Electrolytic Wire as an Alternative Bio Interface: A Case Study in Plant Tissue

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Abstract: One of challenge in physiological research is how to reconnect bioelectricity or turn on the transduction of signals in biological systems such as nerves and other tissues after some injuries or degenerative process. The electrical interactions in biological system can be understood by looking into the extracellular space between cells. In such spaces, contain ions and several charged organic molecules. Despite the fact that the common way to artificially link biological systems reported in the literature is by using metallic wires or bio-potentials electrodes, this paper present the hypothesis that an electrolytic conductor is more efficient to transmit information between biological systems when compared to the transmission carried out using electronic conductors. To test this hypothesis an experiment was conducted using two leaves of ornamental plant (*Agave atenuata*) connected by means of electronic and electrolytic wire and stimulated with electrical square waves with 1V of amplitude at 20Hz. The quality of signal transmitted using electronic conductor was compared to the signal transmitted using electrolytic conductor by measuring the distortion of the signal transmitted. The results shown that the transmission of stimuli using electrolytic wire is less disturbed than by using electronic wire.

1 INTRODUCTION

In this century, many technological approaches have been tested to develop systems that link biological system with electronic systems (Navarro *et al.,* 2005) or others biological interfaces (Agnew *et al.,* 1989; Hwang *et al.,*2016) to improve or to restore sensory functions in several kinds of diseases. A number of scientific approaches have been presented in order to the establishment of state-of-art in the biological and bionic interfaces (Lauer *et al.,*2000).

Each interaction among biological system involve bioelectrical information generated, transmitted, and broadcasted through organics pathways that link the bio-processors, biosensors and bio-actuators embedded throughout the organic systems (Enderle, 2011). The development of an interfacing method to artificially place information into the biological system, or to monitoring the information from it, would improve the way one can make the biological systems interacts each other and with the artificial systems.

Bioelectrical signals like EEG, EKG and EMG are detected by means of skin contact with electrodes connected to signal amplifiers (Enderle, 2011). The electrical contacts are performed by using biocompatible conductive hydrogels applied between skin and electrode. This process create an interface that influences the quality of signal and depending of this interface the signal quality is improved due the presence of conductive hydrogel (Pedrosa *et al.*,2017). The use of such electrolytic gels provides an effective contact but the information acquired from the biological system mediated by ionic interaction must be transduced in to electronic information in the metal electrode side (Clement *et al.*,2011). Despite this electrode provide excellent signal quality there are several difficulties related to it is use and to overcome such difficulties, some alternative electrodes that would be acceptable in physiological research were tested, for example dry electrodes (Mesiane *et al.*,2013). Even the most efficient electrodes still present an interface between an electronic conductor and the biological medium.

So far, an evaluation of electrodes technology applied to link biological system is little understood, this paper present an investigation on conductive hydrogels capability to be used like an electrolyte

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wire to conduct bioelectrical signal in plant tissue and then we suggest that this kind of wire could be considered as a future solution to bio-electronic interface.

2 ELECTROLYTIC CONDUCTOR

The electrical interactions in biological system can be understood by looking into the extracellular space between cells. In such spaces, with no more than 150 Å wide, contain ions and several charged organic molecules that are not only sensitive to electric fields but also generate their own fields and these electrical interactions flow to neighbouring disturbing it. For the sake of simplicity, it is inferred that this space is filled by an electrolytic solution.

Before the application of an external field in an electrolytic solution, it is behaviour can be understood by having a time-averaged electro neutrality in the electrolyte i.e. the net charge in any macroscopic volume of solution is zero because the total charge due to the positive ions is equal to the total charge due to the negative ions. If an electric field arise in an electrolytic solution, the opposite occur. The effect of this ionic drift on the state of charge of an electrolytic solution is to send positive ions near the positively charged area and the negative ions near the negatively one producing a spatial separation of charge. Because of this gross charge separation, the electro neutrality tends to be disturbed. Additionally, the separated charge tends generate its own field, which would be contrary to the externally applied field but equal in magnitude and then the resultant field in the solution will vanish. This not imply that an electrolytic solution would sustain only a transient migration of ions because in practice, an electrolytic solution can conduct electricity i.e., keep a continuous flow of ions. It can be understand by comparing electrolytic solution with a metallic conductor (Horno *et al.*,1992).

