

Research Article

Android and PSoC Technology Applied to Electronic Tongue Development

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Abstract: Nowadays, in the food industry, analyzing the quality of alimentary products has become a necessity. As a result, producers have been searching for new accurate methods to analyze food quality. The development of bio-inspired devices (electronic nose and electronic tongue) is a potential alternative to supply this need. The current project shows the development of a prototype circuit based on PSoC technology, which is used as a signal processing stage in an electronic tongue device with the ability to discriminate and classify samples of raw milk. In general, electronic tongues consist of electrochemical sensors array, a signals processing stage and a data processing stage. PSoC is an integrated circuit composed of analog and digital blocks into a configurable core. With the use of PSoC microchip, it is possible to develop a portable and small electrochemical device. This prototype takes measures from electrochemical sensors exposed to samples of drinks using the cyclic voltammetry technique; these signals are processed and transmitted to the next stage, which shows the response from the electrochemical sensors through an I-V curve, called voltammogram. With the development of this device, it was found that the application of PSoC technology on electrochemical measurement devices is important, due to its ability to develop cheaper, smaller, faster and sturdier devices.

Keywords: Electrochemical sensors, electronic tongue, PSoC technology

INTRODUCTION

In the food industry, the use of sense organs to analyze the characteristics of the products play an important role, since appearance, aroma and flavor are determinants to accept a food product (Almarío *et al.*, 2014). Even though there are expert people, tasting panels, capable to determine the quality of some food, especially drinks, it is necessary to contribute in the food sector developing devices that can be able to take signals from samples of drinks and to process these signals with the purpose to control the quality of their products, since the organoleptic analysis that a tasting panel make is very expensive. Although there are electrochemical devices that can be used to analyze a sample of drink, in the particular case of dairy sector, the device used must be portable, therefore, the use of PSoC technology is a suitable alternative to develop a device that gathers these characteristics. The structure of a PSoC circuit provides the flexibility that separates the PSoC family with regard to other microcontrollers. With the use of this technology, it is possible to reconfigure a device without the need to make changes on the hardware of its stages, since the changes are made on the chip. The PSoC technology is used to make analog signal treatment according its characteristics, for example the development of a

system which applies cycle tests method for lithium-ion secondary batteries was possible using the PSoC technology (Kato *et al.*, 2003).

So far, one of the most rigorous techniques to evaluate a specific drink is through a tasting panel, which consists of expert people capable to evaluate the taste and smell of a type of food, these are known as organoleptic characteristics (Lindemann, 1996). The method previously mentioned is costly in money and time, given that the process should be done under strict conditions, experts can only do few ratings per day, experts should have the best possible health, etc. Also, in the dairy sector, according to the decree 616 of 2006, during the collection it is really necessary to make a physicochemical and organoleptic inspection of raw milk (Ministerio de la Protección Social, 2010), so it is necessary to train collectors, exposing them to acquire zoonotic diseases. So far, the progress has been made in the analysis of wine (Parra *et al.*, 2006), beer (Arrieta *et al.*, 2010a) and coffee (Angel and Liliana, 2014), but this technology is still at a preliminary stage. Therefore, the current work intends to show the development of an electronic tongue, formed by an electrochemical sensors array, a processing signal stage based on PSoC technology and a data processing stage, thus it is possible to discriminate and classify samples of raw milk.

