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New Portable Electronic Tongue Integrated on a Single Chip to Analysis Raw Milk

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Abstract

Objectives: The aim of this work is shows the elaboration of a device based on PSOC technology called electronic tongue, which is able to separate samples of raw milk. **Methods/Statistical Analysis**: The device developed consists of an electrochemical sensor array based on conductive polymers, a multi-channel system of electrochemical measurements, responsible for acquire and processing signals from substances trough sensors, and a data processing stage capable to discriminate different substances with multivariate statistical methods. **Findings**: The results show how this system was capable of offering unique signal front for each different samples of milk, the data obtained were discriminated by data processing stage thanks to the use of a multivariate statistical method called Principal Components Analysis. This work has been focused on the dairy sector, with the purpose to provide a device capable to make inspection of the raw milk in field. **Application/Improvements**: The device elaborated in our laboratory is compact and portable (347 g). The signals registered with the sensor array of the electronic tongue allowed to discriminate adulterated milk samples.

Keywords: Electronic Tongue, Electrochemical Sensors Array, PSOC Technology, Milk

1. Introduction

In the food industry, the appearance, aroma and flavour of the food products are key features fortheiracceptance on the market. Because of this, there are teams formed by expert people responsible to evaluate the organoleptic characteristics of foodstuff, these teams are called tasting panels^{1,2}. Additionally, it has become a necessity for collectors to make physicochemical and organoleptic tests to the raw milk due to the Colombian decree 616 of 2006²; howeverthis method requires strict conditions of healthy and only can be done few ratings per day.

On the other hand, thanks to technological advances, bio inspired devices as electronic tongues have been developed, which are capable to make organoleptic analysis to the food products^{4–7}. An electronic tongue is comprised of an electrochemical sensor array, an electric signals measurement system and data processing software based on multivariate statistical methods. This work is focused to signals processing stage; where the primary purpose is to acquire information from a substance through electrochemical sensors. To perform this function, is used an electrochemical technique called cyclic voltammeter, which is responsible for applying a potential ramp (V) in a substance and reading the current (I) flowing in the reaction produced, then the graphic I versus V is a curve termed voltammogram⁸. This technique is applied by an electrochemical device called potentiostat, which interacts with the analysed substance through three electrodes (counter, reference and work-

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ing), where the working electrodes (sensors) are used to obtain the current. When cyclic voltammeter is applied, the voltammogram acquired is a characteristic pattern of the analysed substance and the material of the working electrode; therefore, to get as much information as possible about this substance, it is really necessary to add others working electrodes, then the Potentiostat must be multi-channel.

Usually, the electronic tongues use the potentiostat equipment as electric signals measurement system and the entire process is completed with help of computer equipment, however, in the dairy sector the organoleptic analysis must be evaluated in field, for that reason the system must be portable. The use of PSOC technology is a potential resource to cover such need, this technology has gained importance in the development of miniaturized circuits and some applications can be found in the literature 9-12. PSOC (Programmable System on Chip) is a family of microcontroller, which contains digital and analogy blocks configured on a single chip, these characteristics make them different from other microcontrollers¹³. Whit the help of PSOC technology, in this paper it is shown the development of an electronic tongue integrated on a single chip, capable to acquire and processing signals from samples of raw milk and discriminate them according its taste characteristic.

2. Methodology

It is necessary to know the behaviour of the human taste system to understand the electronic tongue functioning. The brain is responsible to produce the taste sensation since electrical pulses generates in the tongue when it is exposed to the foods 1.14. According to this, the electronic tongue developed consists of three parts, which are explained below.

2.1 Electrochemical sensors array

In an electronic tongue, the element responsible of acquire the signal from a sample is the most important stage, according its chemical properties it is possible to obtain correct information about analysed samples. Often, to apply the cyclic voltammeter technique three electrodes are used (counter, reference and working), however the electronic tongue requires of obtaining great information from analysed substance. Consequently, in this we used a sensor array which is comprised by nine electrodes (Figure 1). It has a Counter electrode (C), a Reference electrode (R) and seven Working electrodes (W1-W7). Originally the material of working electrodes was metal; however each working electrode was modified with conducting polymer (polypyrrole) in order to acquire major information of the analysed substance.



