

Solar-powered Biosensor in the Perspective of the EPOSMote Wireless Sensing Platform

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Abstract. *Recently, biosensor applications have explored their ability to detect analytes through physicochemical detectors in field. Nevertheless, complex adjacent instrumentation has severally hampered their deployment. In this paper we propose to combine the versatility of EPOSMote wireless sensing platform to build biosensors that can be easily employed in field. The signal captured from hydroquinone biosensor is amplified and filtered by a conditioning circuit. This signal is sampled and transmitted over a wireless network by the EPOS-Mote radio. Finally, a central system is responsible for receiving and interpreting the acquired data. Our conditioning circuit was simulated using MatLab - Simulink® in order to evaluate its performance. Comparing our results against the potentiostat-galvanostat PGSTAT12 measurements we conclude that our system accuracy is enough for detecting hydroquinone concentration in agrochemicals.*

1. Introduction

Biosensors have been hardly explored and studied over the last few decades. They are defined as an analytical device which converts a biological response into a quantifiable and processable signal [?]. However, it is necessary an electrical interface (transducer element), a signal amplifier in order to obtain this signal.

They are used in order to determine the concentration of substances and other parameters of biological interest even where are not utilized biological system directly [?]. Biosensors may be applied in a large variety of samples including body fluids, food samples, cell cultures and environmental analysis (e.g. hydroquinone).

Hydroquinone (1,4-dihydroxy-benzene) is a phenolic compound and often coexist as isomers in environmental samples. Determination of hydroquinone levels is great necessary because of its coexistence in environmental pollutants with high toxicity [?] like pesticides.

Hydroquinone Biosensors have a fast and simple preparation process and the possibility of renewing the electrode surface. Due to this, they can be a good way to test the final efficiency of the device[?].

Although there are many applications in controlled environments, biosensor can be used in toughest environments. In many cases the main limitation of collect data using biosensors is the lack of cheap and effective handheld devices. Thus, they have to be confined to expert users of high-cost equipment in a lab environment and cannot be used semi-skilled operators [?]. Tools used for the management of biosensors like potentiostats tend to be big and expensive, restricting its application in field where is preferable to have a small, cheap and portable technology.

Technologies such as Wireless Networks (WN) and Solar Power Energy can assist the independence of portable devices. WN facilitate the communication between the local to be monitored and the control unit, enabling data transmission without wires dependence [?][?]. In addition, harvesting Solar Energy raises the possibility of infinite lifetime for the battery supplies [?].

In this paper we present a proposal for a portable and effective device. We developed a Solar-powered tool capable to assist in hydroquinone level measurement and transmit it over wireless network using EPOSMote platform [?].

This paper is organized as follows. Related work in section 2. In section 3, we will present a description of the implemented architecture. A brief overview about the biosensor used in Sections 4. A Presentation of the filter described in Sections 5. The results obtained are presented in section 6. And finally, we explain our conclusion in Section 7.

2. Related Work

In this section we will present the projects which have some relevance for this experiment and how they helped us reach our goal.

In the Salerno University, [?] an innovative measurement system for automatic FIA(Flow Injection Analysis) is proposed. It has a local measurement units and a central control unit. The main innovations are concentrated in the digital signal processing: peak amplitude measurement is fully automatized because the proposed units are able to detect the correct peak. The biosensor characteristics can be memorized in order to provide the analyte concentration as result. Furthermore, the LMU's (Local Measurement Unit) can be interfaced via RS485 port to a controller in order to be used in a multisensor measurement system for FIA process automatic management. A novel unit playing the role of controller (Manager Unit) has been designed to control several LMU's and a set of actuators, e.g. pumps and valves. Nevertheless, the communication between LMU and MU can be realized through a serial link. In this project was not used a WSN for transmitting data and control actuators, the mobility of equipment may be improved and the range of applications can be expanded attaching a wireless network.

An experience supported by Chinese Academy of Sciences [?] describes the development of a wireless biomedical sensor interface system-on-chip (SOC) that aims to combine many of the functions of the BSN microsystems onto a single substrate. The design is specified for a biosensor system with up to eight pH and temperature data channels communicating via an encoded wireless interface to a remote base station. The system comprises analog sensor interface circuit, data-conversion circuits, a microcontroller, a data encoder, and a frequency-shift keying (FSK) RF transmitter. However it takes experi-

ments [?], [?] , which report bioeffects, into account. Bioeffects, such as signal absorption by the organism can impair efficiency of a small antenna in enviromental measurements.