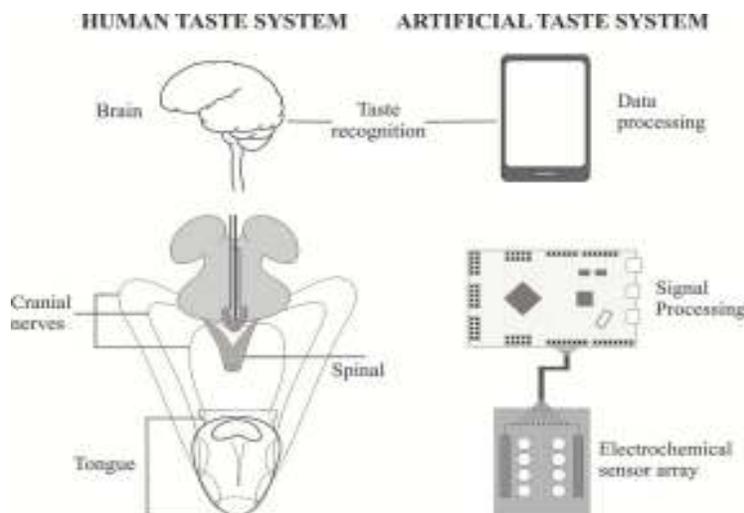


Fig. 1: Functional analogy between the human taste system and the electronic system of flavors detection

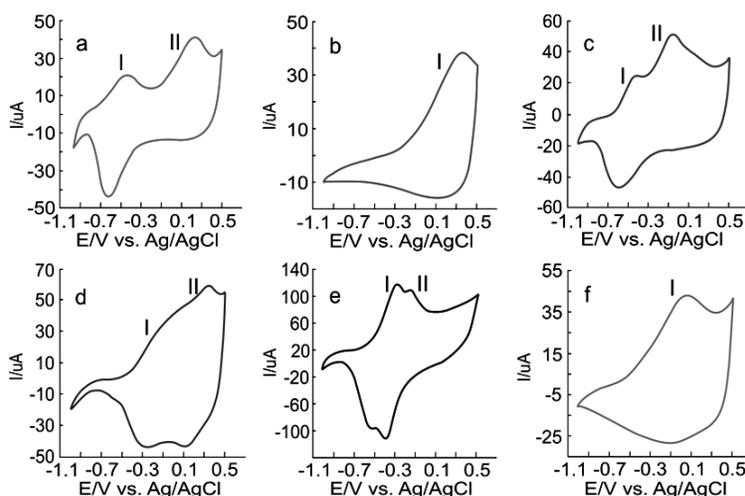


Fig. 2: Voltammetric signal obtained in wine, (a) PPy/DSA, (b) PPy/TSA, (c) PPy/AQDS, (d) PPy/FCN, (e) PPy/PWA y, (f) PPy/SO4 (Almario *et al.*, 2014)

MATERIALS AND METHODS

To develop a bio-inspired device like the electronic tongue, first, it is good to understand the behavior of human taste system. The taste system responds to electrical pulses that taste cells of the tongue produce when these are in touch with food. The pulses are transmitted to the brain where the taste sensation is produced (Lindemann, 1996). Figure 1 shows an analogy between the human taste system and an artificial taste system.

Sensors: The sensors are the most important stage in an electronic tongue, these are responsible to acquire the useful information from electrochemical reaction. It is important to bear in mind the material of the sensor, which should have good chemical stability and cross-sensitivity. There are developments of sensor based in metals and other based in conductive polymers, some of

these are found in the literature, (Winqvist *et al.*, 1997; Ivarson *et al.*, 2001; Woertz *et al.*, 2011; Arrieta *et al.*, 2010b).

Cyclic voltammetry technique: This technique is used to acquire information from electrochemical signals through three electrodes called reference, counter and working. The cyclic voltammetry is a technique used frequently in electronics tongue. This technique is responsible to the analysis of the current (I) flowing through an electrochemical cell while a potential ramp is applied, finally, it is possible to get a I - V curve, which describes the behavior of the electrochemical cell (Gonzales, 2005). According to the material of the working electrode and properties of the substance, different curves are obtained in this technique, the Fig. 2 shows voltammograms obtained from six different working electrodes in a sample of wine.

