An Experiment to Assess an Acquisition Platform and Biomedical Signal Conditioning

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Abstract: As physical computing has grown and the concept of "Do it Yourself" (DIY) increased, various open-source electronics platforms emerged, such as Arduino and Raspberry pi. Still, these platforms aren't suited for acquisition and conditioning of biomedical signals. Inspired by the DIY concept, this paper presents a framework for acquisition and conditioning of biomedical signals composed of various interconnected, interchangeable, inter-configurable and reconfigurable boards, called YouMake. Moreover, they are low cost and have good documentation, making it easy for prototyping. The experimental evaluation of the platform was performed in a group of people who used it to show the level of usability and the time spent. The results showed that there are no statistical differences between the groups "with experience" and "without experience", and even more, that it can reliably be used for a low cost alternative for acquisition and conditioning of biomedical signals.

1 INTRODUCTION

The Luigi Galvani (1737-1798), Alessandro Volta (1755-1832), George Ohm (1787-1854) and Michael Faraday (1791-1867) researches provided the basis for the understanding of electrical potential and electric current, which helped studies of the electrical properties of cells and tissues, also known as electrophysiology. They have also shown that living tissues have electrical properties (Collura, 1993).

Collura (1993) also claims that the first scientists to focus their work on the electrical phenomena were Carlo Matteucci (1811-1868) and Emil du Bois-Reymond (1818-1896). The first studied the muscle properties of frogs and was the first to observe the potential action that precedes the contraction and the extent reduction of muscle during this contraction. Meanwhile, Du Bois-Reymond built a galvanometer of more than 4000 turns of wire in its coil, increasing its sensitivity. Moreover, Du Bois-Reymond developed non-polarizable electrodes made of clay and understood the importance of their use.

This study and the use of physiological signals increased in the engineering community. Thus, new application fields were born in addition to the more traditional areas of medicine. Such applications range from monitoring of human activity, human-machine interactions in games, and even biometrics, through new systems based on electrocardiography (Guerreiro, 2013).

As the high cost of professional equipment prevents the use of such equipment for engineering students in the field of physiological signals, alternatives to acquisition and conditioning of these signals are necessary.

In practice, it is often necessary to make measurements of different electrical human signals through simple devices. Although there are many bio-amplifiers with excellent precision and multi-channel, these are very expensive for general purpose (Babusiak and Borik, 2013).

Physical computing has grown as a field in its own right field (O'Sullivan and Igoe, 2004) and with the increasing concept of "Do it Yourself" (DIY) various open-source electronics platform emerged, such as Arduino and Raspberry pi.

However, until now, physical computing has been mainly used with equipment designed to meet requirements which are not compatible with the acquisition of physiological signals, such as relatively high noise tolerance and low sampling rate (Silva et

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al., 2014). In addition these requirements, physiological computing requires a circuit for acquisition of biomedical signal, which is not suitible through equipment designed for physical computing.

Thus, equipment commonly used in physical computing such as Arduino or Raspberry Pi are not viable in physiological computing, because they interact with simple actuators and sensors, not having channels for acquisition of biomedical signals and besides having few signals requirements.

Since then, many researchers turned to the study of physiological signals, improving the acquisition and conditioning of signals obtained and making it possible to find high-precision apparatus for use in modern medicine. However, such devices are expensive as they are meant for professional use in hospitals and clinics.

Thus, continuing the "DIY (Do-It-Yourself)" idea, this work presents a platform for acquisition and conditioning of physiological signals with low cost, versatile, generic and easy prototyping. This platform has the characteristics the fact of being composed of interlocking, interchangeable, inter-configurable and reconfigurable boards. It also has a strong documentation, enabling easy prototyping and manipulation.

The evaluation of this tool was made by the SUS scale developed by Brooke (1996) in what concerns the usability of the system. For comparison, it was used the usability of “experienced people” with “less experienced people” in the studied area, and a comparison was made with another work which used the same scale in its context.

The development of a tool such as presented here may be of interest to the Hardware laboratory in the computer department of the Sergipe Federal University (UFS) and other engineering such as electronics or electric, as well as people who work with biomedical engineering. The technology domain enables its flexibility and adaptation in several different surveys, enabling the possibility of integrating hardware with various laboratory equipment, allowing undergraduate and postgraduate students work in biomedical engineering.

The results of this experiment showed that there is no statistical difference between the prototyping time obtained for the "experienced people" and "inexperienced people" groups, also showing the platform usability note with a value A+ (on a scale going from F to a A+). It was also shown that the average usability of the "experienced" group is not different from the average usability of the "no experience" group, thus showing that a person with no experience in the field makes the prototyping with the same ease of a person with experience due to the platform's usability.