There is a lattice of positive ions that hold their equilibrium positions during the conduction process in a metallic conductor and, there are free conduction electrons, which transport charge. In the electrolytic conductor, however, if an electrical contact to and from the electrolyte is mediated by an interface electricity in the interface side and ions carry the charge in the electrolytic solution and if a change of charge carrier at the interface exist then a steady flow of charge in the entire circuit will be maintained. This electron transfers phenomenal between ions and the interface result in chemical changes.

The occurrence of a reaction at interface side is equivalent to the removal of equal amounts of positive and negative charge from the solution. In other words, when electronic disturbance reactions occur in the interface side, the ionic drift does not lead to the charges separation and no opposite field is created and then the flow of charge can continue i.e., the solution conducts, it is an electrolytic conductor.

In view of the above, the hypothesis that an electrolytic conductor is more efficient to transmit information between biological systems when compared to the transmission carried out using electronic conductors is postulated. To test this hypothesis an experimental setup using plant tissue is presented.

3 PLANT BIOELETRICITY

Literature studies shown that bioelectrical signals play central role in both cell-cell and long-distance communication in plants (Van Bel *et al.,*2014). There are four types of bioelectrical signals generated by plants: oscillatory potentials – OP, action potentials – AP, variations potentials – VP and system potentials –SP. Although AP, SP and VP is generated by distinct molecular dynamic, OP arise from complex mixing of bioelectric activities (AP, SP,VP) by means of a complex web of systemic interaction at short a long range level (Cabral *et al.*,2011; From *et al.*, 2013; Choi *et al.*, 2016). Plant Bio-potentials has lot of important information related with plant behavior and then can be used for test several aspects of bioelectricity.

4 MATERIAL AND METHODS

This experiment was carried out in Applied Physics and Computational Laboratory (LAFAC) at the Faculty of Animal Science and Food Engineering, University of São Paulo (USP), Brazil.

Leaves of ornamental plants *Agave atenuata* were collected in pairs and packaged in a beaker containing water. One leave was designed to be stimulate (Ls) and another leave (Lr) was designed to receive the stimuli transmitted by Ls. Each experimental section took place over 1 hour after leaves preparation. The experiment were conducted in the Faraday cage with controlled light incidence, and the temperature and relative humidity in the cage did not change significantly during the experience. To monitor the bioelectricity transmission between Ls and Lr, they were connected each other in two experimental arrangement. The first using normal wire needle electrode connecting the leaves and the second using electrolytic wire conductor. The schematic diagram of experimental setup concept is illustrated in diagram of Figure 1 and experimental arrangement is illustrated in Figure 2.

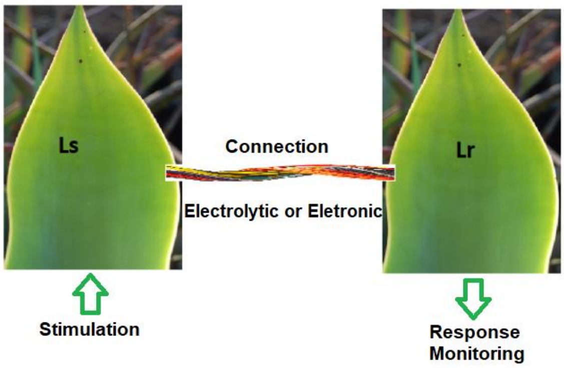

Figure 1: Schematic diagr am of experimental setup concept.

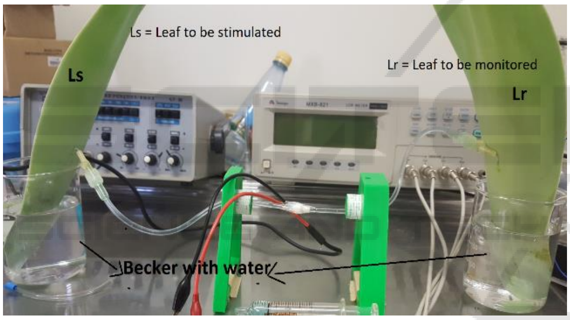

Figure 2: Experimental arrangement.

The electrical signals from the leave Lr were monitored using two Ag/AgCl disc electrodes connected to the leave surface, by means of a conductive aqueous gel as described in Cabral *et al.*, (2011). The electrodes were connected with screened cables to a high-input impedance (≈109 MΩ) electrometer that sent the data acquired to a computer by using wireless technology in real-time at sample rate frequency of 200 Hz.

The electrolytic wire was built by using a flexible non-conducting polymeric tube with the extremity needle-shaped to be connected in the leaf tissue and filled with a hydrophilic polymer known as hydrogels (Farina *et al.*, 2004). Figure 3 illustrate the electrolytic wire developed.