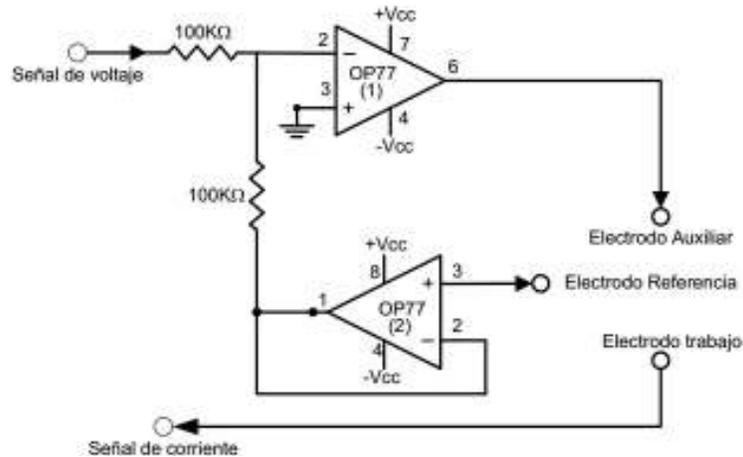


Fig. 3: Basic potentiostat circuit (Angel and Liliana, 2014)

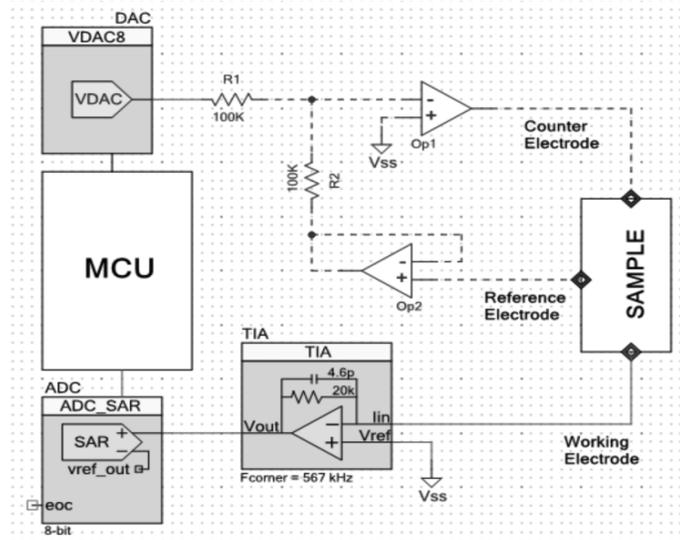


Fig. 4: Signals processing stage

Potentiostat: The stage responsible to acquire the signals from electrochemical sensor is based on a circuit of basic potentiostat, which apply the cyclic voltammetry technique. The use of cyclic voltammetry is important in the development of electronic tongue, this is used for acquiring information from electrochemical reactions. Figure 3 shows schematic circuit of a basic potentiostat.

As seen in Fig. 3, three electrodes (Counter, Reference and working) are in touch with the sample, when a voltage is applied between reference and working electrode, an electrochemical reaction is produced, the potentiostat is responsible to apply the potential and take the current flowing through the working electrode. The primary aim of a potentiostat circuit is to generate between reference and working electrode the same input voltage (Orazem and Tribollet, 2008). Figure 4 shows a complete diagram of the signals processing stage.

PSoC technology: The Micro-Controller Unit (MCU) is the principal component in this grade; it is responsible to control the behavior of all the subcomponents. The stage contains a potential control loop and a Trans-Impedance Amplifier (TIA) that provides an operational amplifier based on current-to-voltage. The Digital-Analog Converter DAC component produces the potential ramp between reference and working electrode, necessary to generate the electrochemical reaction and the Analog-Digital Converter (ADC) component is responsible for the conversion of analog signal to digital data, which will be transmitted to the data processing stage. With the use of the PSoC technology it is possible to develop the signal processing circuit on a simple chip. PSoCs are electronic microchips made by Cypress Company which are composed of analog and digital blocks, the structure of a PSoC circuit provides the flexibility that separates the PSoC family with regard to other