Figure 1. Electro chemical sensors array.

2.2 Multi-Channel System of **Electrochemical Measurements**

The multi-channel system was based on a potentiostat circuit, which is responsible for applying the potential ramp in the analysed substance and read the produced current, this circuit is shown in Figure 2.

In the circuit of the Figure 2, the potentiostat is formed by two Resistors (R1, R2), two Operational amplifiers (OP1, OP2), and counter electrode, reference electrode and working electrodes. Through the reference electrode and the working electrode it is supplied a voltage to the samples equal to input voltage (VRAMP)15.16. The working electrodes read the current produced and the voltage is read by the output of OP2, then a voltammogram is obtained through current VS voltage graphic.

The multi-channel system was implemented into a single chip thanks to the PSOC technology. Freesoc board was used for this application, which includes 60 general purpose I/O pins and eight special purposes, high current outputs. Each pin can be used as digital or analogy input or output terminal; in addition, the pins can be configured as Rx and T using a component of communication. As is known, PSOC chip contains the necessary components to develop the signals processing stage, which is based on a multi-channel potentiostat.

2.3 Data Processing Stage

This stage is responsible to acquire data from Bluetooth module, sequentially a voltammogram is made based on current (I) VS voltage (V) graphic. In addition, this stage generates a text file of content data of the currents

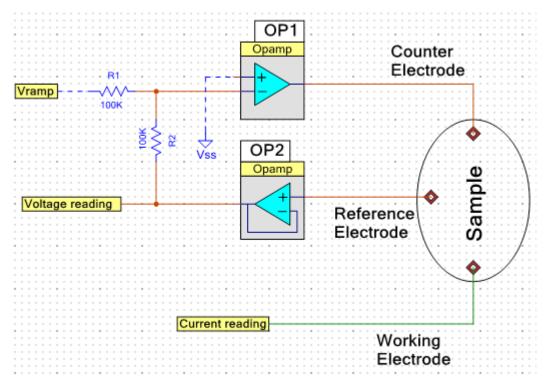


Figure 2. Basic potentiostat circuit.

registered during the process. Finally, software based on principal component analysis was developed in order to discriminate the analysed samples of raw milk adulterated with water. The software serves as a pattern recognition technique, since it is possible to reduce the dimensions of data without losing any critical information and the data obtained have the maximum variability. Finally the information about each sample acquired by the system can be represented by two-dimensional plane, where the discrimination according taste characteristics is shown.

3. Results and Discussion

The Figure 3 shows the schematic circuit designed and implemented on the FREESOC board. In the circuit of the Figure 3, there is a potentiostat formed by two Resistors (R1, R2), two Operational amplifiers (OP1, OP2), and Counter and reference electrode. The input voltage is a potential ramp generated by a Digital to Analogue Converter (DAC), while the signals are registered by two Analogue to Digital Converters - ADC components (ADC_V, ADC_I), however to read the currents in the

working electrodes, it is necessary to use an analog multiplexor, which choose one by one the inputs connected in working electrodes, in addition a Trans-Impedance Amplifier (TIA) is placed before ADC_I component in order to convert currents to voltages signals and the voltammogram can be generated. Finally, the signals are transmitted to the next stage by UART component through a Bluetooth module. To test the electrochemical sensors array, cyclic volt am meter technique was applied through the working electrodes, which were confronted to a samples of raw milk adulterated with different concentrations of water. Figure 4 shows the sensors' response of four working electrodes. As expected, different voltammograms were obtained by each sensor in a same sample, which mean that the electrochemical sensors array comply with the request to acquire as much information as possible of the analysed samples. Another important aspect is the capacity of discrimination of the sensors, the responses were unique according to the water concentration in the milk samples, and then it is possible to offer to the processing stage the correct information about the analysed samples.

