) and ANN (Artificial Neural Networks).

The processing software of electronic nose system can be implemented on a digital signal processor DSP using an artificial neural network like the alcohol research case presented in section 3 which used a Feed-forward back propagation network, which was trained with the aim of identifying and quantifying Ethanol and Methanol of different samples. As result the percentage of Ethanol and Methanol of the samples were obtained.

The artificial neural network that was used for the identification and quantification of Ethanol and Methanol was trained and tried using R2006a Matlab software; the training results were used to codify the the artificial neural network program in C++ language and subsequently downloaded this program in the digital signal processor DSP56F801 of Motorola.

The results of PCA analysis for samples of healthy controls and patients with COPD showed differences in the low dispersion of the measurements taken of healthy controls and high dispersion of the measurements taken of patients with COPD; due to the fact that not all patients have the disease at the same level.

6. Acknowledgements

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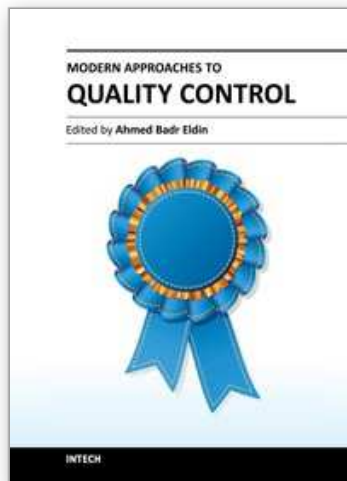
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