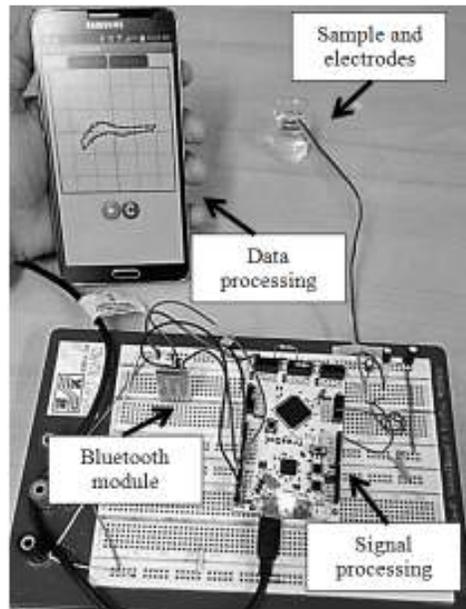


Fig. 5: Design implemented with FREESOC

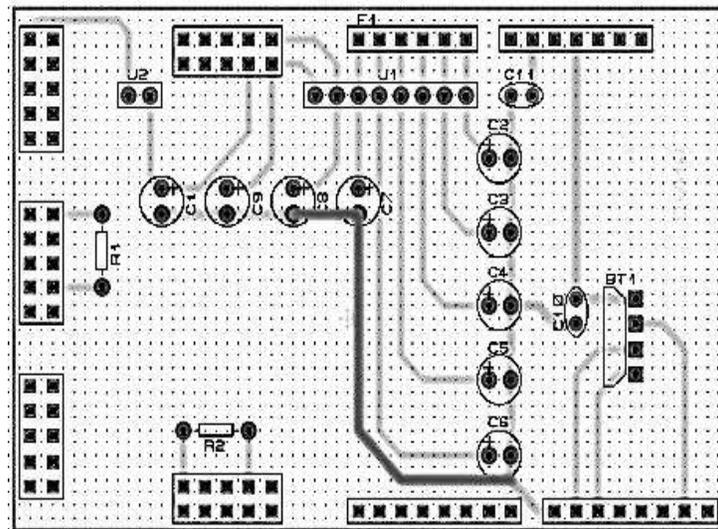


Fig. 6: Printed circuit board design

microcontrollers (Mar *et al.*, 2003). There are works where the PSoC technology is used, some of these are found in the literature (Cabrera-López and Velasco-Medina, 2008; Jackson *et al.*, 2006; Cabrera-López and Velasco-Medina, 2011). There are three principal families of PSoCs microchips, PSOC 1, PSOC 3 and PSOC 5. In addition Cypress provides an open software called PSoC Creator to design the electronics system based on PSoC. PSoC Creator 3.0 software was used to design the circuit shown in Fig. 4. The design was implemented in a FREESOC target, which contains a PSoC 5. Figure 5 shows the prototype implemented.

As seen in Fig. 5, the experiment involved the use of only three electrodes (R, C and W electrodes),

however, it is necessary to use a sensors array formed by eight working electrodes for obtaining as much information as is possible. Also external components as resistors, capacitors and connectors must be used, since the PSoC does not have passive components inside and then it is necessary to develop an additional circuit board, which is formed by passive components and connectors. Figure 6 shows the design of Printed Circuit Board (PCB).

The printed circuit board in Fig. 6 is formed by eight working electrodes, one reference electrode and one counter electrode; nine capacitors are connected to the eight working electrodes and reference electrode in order to filter the signal noise, finally one Bluetooth

