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Research Article

Electronic Tongue: New Tool for Food Analysis Based a PSoC (Programmable System-on-Chip) Technology

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Abstract: The aim of this study is to show the development of a signals processing system on a single chip, based on PSoC technology, as stage of a portable electronic tongue, with the aim to discriminate samples of some substances according to their taste properties. The system applies a technique called cyclic voltammetry in order to obtain signals from a substance through of an electrochemical sensors array, these signals are processed and transmitted via bluetooth to a Smartphone with Android operating systems, where it is possible to look the behavior of the electrochemical sensors array front the analyzed substances. The cyclic voltammetry was applied to samples of saccharose and milk, using an electrochemical measurement device and the prototype developed; it was possible to check that both devices described the same behavior of the samples. On the other hand, the system was confronted with samples of milk, lactic acid and saccharose, where was possible to note the capability of this system to offer single response in front of different substances, which is a vital result thereof when discriminating a liquid substance according its flavor.

Keywords: Android, cyclic voltammetry, electrochemical, electronic tongue, PSoC technology, sensor

INTRODUCTION

One of the most rigorous methods to evaluate some properties of foodstuff is through a tasting panel; this is a group of people capable to examine the taste characteristic known as organoleptic (Lindemann, 1996). The method previously mentioned is costly in money and time, due to this, electronic tongues arose to supply the need of value the taste quality of food products in the food industry, since appearance, aroma and flavor are determinants to accept them (Angel and Liliana, 2014).

So far, electronic tongues are devices based on electrochemical equipment and computers, hard to carry out in field, the research group DANM (Desarrollo y Aplicación de NuevosMateriales) from Universidad PontificiaBolivariana- Montería and Group of Solid State Physics from Universidad de Valladolid has been working on the development of electronic tongues, which is important to discriminate and classify drinks, 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). An electronic tongue consists of an electrochemical sensor array, an electrochemical measurements device and software of data processing. Signals are obtained by an electrochemical technique called cyclic voltammetry, which provides a potential ramp and registers the current flowing through the electrochemical sensors, the curve current (I) vs potential (V) is known as voltammogram, which is an unique pattern according to the taste characteristics of sampling substance. To apply cyclic voltammetry technique it is necessary the use of an electrochemical measurement device known as potentiostat, but this device can not to carry out in field, which is necessary in the dairy sector, considering that in the dairy sector, according to the Colombian decree 616 of 2006 (Ministerio de la Protección Social, 2006), during the collection it is really necessary to make a physicochemical and organoleptic inspection of raw milk. In this respect Android and PSoC technologies are important tools to develop a portable electronic tongue capable to apply the cyclic voltammetry and processing the data obtained in field. PSoC (Programmable System on Chip) is a family of microcontroller composed of programmable analog and digital electronic blocks, the structure of a PSoC chips provides the flexibility that separates the PSoC family from other microcontrollers and it is used to make analog signal treatment according its characteristics

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(Kato *et al*., 2003). Android is an open operating system for Smartphones, tables and other electronic devices, which allow the programming software for these devices through a programming environment called Android Studio.

This study shows the development of a bio-inspired device based on taste human system, which comprise an electrochemical sensors array, an electronic circuit of signal treatment configured on a single chip PSoC 5LP and an Android application capable to connect with the electronic circuit via bluetooth, in order to show the voltammogram obtained from different liquid samples and to observe the behavior of developed system according them taste characteristics.

MATERIALS AND METHODS

To develop a bioinspired 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 they 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.

In an electronic tongue, the electrochemical sensor array is very important to register the useful information from electrochemical reaction; the material of sensor plays an important role, 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 (Winquist *et al*., 1997; Ivarson *et al*., 2001; Woertz *et al*., 2011; Arrieta *et al.*, 2010b).

The use of cyclic voltammetry is important to acquire the information from electrochemical sensors. This technique is responsible for 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). To apply the cyclic voltammetry is necessary to use electrochemical measurements equipment called potentiostat, 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 2 shows a complete diagram of the signals processing stage based on a potentiostat circuit.