In [?]have been developed a short-range wireless RF tag capable of measuring pH and sending that data to a nearby reader. The tag contains a pH sensitive optrode that exploits the differential absorbance of light in a thin-film of bromocresol green indicator dye at two wavelengths. The measurement wavelengths correspond to the isosbestic point and the pH sensitive peak of the optical absorbance curve. The sensor is responsive over the range from 5.2 –8.3 pH units. Because the wireless system is based on the ISO standard RFID platform, it could in the future be suitable for use as a chemical and biological detector in different industries where this standard has been adopted. By adapting and modifying the specific indicator chemistry and optoelectronic detector measurement strategy, the platform could be deployed for different chemical and biological analytes, in addition to just pH. Conversely, The RFID reader energises and communicates with passive tags wich do not contain a battery or power supply, but operate by scavenging energy from the electromagnetic field generated by the antenna connected to the reader. Beside that, these passive devices do not generate machinereadable digital data, they do not easily scale from one to "many" devices, and cannot form or join wireless networks. Because they lack a core microprocessor, the devices cannot be programmed to conform to any of the established wireless protocols, which is a serious limitation to their widespread adoption.

3. Local measurement unit

In order to simplify the structure of the tool, it is separate in three main blocks: Sensible element, Conditioning circuit and Processing unit. Fig. 1 presents the block diagram of the Local measurement unit (LMU).

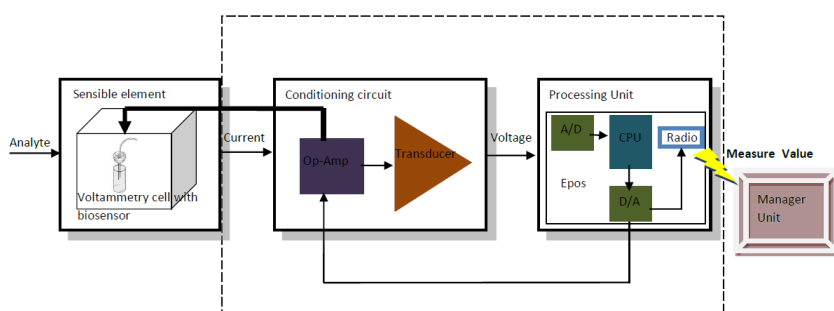


Figure 1. Block diagram of the Local Measurement Unit

3.1. Sensible element

The sensible element is comprised of three electrodes interacting in a voltammetry cell. The working electrode (WE) serves as the transduction element in the biochemical reaction works as the anode while the auxiliary electrode (AE) works as a cathode. Thus, electrons go out from the anode into the solution, being attracted by the cathode. The AE has an exclusive function of being a source or drain of electrons.

To make the result obtained repeatable, it is essential for the difference of potential between both electrodes to remain constant. To maintain a constant difference of potential

between the AE and the WE, a third electrode called reference electrode (RE) is added to the electrochemical cell. This is necessary because the potential difference between electrode working and counter electrode varies due to the change in electrical resistance of solution, which occurs due to mass transfer kinetics and reduction of ions

The RE establishes a constant reference potential in the electrochemical cell. A stable reference potential with temperature and time is essential in the RE. Also, there should be no chemical reactions involving the components of the electrolyte and the reference electrode.

Figure 2 provides an illustration of a voltammetry cell and directions of the electrons and current flow. A current is forced between WE and AE, high enough and in proper polarity to keep the working electrode potential at a constant value with respect to the RE electrode[?].

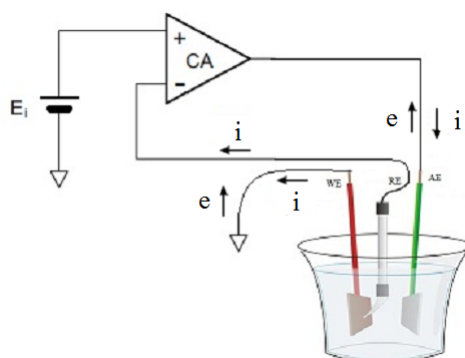


Figure 2. Voltammetry cell with three electrodes

3.2. Conditioning circuit

The conditioning circuit block diagram is presented in Fig. 3. A triangular voltage waveform, generated by the microcontroller, is imposed between the reference and working electrodes and the resultant current through the cell is measured between the counter and working electrodes. The output signal received in WE is amplified and converted by I-V circuit. Furthermore, the peak value of the current measured over a linear potential range is directly proportional to the bulk concentration of the analyte.