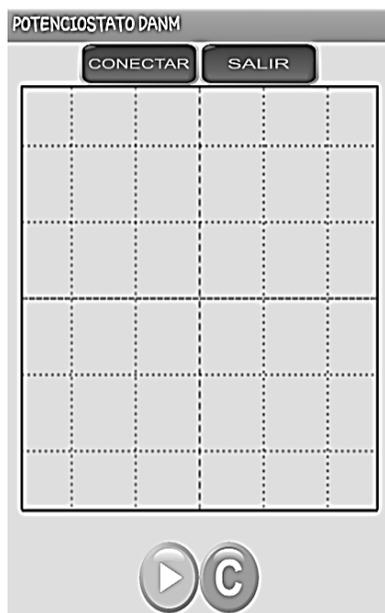


Fig. 7: Android application design

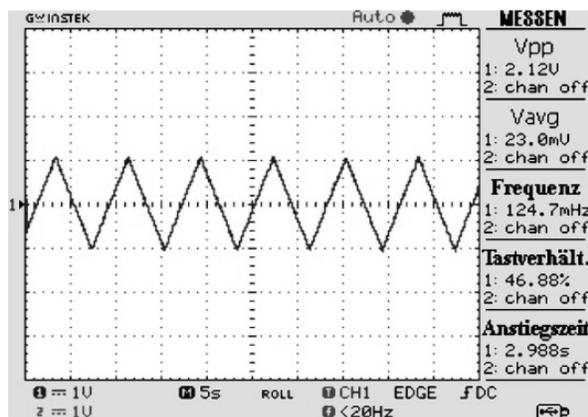


Fig. 8: Potential ramp 2 Vpp /125 mHz

module is connected in the circuit board for the communication.

To save the data the experiment produced, it was developed a program capable to take each signal from the working electrode, organize it in an array and finally generate a text file, using the free software Processing. Then the text file contains an array that can be used by other program of data processing as MATLAB.

Android application: To process the data obtained, an android application was made able to connect via bluetooth with the prototype. Android is an operative system deign to cellphones, tablets, TVs, etc., (Báez *et al.*, 2012), the use of android applications where is required signals processing has played a useful role nowadays, some papers about the use of android

are found in the literature (Dantu *et al.*, 2014; Lopez-Ruiz *et al.*, 2014, 2012). In this project, the application receives the data from bluetooth connection, then the data are placed in a canvas according to their value, finally it is shown a voltammogram in the canvas. Figure 7 shows the android application design.

RESULTS AND DISCUSSION

After To test the efficiency of the prototype, it was applied cyclic voltammetry technique in two samples of milk and lactic acid, respectively, using a commercial potentiostat. The same experiment was repeated using the device developed in the laboratory. The potential ramp generates a voltage of -1 to 1 V with a period of 8 sec (Fig. 8).

To calibrate the prototype, a comparison between the voltammograms obtained by the device developed in the laboratory and a commercial potentiostat was made. In this experiment, the cyclic voltammetric technique was applied to two samples of control, the experiment was done under the same conditions on both devices. Figure 9 shows the voltammograms obtained in the experiments.

In the Fig. 9, it is worth noting that the behavior described by both devices is very similar, which had shown that the prototype can be used as a signal processing stage in an electronic tongue device.

Furthermore, the maximum range of potential ramp that the device based on PSoC technology is between -2 and 2 V because the microcontroller provides 5 V, however these values are sufficient for applications of electronic tongue. For example, in this case, the potential ramp is between -1 and 1 V. On the other hand, the TIA component provides an operational amplifier based on current-to-voltage, the TIA has a conversion factor between 20 and 1000 K Ω and then it is important to take into account these values, since according to currents range, the conversion I to V does not exceed the voltage allowed by ADC component in PSoC. In this particular case, it was chosen a conversion factor of 560 Ω which was obtained with internal resistor of 1000 K Ω in parallel with external resistor of 560 Ω , according to that, the value obtained from ADC component ought to be divided by 560 to obtain the real current in working electrode.

In the android application the button called "CONECTAR" starts the connection with bluetooth module, once the devices is connected, the button with the play symbol, initiates the transmission of data to the android application, the data are placed in the screen until it is obtained a voltammogram, "C" button clears the screen and the "SALIR" button closes the application.