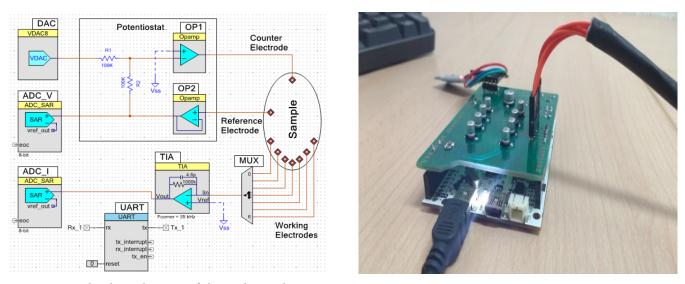


Figure 3. Multi-channel system of electrochemical measurements.

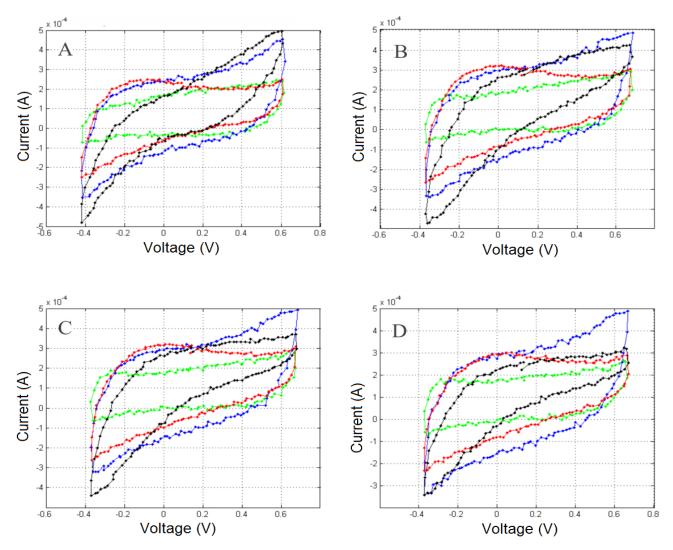


Figure 4. Voltammogram obtained from raw milk adulterated. (a) 0% water, (b) 5% water, (c) 10% water, (d) 20% water.

Finally, it was applied the principal component analysis method in the obtained data in order to test the discrimination capability of the system. In this case were made four measurements per sample and the resultant graphic is shown in the Figure 4.

As shown in Figure 4, each adulterated sample of raw milk was discriminated according its water concentration, the electronic tongue was capable to detect up to 5% of water in milk, which is vital to the quality control in the dairy sector, taking a count that in this industry analysing of raw milk is required in field.

The discrimination capability of the electronic tongue was evaluated by applying of principal component analysis. In Figure 5, it is shown the result of the execution of the principal component analysis of the data obtained from the device. As can be observed in the figure, the electronic language is able to clearly discriminate the four types of milk samples analysed. Unadulterated milk is seen on the right side of the figure, while that the samples of milk adulterated with water were shown on the left side. In addition, the adulterated samples with less water were observed in the inferior part of the left side of the figure and the samples with more water were observed in the part superior, following a spatial distribution consistent with the amount of water used like adulterant.

4. Conclusions

With the work developed, it was possible to show that PSOC technology is a very good alternative to design miniaturized circuits, which is essential to develop a portable electronic tongue.

In the other hand, it was possible to demonstrate that modified electrochemical sensors array play an important role in this device, since these sensors can offer correct information about analysed substance and the result of the all system depend of this.

The development of bio inspired devices, like electronic tongue is very useful in the dairy sector, since; offer this tool involves an increasing quality of foodstuff, and it is possible to make an organoleptic inspection of raw milk in field, without the need to expose people to zoon tic diseases cause of tasting inspection.