Because of different characteristics on the active substances, it is necessary a particularly input voltage depending on its statement. To change the output voltage to bipolar an op-amp level shifter circuit is used between RC circuit and the AE .

3.3. Processing unit

The chosen PiP (Platform-in-Package) was the Freescale MC13224V, it's based in an 32-bit ARM7 core and an integrated PA which provides programmable output power from

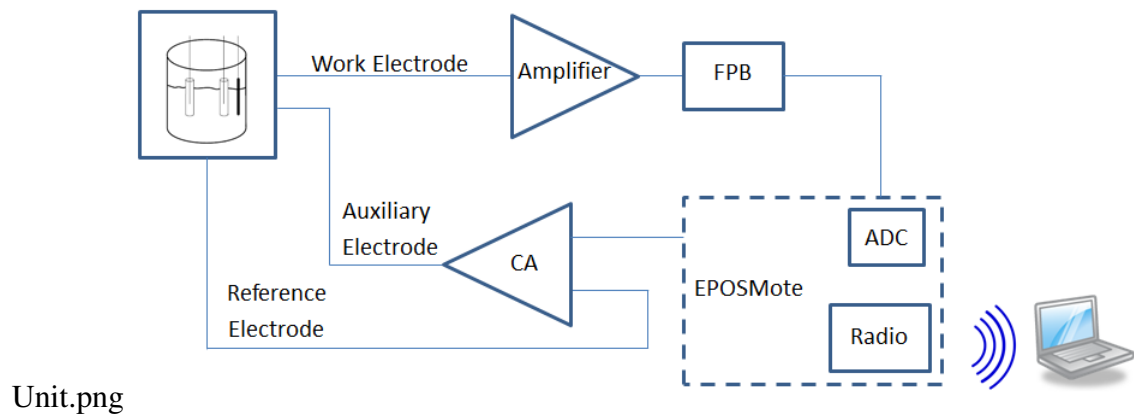


Figure 3. Voltammetry cell with three electrodes

-30dBm to +4dBm, all this in a $9.5 \times 9.5 \text{ mm}^2$ footprint. Moreover it owns low power consumption supply voltage 2.0 - 3.6 V.-96dBm for 1% RX sensitivity. high-density memory bandwidth 2.4 GHz with 8 input channels



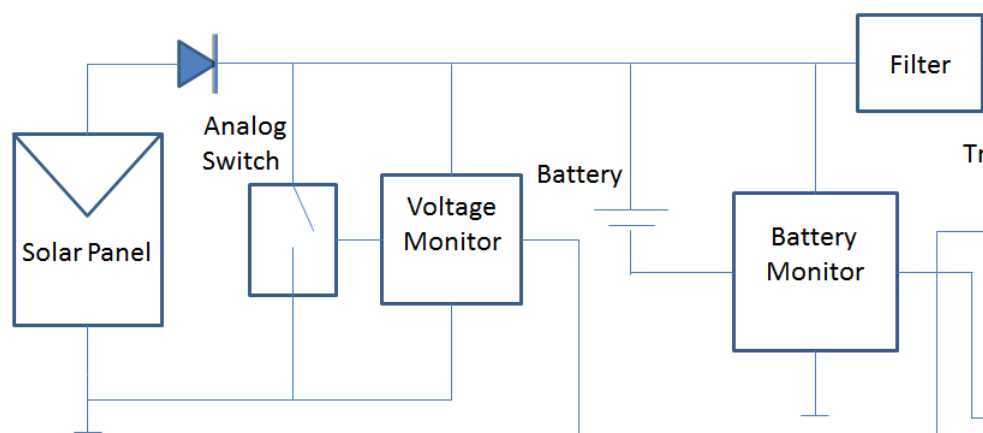
Figure 4. EposMotell

carried out by a ARM7TDMI microcontroller. In this project a PWM was implemented rasing its duty cycle and using a RC filter to generate a triangular waveform. The input waveform is fed to a current buffer AE and to the RE, stimulating a reaction between all reactants. The input voltage from the WE to A/D converter is variable and depends on the voltage on the reference pin (ranging between 0 and 4096). Due to this, the sent value to a sink sensor is proportional to the current value. The communication between LMU and manager unit (MU) is realized through wireless link via radio. EPOSmotess can perform data transmission to an average distance of 20-100 meters depending on the terrain and obstacles in the middle.