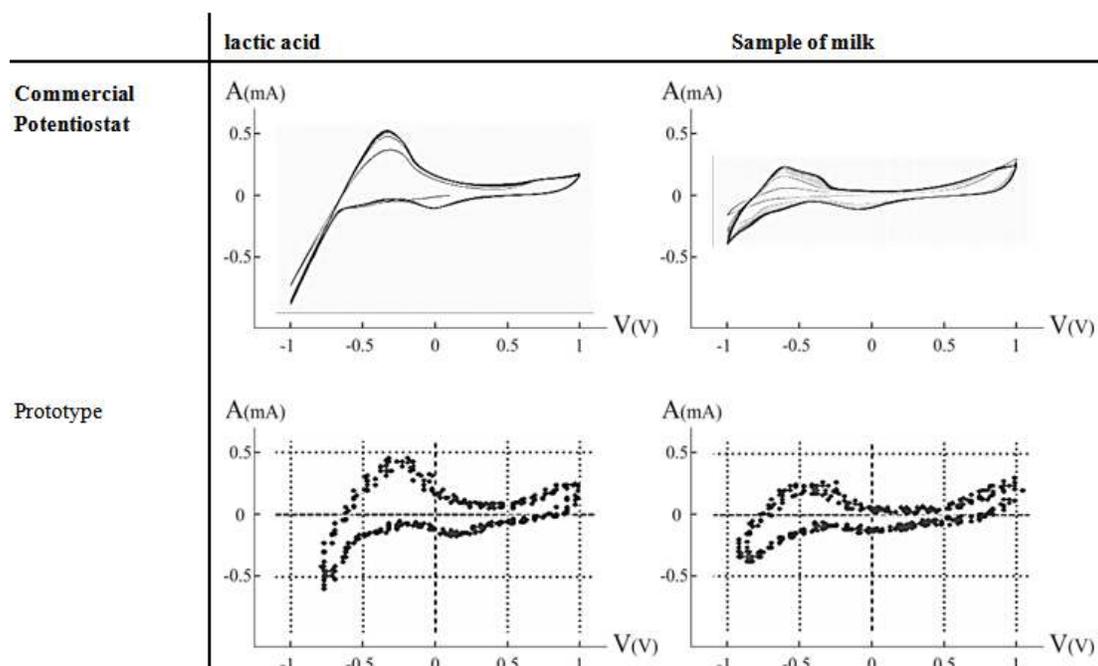


Fig. 9: Voltammogram obtained in two samples of control

CONCLUSION

PSoC is a very good tool for applications where small signal processing is necessary, due to PSoC contains high quality digital and analog components.

With the development of this device, it was checked that the use of PSoC technology on electrochemical measurement devices, allows developing cheaper, smaller, faster and sturdier devices, which is essential to electronic tongue in the dairy sector.

It seeks to develop an array of electrochemical sensors that can obtain as much information as possible from an electrochemical cell. Also aims to develop a stage of data processing that can implement multivariate statistical methods, in order to provide for the food industry, a portable electronic tongue device capable to discriminate and classify samples of raw milk.

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REFERENCES

Almarío, Á.Á.A., O.C. Fuentes Amin and A.F.J. Muñoz, 2014. Sistema portátil de sensores inteligentes (lengua electrónica) para el análisis de alimentos. *Rev. Invest. Apl.*, 8(1): 30-36.

Angel, A.A.Á. and T.C.R. Liliana, 2014. Sistema multipotenciostato basado en instrumentación virtual. *Ing. Invest. Tecnol.*, 15(3): 321-337.

Arrieta, Á.A., M.L. Rodríguez-Méndez and J.A. De Saja, 2010a. Aplicación de una lengua electrónica voltamétrica para la clasificación de vinos y estudio de correlación con la caracterización química y sensorial. *Quím. Nova*, 33(4): 787-793.

Arrieta, Á.A., M.L. Rodríguez-Méndez, J.A. de Saja, C.A. Blanco and D. Nimubona, 2010b. Prediction of bitterness and alcoholic strength in beer using an electronic tongue. *Food Chem.*, 123: 642-646.