5. Acknowledgements

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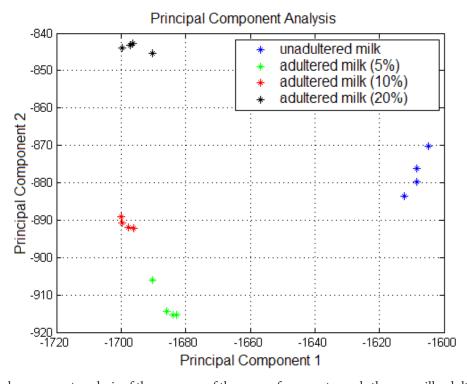


Figure 5. Principal component analysis of the response of the array of sensors towards the raw milk adulterated samples.

6. References

- Mendez MLR, Saja JAD, Medina-Plaza C, Garcia-Hernandez C. Electronic Noses and Tongues in Food Science. London: Academic Press; 2016. p. 1-12.
- 2. Lindemann B. Taste reception. Physiological Reviews. 1996; 76(3):719-66. Crossref.
- 3. Ministerio de la proteccion social. Decretonumero 616. Bogota D.C. 2006. Available from: http://www.ica.gov.co/getattachment/15425e0f-81fb-4111-b215-63e61e9e9130/2006D616.aspx
- 4. Arrieta A, Tarazona R. Sistema multi potencio tato basado en instrumentacion virtual. Ingeniería Investigaciony Tecnologia. 2014; 15(3):321-37. Crossref.
- Woertz K, Tissen C, Kleinebudde P, Breitkreutz J. Taste sensing systems (electronic tongues) for pharmaceutical applications. International Journal of Pharmaceutics. 2011; 417:256-71. Crossref.
- Fuentes O, Arrieta A, Jaramillo A. Sistema portatil de sensores inteligentes (lengua electronica) para el analisis de alimentos. Revista Investigaciones Aplicadas. 2014; 8(1):30-6.
- Rosa DA, Leone F, Cheli F, Chiofalo V. Fusion of electronic nose, electronic tongue and computer vision for animal source food authentication and quality assessment – A review. Journal of Food Engineering. 2017 Oct; 210:62-75. Crossref.

- 8. Gonzalez J. Tecnicas y metodos de laboratorio clinico. Masson, SA. 2nd Ed. Barcelona. 2005. p. 1-560.
- Arrieta A, Fuentes O, Palencia M. Android and PSOC Technology Applied to Electronic Tongue Development. Research. Journal of Applied Sciences, Engineering and Technology. 2015; 10(7):782-8. Crossref.
- Cabrera J, Velasco J. Implementacion de Filtros Analogos Usando PSOCS/FPAAS. Revista Colombiana de Fisica. 2008; 40(2):399-401.
- Jackson A, Moritz CT, Mavoori J, Lucas TH. The NEUROchip BCI: towards a neural prosthesis for upper limb function. IEEE Transactions on Neural Systems and Rehabilitation Engineering. 2006; 14(2):187-90. Crossref.
- 12. Massot B, Gehin C, Nocua R, Dittmar A, McAdams E. Centrale de mesure ambulatoire biomedicale sur PSOC. Journal IRBM. 2009; 30(4):150-2. Crossref.
- 13. Mar M, Sullam B, Blom E. Architecture for a configurable mixed-signal device. IEEE Journal of Solid-State Circuits. 2003; 38(3):565-8. Crossref.
- 14. Toepel U, Murray M. Human gustation: When the brain has taste. Current Biology. 2015; 25(9):381-3. Crossref.
- 15. Orazem M, Tribollet B. Electrochemical Impedance Spectroscopy. New Jersey: Wiley; 2008. Crossref.
- 16. Zaripova VM, Yu Petrova I. Information technology of concept design of biosensors. Indian Journal of Science and Technology. 2016; 9(1):1-11. Crossref.