3.4. Manager unit

A sink sensor is responsible for acquire the transmitted data from the sensor node. The data is stored in a buffer and wrote in the serial port where they can be written in a text file. The last step in process the value in file, converting them to values according the current applied in the WE and the voltage applied in AE. Thus, we can plot different kind of graphics and indentify peaks of current and therefore the level concentration of the solution.

3.5. Power Supply



energy.png

Figure 5. EposMotell

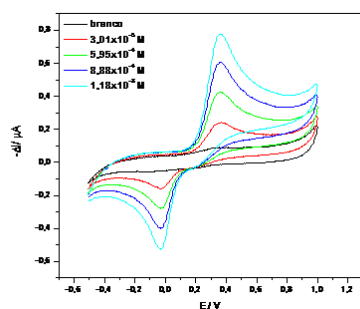
4. Experiment

The voltammetric measurements were performed, at first, on a potentiostat-galvanostat PGSTAT12 the Autolab (Eco Chemie, Sweden) using a software GPES version 4.9.006, Eco Chemie, see Figure 3. A glass cell with PVC cover was used without dividing compartment containing 10 mL of acetate buffer 0.1 mol L⁻¹ (pH 5.0) with aliquots of standard solution of hydroquinone. The three electrodes used were constructed using the biosensor as working electrode, a carbon tube (0.5 cm²) electrode used as auxiliary electrode and Ag / AgCl (3.0 mol L⁻¹ KCl) as reference electrode. Electrochemical measurements realized are reported in Table 1, indicating the potential and current according to the concentration of the solution for the volume of hydroquinone injected into the cell.

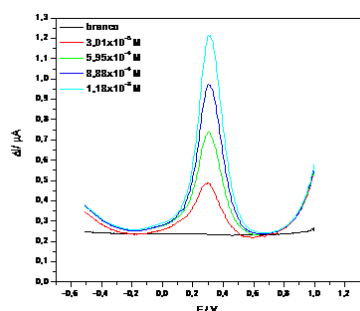
Volume of the aliquot	Concentration of hydroquinone (mol / L)	Square wave voltammetry		Cyclic voltammetry	
		Current	Potencial	Current	Potencial
50 uL	3,01x10 ⁻⁵	2,733x10 ⁻⁷	+0,289	1,43x10 ⁻⁷	+0,357
100 uL	5,95x10 ⁻⁴	5,079x10 ⁻⁷	+0,304	3,06x10 ⁻⁷	+0,362
150 uL	8,88x10 ⁻⁴	7,595x10 ⁻⁷	+0,304	4,59x10 ⁻⁷	+0,352
200 uL	1,18x10 ⁻³	9,97xx10 ⁻⁷	+0,313	6,08x10 ⁻⁷	+0,348

Table 1. Electrochemical measurements realized on a potentiostat-galvanostat PGSTAT12

With the measures outlined above a graph of current versus voltage (Cyclic voltammetry) can be generated to facilitate the understanding of the sample as shown in Figure 6a, and a square wave voltammetry as shown in figure 6b.



(a) Cyclic voltammetry



(b) Square wave voltammetry

Figure 6. (a) Cyclic voltammetry with velocity of 500 mV/s and Potential between -1,0 to +1,0 V.(b) Square wave voltammetry with frequency of 100 Hz, amplitude = 50 mV and a Increment = 5 mV/s and Potential between -1,0 to +1,0 V.

Based on information presented above, the shift circuit was configured to operate between 1,5 V to -1,5V as showed in Figure 7. In this range of voltage occurs the hydroquinone reaction.