Báez, M., Á. Borrego, J. Cordero, L. Cruz, M. Gonzáles, F. Hernández, D. Palomero, J. Rodríguez de Llera, D. Sanz, M. Saucedo, P. Torralbo and Á. Zapata, 2012. *Introducción a Android*. E.M.E. Editorial, Madrid, España.

Cabrera-López, J.J. and J. Velasco-Medina, 2008. Implementación de filtros análogos usando PSoCs/FPAAs. *Rev. Colomb. Fís.*, 40(2): 399-401.

Cabrera-López, J.J. and J. Velasco-Medina, 2011. Diseño e implementación de un sistema embebido para el procesamiento de señales ultrasónicas. *Rev. Colomb Fís.*, 43(1): 100-104.

Dantu, V., J. Vempati and S. Srivilliputhur, 2014. Non-invasive blood glucose monitor based on spectroscopy using a smartphone. *Proceeding of the 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. Chicago, Estados Unidos.

Gonzales, J., 2005. *Técnicas y Métodos de Laboratorio Clínico*. 2nd Edn., Masson, S.A., Barcelona, España.

- Ivarson, P., S. Holmin, N. Höjer, C. Krantz-Rülcker and F. Winquist, 2001. Discrimination of tea by means of a voltammetric electronic tongue and different applied waveforms. *Sensor Actuat. B-Chem.*, 76: 449-454.
- Jackson, A., C.T. Moritz, J. Mavoori, T.H. Lucas and E.E. Fetz, 2006. The neurochip BCI: Towards a neural prosthesis for upper limb function. *IEEE T. Neur. Sys. Reh.*, 14(2): 187-190.
- Kato, K., A. Negishi, K. Nozaki, I. Tsuda and K. Takano, 2003. PSOC cycle testing method for lithium-ion secondary batteries. *J. Power Sources*, 117: 118-123.
- Lindemann, B., 1996. Taste reception. *Physiol. Rev.*, 76: 719-766.
- Lopez-Ruiz, N., A. Martínez-Olmos, I.M. Pérez de Vargas-Sansalvador, M.D. Fernández-Ramos, M.A. Carvajal, L.F. Capitan-Vallvey and A.J. Palma, 2012. Determination of O₂ using colour sensing from image processing with mobile devices. *Sensor Actuat. B-Chem.*, 171: 938-945.
- Lopez-Ruiz, N., V.F. Curto, M.M. Erenas, F. Benito-López, D. Diamond, L.F. Capitan-Vellvey and A.J. Palma, 2014. Smartphone-based simultaneous pH and nitrite colorimetric determination for paper microfluidic devices. *Anal. Chem.*, 86(19): 9554-9562.
- Mar, M., B. Sullam and E. Blom, 2003. An architecture for a configurable mixed-signal device. *IEEE J. Solid-St. Circ.*, 38(3): 565-568.
- Ministerio de la Protección Social, 2010. Decreto Número 616. Bogotá, D.C.
- Orazem, M.E. and B. Tribollet, 2008. *Electrochemical Impedance Spectroscopy*. John Wiley and Sons, Hoboken, New Jersey, USA.
- Parra, V., Á.A. Arrieta, J.A. Fernández-Escudero, M.L. Rodríguez-Méndez and J.A. de Saja, 2006. Electronic tongue based on chemically modified electrodes and voltammetry for the detection of adulterations in wines. *Sensor Actuat. B-Chem.*, 118: 448-453.
- Winquist, F., P. Wide and I. Lundström, 1997. An electronic tongue based on voltammetry. *Anal. Chim. Acta*, 357: 21-31.
- Woertz, K., C. Tissen, P. Kleinebudde and J. Breitzkreutz, 2011. Taste sensing systems (electronic tongues) for pharmaceutical applications. *Int. J. Pharm.*, 417: 256-271.