Figure 2, three electrodes C, R, W (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. PSoC 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) responsible for current-to-voltage conversion. The Digital-Analog Converter DAC component produces the potential ramp between reference and working electrode, necessary to generate the electrochemical reaction and the Analogs – Digital Converter (V_ADC and I_ADC) components are responsible for the conversion of analogs signal to digital data, which will be transmitted to the data processing stage. PSoC Creator 3.0 software was used to design the circuit

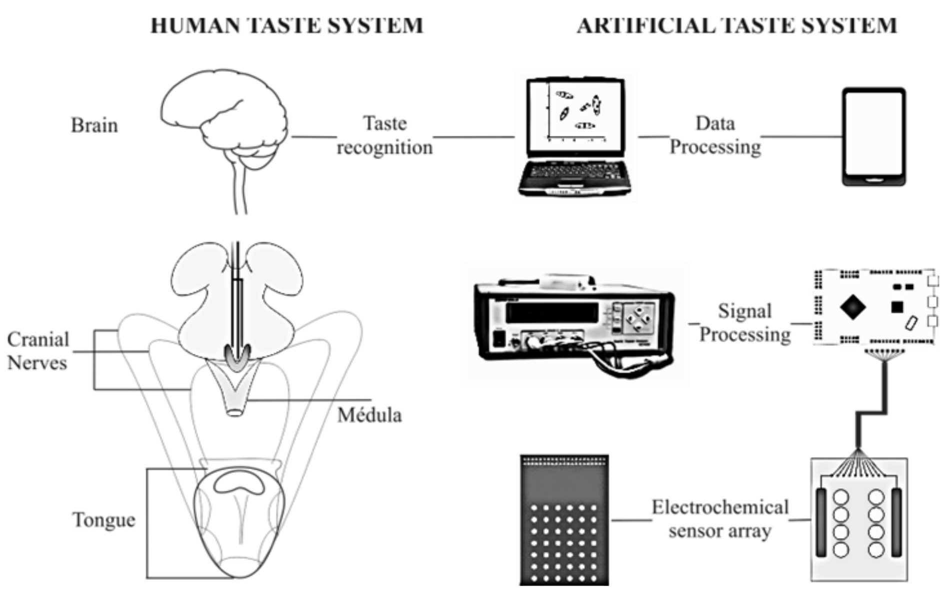

Fig. 1: Functional analogy between the human taste system and the electronic system of flavors detection

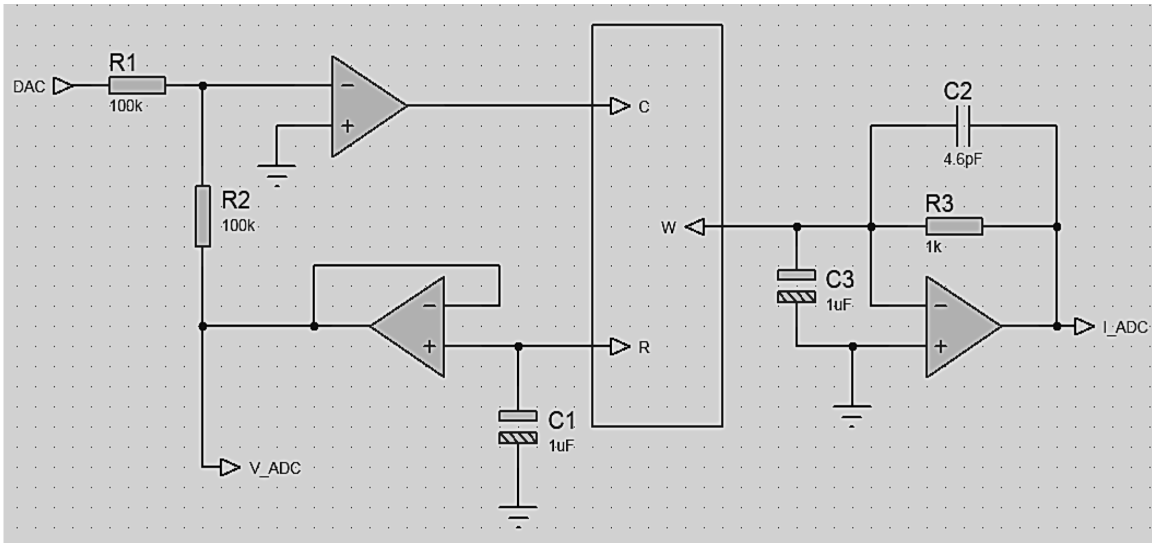

Fig. 2: Signal processing stage

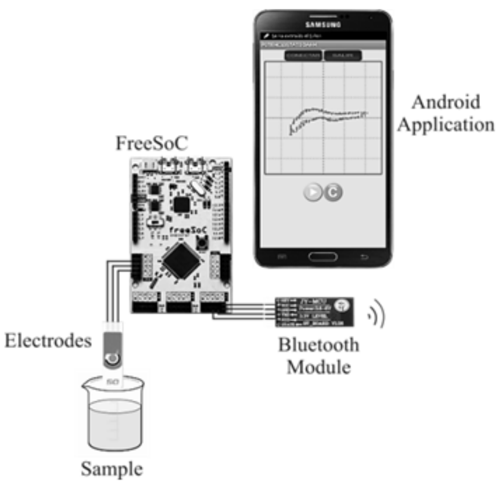

Fig. 3: Design implemented with freesoc and android

shown in Fig. 2. The FreeSoC target was used to implement the circuit, Fig. 3.