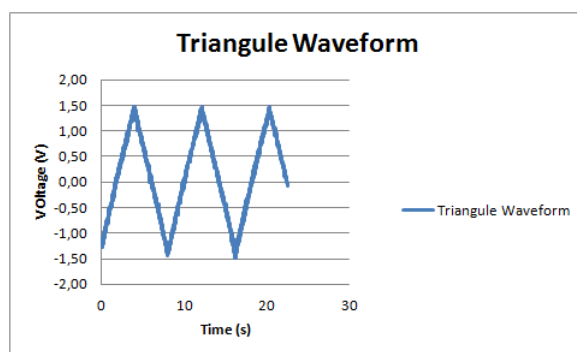


Figure 7. Output voltages of level-shifter amplifier

4.1. Biosensor

The implementation of LMU was started by means of amperometric biosensors for the determination of hydroquinone using a carbon paste electrode owing to important advantages to all other solid electrodes. The speed and simplicity of the preparation process, and the possibility of renewing the electrode surface with each new measure. This is important in the analysis of compounds where the reaction products are adsorbed on the electrode surface. Another important property is the low residual current, which is lower than pyrolytic graphite electrodes and carbon vitreous. However, some difficulties to de-

termination of substances with a carbon paste electrode may arise due to its high detection limit, which complicates the analysis of trace substances[?].

5. Experimental Results

To prove the effectiveness of the experiment, whole system was evaluated in the real case scenario using a simulation in MATLAB - Simulink@. In figure 7, we simulated our system with the data obtained by a potentiostat PGSTAT12 with the parameters cited in tab 1.

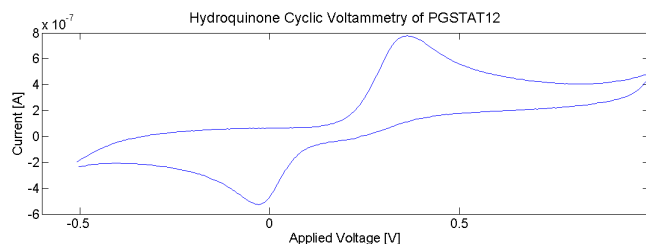


Figure 8. Hydroquinone cyclic voltammetry provided by potentiostat-galvanostat PGSTAT12 using a software GPES version 4.9.006. We used a solution containing 10 mL of acetate 0.1 mol L⁻¹ (pH 5.0) with a aliquots of 200 μ L of standard solution and a hydroquinone concentration of $1,18 \times 10^{-3}$ (mol/L).

In order to test the planned circuit we had to implement a low pass filter of 4th order and used all necessary information from datasheets. The graph in Figure 7 shows the final sample using noises and amplified values indicating the efficiency of the work.

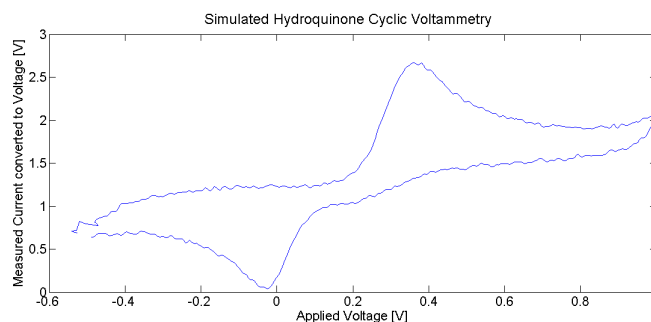


Figure 9. Signal conditioning hydroquinone cyclic voltammetry simulated in MATLAB - Simulink@ using a low pass filter of 4th order.

Comparing the realized measurement with Figure 7, we note that the current flow are increasing at the same time as the measure from PGSTAT12 demonstrating that it is able to exhibit a constant performance. The LMU implemented can keep the accuracy is enough for detecting hydroquinone concentration, shown in Figure 5.

Summarizing, the data were properly amplified with sufficient quality and accuracy so the experiment can help biosensors to be more used.

6. CONCLUSION

To achieve the goal, we present the design of a low-cost portable instrument for amperometric chemical sensors. It was tested by means of amperometric biosensors for the determination of hydroquinone. A methodology based on the presentation and development of a technology project that aims to detect a concentration of an analyte by sending

it via a wireless network for this information to be used in the receiver that will manipulate it according to need. In order to obtain a high precision solution, a low pass filter was implemented. Its noise level is low enough to measure dc currents with a resolution of 50 pA to 25 fA. In addition, because the reduced size, low cost, battery-powered and WSN interface it is suited to be used directly in field applications.

It is a computer system that assists in obtaining measurements, improved productivity, ease storage of information that can result in a historical, research enabling better accuracy in determining the time between data collection.

In the future projects is desirable improve this sensibility and create a thorough protocol to send data without transport restrictions testing with different types of biosensors.