The work is divided into eight sections, the first introduction, and the second related work. The third section presents the methodology of the work focusing on describing how the board is designed and assembled. The fourth section contains the experiment planning and the fifth section details the operation of the same. The sixth section presents the results and discussion of the experiment. The seventh section highlights the threats to the validity of the experimental study and eighth section presents the conclusion and future work.

2 RELATED WORKS

Due to mismatch between the relevance and timeliness of biomedical engineering and the structure of electrical engineering courses in Brazil (Andrighetto et al., 2008), a postgraduate team of biomedical engineering institute of UFSC has developed a platform called SPSB-MD (Biomedical Signal Processing System - Teaching Modules) for acquisition and digitalization of electrocardiogram, electromyogram, electrooculogram and electroencephalogram signals, in order to fill the gap in biomedical engineering disciplines in undergraduate and postgraduate in UFSC. Despite the platform developed by Andrighetto et al. (2008) allow user access to analog components, it has distinct modules for acquisition and conditioning of each type of physiological signal. Unlike YouMake that has a module of acquisition and signal conditioning that can be modified by the user through prototyping to the specifications of the signal of interest.

The BITalino, developed by Silva et al. (2014) consists of a hardware card type framework for acquiring physiological signals focused in all in one, low cost. This cost is €149 in a configuration "Board Kit", €159 in the configuration "Freestyle Kit" and 169 euros in the configuration "Plugged Kit" (Bitalino, 2016). This platform is for general purpose and able to acquire electromyography signals, electrocardiography, electrodermal activities and accelerometry by fitting sensors blocks in the control block. While BITalino does not allow the change and adjustment of frequency bands and gains in filters and amplifiers, YouMake allows the user to modify these values freely, adapting the platform to the signal of interest. Furthermore, in BITalino it is not possible to connect a sensor block in another sensor block, in order to integrate the filter and improve them. In

YouMake it is possible to connect the boards to integrate filters and gains of the amplifiers. There is still a difference in cost, since the BITalino has estimated cost of between €149 and €169 and YouMake can be mounted with only €3,06.

Babusiak and Borik (2013) developed a four-channel amplifier for measuring the neurophysiological signals of humans, able to acquire the electrocardiogram, electroencephalograms and electrooculogram signals. This amplifier features variable gain and programmable through digital potentiometers, and allows you to change the lead in the measurement, considering the type and characteristics of the signal to be measured. However, in this device it is not possible to learn through prototyping and even interconnection between filters, which can be found in YouMake.

Meanwhile, Zanetti (2013), decided to develop a platform focused in the acquisition of electroencephalogram called RITMUS, having high performance, but because of its robustness, the price is high, around $495.36. Besides the high price, it is not as versatile and general as YouMake.

Finally, much of the work related to the acquisition of biological signals uses it for an application, such works develop a platform specific to acquire the desired signal, this is the case of Silva et al (2008), which develops a platform to acquire the signals of heart rate, respiration, and galvanic skin response in order to detect anxiety levels. Thus, Vijayprasath, Sukanesh and Rajan (2012) also focused on creating a platform for a specific application. This platform performs the acquisition and amplification of electrooculogram signals in order to use such signals in mouse cursor control through the eyes.

3 METHODOLOGY

As this work is to develop a low-cost platform for acquisition and conditioning of biomedical signals, specifically ECG, EOG and EMG, the first step was to design the acquisition and conditioning circuits, paying attention to the use of cheap and commercial components the manufacture of the boards.

With the boards ready and the components purchased, a guide and video was made for the user, in which show how to mount the platform and use it. For evaluation of the work, usability study for the platform was performed, checking the easiness of and the average time spent by users to mount. This usability study was done experimentally and with humans, for this reason, the study was submitted to the ethics committee and approved under the number CAAE: 58536416.6.0000.5546.

The block diagram in Figure 1 illustrates the YouMake's modules.

The following sections describe how it was designed and assembled the proposed platform.

3.1 Materials

The necessary low cost materials for the assembly of the platform are:

• Set of printed circuit boards with the project that will be shown in the following sections: each plate cost $1.4 and it took only two plates in this work;