As seen in Fig. 3, 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 4 shows the design of a potentiostat of eight channels.

The circuit shown in Fig. 4 is formed by eight working electrodes connected in a Mux component, responsible for selecting the electrode to be measured, one reference electrode, one counter electrode, two capacitors connected to the mux output and reference electrode in order to filter the signal noise, a Digital-Analog Converter component called dac_ramp, responsible to generate the ramp signal, two Analog–Digital Converter components (V_ADC and I_ADC) to register the voltages and currents and finally one Uart component to send the data to the Smartphone through Bluetooth module.

It was developed an Android application able to connect via bluetooth with the prototype. 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. 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 (Lee and Cho, 2014; López-Ruiz *et al*., 2012; Lopez-Ruiz *et al*., 2014), the Fig. 5 shows the android application design.

The “CONECTAR” button 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, finally the “C” button clears the screen and the “SALIR” button closes the application.

RESULTS AND DISCUSSION

To test the efficiency of the prototype, it was applied cyclic voltammetry technique in two samples using a commercial potentiostat. The same experiment was repeated using the device developed in the laboratory. The potential ramp generates a voltage of -1V to 1V with a period of eight seconds. The cyclic voltammetry was applied in some samples, to register

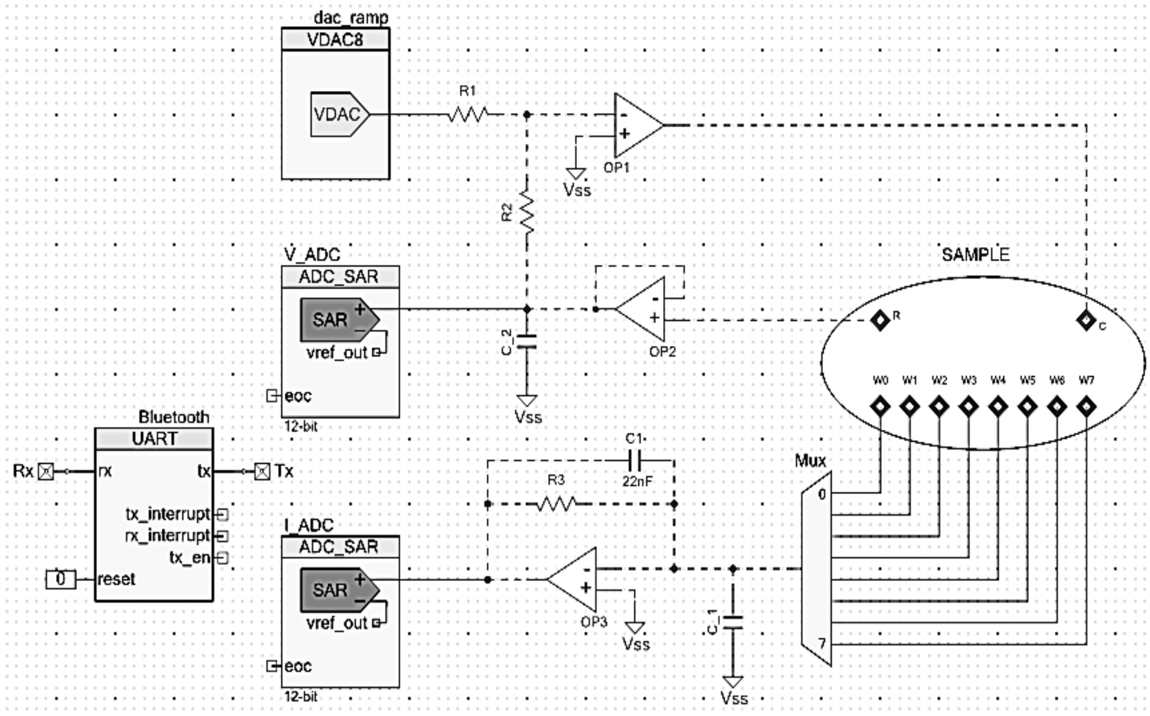

Fig. 4: Eight-channel spotentiostat design

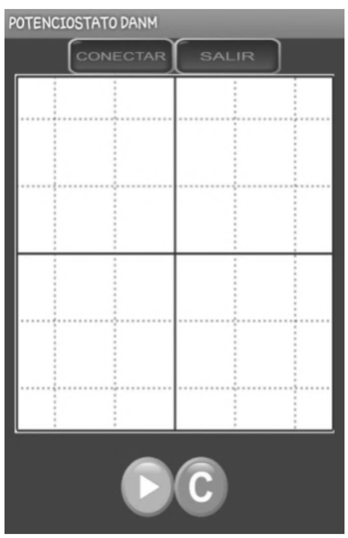

Fig. 5: Android application design

the current in the electrochemical reaction it was used a carbon working electrode and finally it was applied 10 cycles of potential ramp in the electrochemical cell in order to ensure the stability in the sensor response. Figure 6 shows the voltammograms obtained in the experiments with the prototype and a commercial potentiostat.