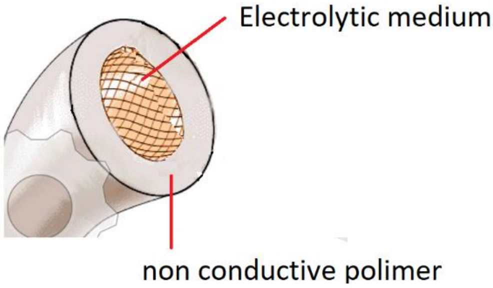

Figure 3: Electrolytic wire.

The Ls was stimulated using a square wave electrical signal with 1 V of amplitude and 20 Hz in frequency. Square wave was chosen because it is commonly used in experiments with stimuli (Declan *et al.*,2014) and 20 Hz was chosen due the fact that plants have oscillatory characteristics in a frequency range from 5 to 15 Hz (Cabral *et al.*, 2011) so 20 Hz is out of this range. Each experimental arrangement was repeated six times. To compare the effect of the type of wire used to transmit the signal from Ls to Lr the signal acquired was analysed by measuring the signals to noise and distortion ratio (SINAD) (Karandjeff *et al.*,2011, Grigoriev and Kharin, 2011) of signal acquired in relation of a signal acquired locally in Ls. The SINAD was used due the oscillatory characteristic of plant response to the stimuli. So, the signal source is the Ls leave response to square wave and the receiver is the Lr bioelectrical signal acquired. The bioelectrical signal from the Ls source is converted in to a form convenient for transmission along the communications channel represented by connection between the leaves. During the conversion, the initial information is distorted due to the fact that the conversion is non ideal.

The distortion measurement was made by using the Matlab® signal processing toolbox and the normalized SINAD results were presented.

The hydrophilic gel have demonstrated great potential to be used in biological systems. The hydrophilic gel polymer is biocompatible due its high water content. Hydrophilic gel polymer have a high affinity for water, nevertheless do not dissolve into it, because of its chemical and physical property; water molecules can only penetrate into the chains of the polymer network, subsequently causing swelling and formation of a hydrogel (Katter *et al.*,2017). For convenience was used the hydrogel currently available in local pharmaceutical market with conductivity (σ) and constant phase element parameters (A) measured in some papers in the literature. The chemical compositions of hydrogel used are listed as follows: water, disodium ethylenediaminetetraacetic acid, lithium chloride, propylene glycol, methylparaben and sodium carbomer. Conductivity (σ) and constant phase element (A) parameters of the hydrogel used has the follow value: $\sigma = 2.02\ \mathrm{S\ m^{-1}}$ and $A = 0.90 \times 10^4\ \Omega/\mathrm{s}^v$ (Freire *et al.*, 2010).

5 RESULTS AND DISCUSSION

In Figure 4 the signal acquired in Lr without any stimulation is shown.

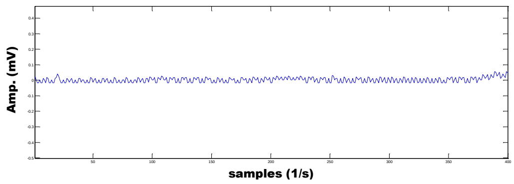

Figure 4: Signal acquired from leaf Lr without any stimulation and disconnected from Ls leaf.

Figure 5 shown the results of signal transmission from Ls connected to Lr by mean of copper wire or electronic conductor. Ls was stimulated by a square wave with 1 Volts of amplitude and 10 Hz of frequency.

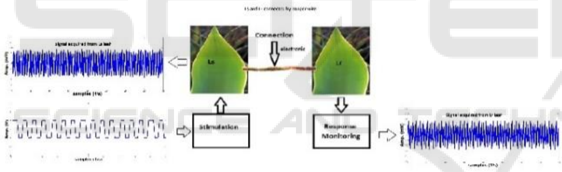

Figure 5: Leaves connected by electronic conductor. Experience with electric square wave stimuli.

Figure 6 shown the results of signal transmission from Ls connected to Lr by mean of electrolytic conductor.

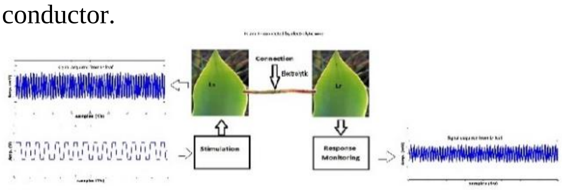

Figure 6: Leaves connected by electrolytic conductor. Experience with electric square wave stimuli.