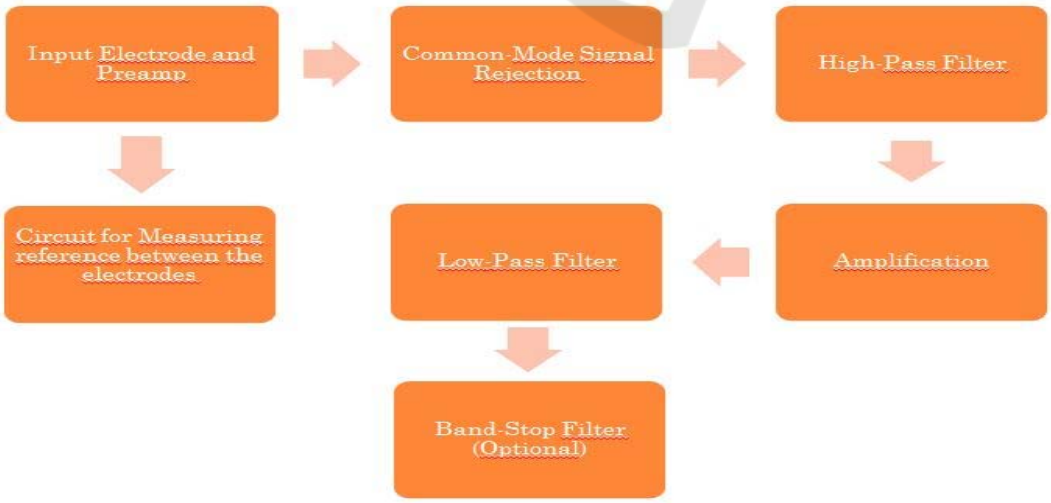

Figure 1: Platform block diagram.

• Integrated circuit LM324: only one was used and cost $0,32;

• Integrated circuit AD620: It was not used in the experiments, but could be used as an option for LM324 in the platform. The average cost is $11,94;

• Integrated circuit LM741: two were used in this work. About $0,32 each;

• Electronic Components: Resistors and capacitors costing a few cents each.

Thus, the estimated cost for the assembly of the platform in this paper was about $3,23 using LM324,

3.2 Supply

The supply of the whole circuit was made with two 9V batteries connected in series forming a symmetrical source of + 9V and -9V. However, it can be powered by any source of symmetrical voltage 5V to 15V. Special care should be taken, since the maximum voltage of the supply is the maximum value that the signal output voltage can reach, due to saturation of the operational amplifiers.

3.3 Biomedical Signals Acquisition Circuit

Figure 2 shows the schematic of the data acquisition board divided into blocks for better viewing. In addition to the blocks, the terminals were named curtly and standardized so that would fit on the board. The following shows the nomenclature of each terminal:

• IN1.AD: electrode input 1 to the circuit using the AD620 and must be connected to an electrode;

• IN2.AD: electrode input 2 to the circuit using the AD620 and must be connected to an electrode;

• TO.AUX.AD: AD620's circuit output that must be connected to the reference circuit (IN.AUX terminal).

• SAIDA.AD: output of the acquisition circuit formed by AD620 and must be connected at the input of the conditioning plate;

• IN1.LM: electrode input 1 to the circuit using the LM324 and must be connected to an electrode;

• IN2.LM: electrode input 2 to the circuit using the LM324 and must be connected to an electrode;

• TO.AUX.LM: instrumentation amplifier output formed by the LM324 and must be connected to the reference circuit (terminal IN.AUX);

• SAIDA.LM: output of the acquisition circuit formed by the LM324 and must be connected at the input of the conditioning board;

• IN.AUX: reference circuit input and must be connected to TO.AUX.LM terminal if the user is using the acquisition circuit formed by LM324, or TO.AUX.AD terminal if the user is using the acquisition circuit formed by AD620;

• SAIDA.AUX: the reference circuit output and to be connected to an electrode;

• V+: supply positive voltage;

• V-: supply negative voltage;

• TERRA: supply reference (ground).

Block 1 of Figure 2 shows AD620 integrated circuit, a circuit suitable for acquisition of biomedical signals. It has three resistors, where R13 and R14 are set to 22K forming a voltage divider in TO.AUX.AD terminal and a resistor R12 which is the resistor which can be varied to obtain different gain values. The terminal TO.AUX.AD must be connected to IN.AUX in block 4 to use the reference circuit with AD620. The circuit's gain is given by formula 1. Such gain should not be too high, otherwise a significantly increase in gain at this stage may adversely affect the signal with noise. The maximum gain achieved, without much noise, was 100, being advisable a gain smaller than 10 at the early stage. This paper uses a gain of 6.26.

$$R_G = (49.4K)/(G—1) \quad (1)$$

The block 2 of Figure 2 shows the instrumentation amplifier mounted with LM324, where the values of the resistors R2 and R3 were selected to be 47K (these values enable a wide range of gain variation according to the value of R1). The value of the gain of this amplifier is given by (2), such gain is varied in accordance with the resistor R1 (also called gain resistor) as it can be seen in Figure 2. This gain must not be too high, since a high gain at this stage may harm the signal with noise. The maximum gain achieved, without much noise, was 8, being advisable not to exceed this value. This paper uses a gain of 7.26.

$$G = 1 + ((R3 \times R2)/(R1)) \quad (2)$$

Block 3 of Figure 2 is rejection circuit for common mode signal, where all resistors have the same value, 10K (R4 = R5 = R6 = R7 = 10K). These values mean that there is no gain in this block.