Figure 6 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 -2V and 2V because the microcontroller provides 5V, however these values are sufficient for applications of electronic tongue. For example, in this case, the potential ramp is between -1V and 1V. 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 KΩ 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, a resistor of 1KΩ was connected in parallel with the internal resistor of PSoC, according to that, the value obtained from ADC component ought to be divided by 1KΩ to obtain the real current in working electrode.

Finally, to probe the cross sensitivity of the carbon working electrode, the same experiment was run in some different substances, Fig. 7.

It is possible to note in the Fig. 7 that the voltammograms obtained are very different, this result is correct, since the substances have different chemical properties. We can see that the prototype is capable to generate different curves according to the organoleptic properties in the samples, it is essential to development an electronic tongue that can discriminate and classify a drink.

By now, the electronic tongues have been based on electrochemical devices of laboratory which those cannot be transported to field, some of this

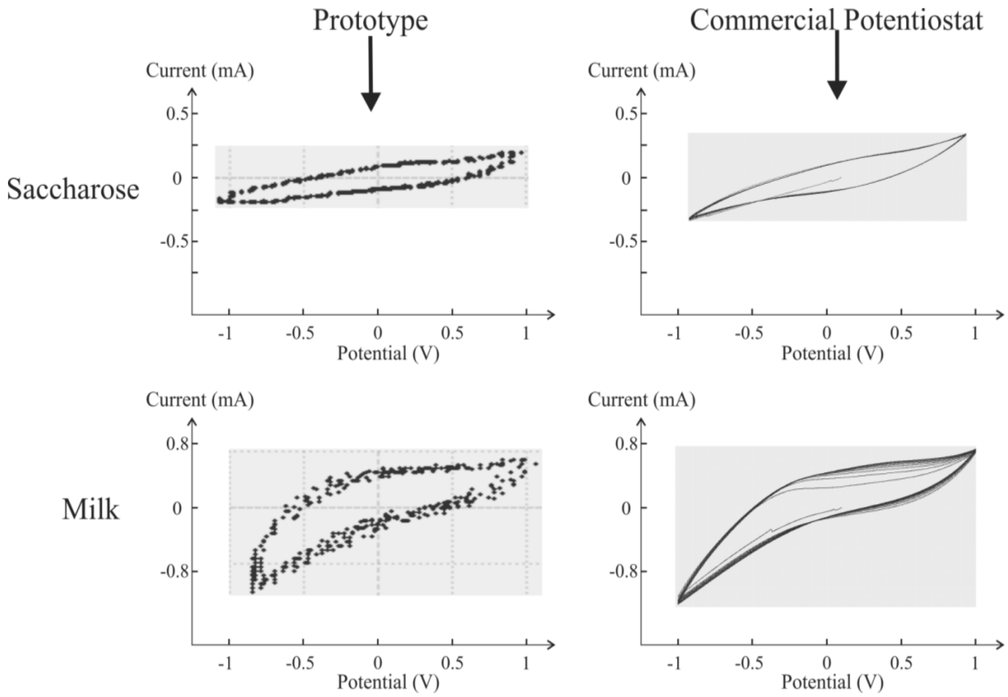

Fig. 6: Voltammogram obtained in two samples of control

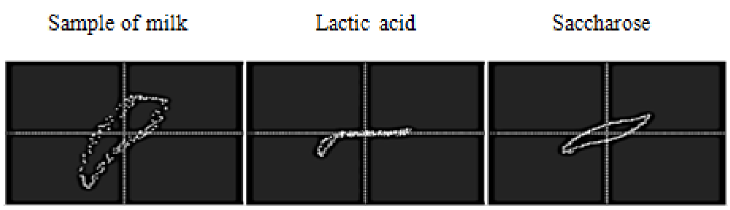

Fig. 7:Voltammograms obtained in some samples with the prototype

developments were previously mentioned. With the PSoC technology and the Android Operating System was possible to develop a portable and small device capable to apply the cyclic voltammetry technique and then it is possible to obtain information from a substance in field.

CONCLUSION

The results above show that the material of the working electrode is a decisive factor to discriminate samples of some substances, different voltammograms were obtained for each sample; finally it is play an important role in an electronic tongue.

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.

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