The signal to noise and distortion ratio calculate for each signal acquired is shown in Table 1.

Table 1: SINAD measurement of signal acquired after electrical stimulation of the leaf Ls. Mean of six experimental run.

Transmission medium	SINAD of signal transmitted measured in Lr (dB)
Electronic	14.45 ± 0.07
Electrolytic	15.12± 0.3

6 A PRELIMINAR MODEL PROPOSITION

One of challenge in physiological research is how to reconnect bioelectricity or turn on the transduction of signals in biological systems such as nerves and other tissues after some injuries or degenerative process (Lauer *et al.*,2000). Some biological systems like in mammals, looks like wired systems, bio-structures like the brain send commands to others bio-structure like muscles. However, the mechanism related to the information transmission along such structures remain misunderstood. In fact, the information is related to the bioelectricity that pass among the structures like nerves, but this bioelectricity do not move in such structures as electrons move through a metallic conductor, for example, the rate of passage in bio structures is slower than that of electrons through a wire.

Another fact is the relationship between the bioelectricity and the electrolytic medium present in the extracellular medium of the biological structures, that is modelled via Nernst-type equation (Horno *et al.*,1992). Thus, the theoretical approach to the passage of bioelectricity through biological systems is related to the electrolytic conduction.

Despite the fact that the common way to artificially link biological systems reported in the literature is by using metallic wires or bio potentials electrodes (Navarro *et al.*,2005) the result in this paper allow us to discuss that another way to do that is using a electrolytic wire. The main argument to support this idea is that if two electrolytic solution is interfaced each other with different ions concentration and different ions mobility then a liquid-junction potential (Enderle, 2011) will arise between them with the magnitude given by:

$$E_{lj} = \frac{(\mu^+ - \mu^-)RT}{(\mu^+ + \mu^-)zF} \ln \frac{A^i}{A^k} \qquad (1)$$

When E_{lj} is the liquid-juction potential; μ^+ and μ^- represent the mobility; A^i and A^k are the activities of the ions of each side of liquid-junction; R is the universal gas constant; T represent the system's temperature; z represent the system's valence and F the system's Faraday constant.

Based in equation (1) the transduction of signal from junction is not necessarily linear and therefore can be modelled as illustrated in Figure 7.

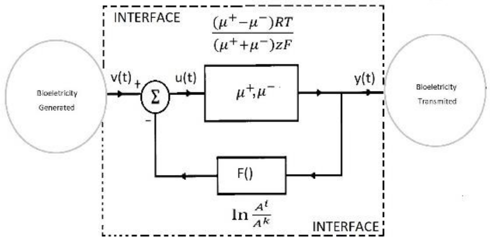

Figure 7: A simple non-linear model proposition for bioelectricity information transmission in an aqueous interface.

In the model of Figure (7) the ions activities will act like a negative feedback function F() and the coefficients μ^{+} and μ^{-} represent the mobility responsible by the nonlinear transduction in the interface. The signal transduction between the interfaces can be described as:

$$u(t) = v(t) - Fy(t) \qquad (2)$$

F represent the ions activities that act like an unilateral transference function. In this model, the distortion of the information caused by the interface is dependent of how the coefficients μ^{+} , μ^{-} and the ions activities are adjusted.

The results presented in this paper, suggest that de SINAD is related to several property of the interface, as described in the literature. When a liquid junction, i.e, an electrolytic wire, makes the transmission, the model proposed in Figure 7 can give a direction to the explanation of why the SINAD of signal transmitted by electrolytic wire is less than the signal transmitted by electronic wire. Future works will conducted in order to test if the model proposed will explain the data obtained. Overall results in this study allow the follow scientific question: is electrolytic transmission the alternative way to send signal in biological structures? To answer this question more experiments must be done with different kinds of biological structures but this start point open a door in the area of bioelectricity transmission.

7 CONCLUSIONS

A new method for transmission of bioelectricity using electrolytic wire was presented. The signal distortion of signal transmitted by electrolytic wire was less than the signal transmitted by an electronic wire. In addition, a non-linear model to explain the effect of aqueous junction was proposed and could explain the results obtained. Overall results allow to conclude that in plant tissues the transmission of bioelectricity is less disturbed than by means of electronic transmission. This research open a new door in the area of bioelectricity transmission among biological structures.

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