For acquisition of biomedical signal a reference is required to measure between IN1 and IN2. This reference is provided by the circuit in block 4, as shown in Figure 2.

Resistor values in the block 4 were chosen according to the datasheet of AD620: R10 = 10K and R11 = 1M. The capacitor C1 has its value set at 100nF. The input circuit (IN.AUX) must be connected to the terminal TO.AUX.LM, which is located at the voltage divider formed by R8 and R9

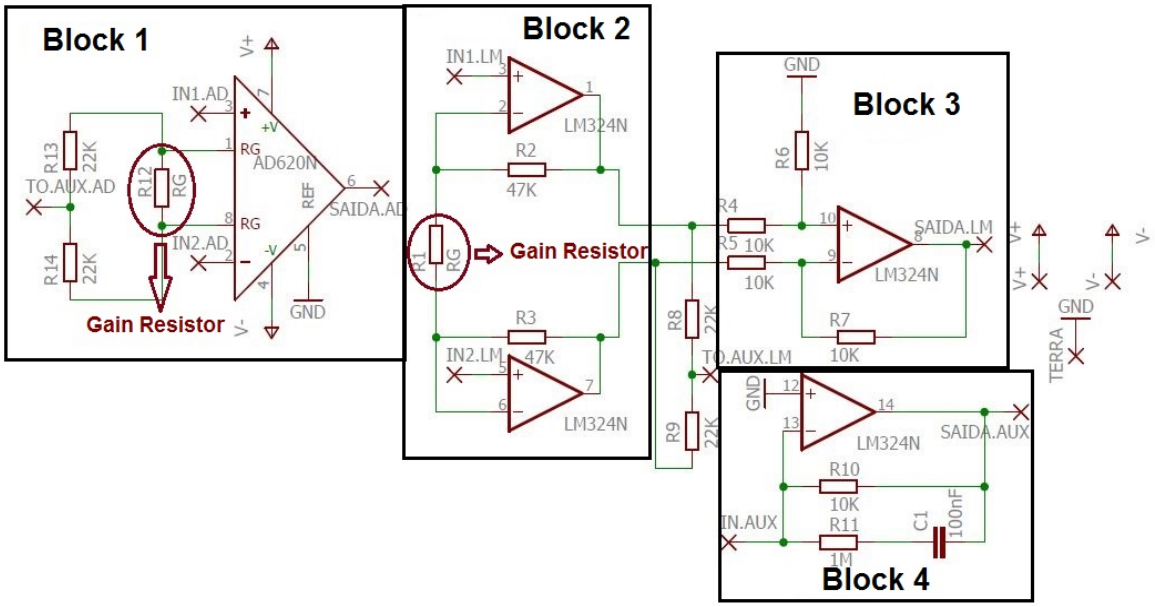

Figure 2: Acquisition board of biomedical signals.

(both resistors have the 22K value) if the user decides to use the LM324 circuit. If you want to use the AD620 circuit, the input of the reference circuit (IN.AUX) must be connected to the terminal TO.AUX.AD, which is located at the voltage divider consisting of R13 and R14 (both with 22K values).

Observing Figure 2, note that there are two separate and distinct acquisition circuits, one formed by AD620 and another by LM324, and blocks 2 and 3 are connected, because together they form the acquisition circuit through LM324. Thus, when one of the two is chosen to be used, you only need to solder the components referred on the chosen circuit, including the electrodes. Also, the block 4 is shared, so if you are using the acquisition circuit formed by AD620, it is necessary that the input of the reference circuit formed by block 4 is connected with block 1. However, if you are using an acquisition circuit formed by LM324, it must connect the block 4 input to terminal TO.AUX.LM between the blocks 2 and 3.

3.4 Biomedical Signals Conditioning Circuit

Figure 3 shows the schematic of the conditioning board. It is divided into blocks for better viewing. In addition to the blocks, the terminals were named curtly and standardized so that they fit on the board. The following shows the nomenclature of each terminal:

• ENTRADA.INVERSOR: inverting amplifier input. Must be connected to the output of the acquisition board;
• S.AMP.I: inverting amplifier output;
• ENTRADA.FILTRO: filter input;
• S.F: filter output;
• V+: supply positive voltage;
• V-: supply negative voltage;
• TERRA: supply reference.

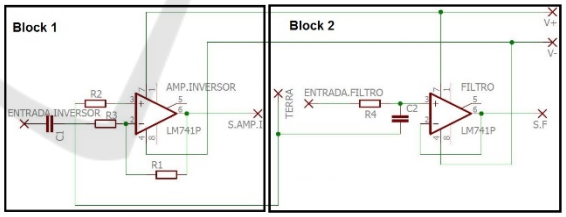

Figure 3: Conditioning circuit schematic.

Figure 3 shows the schematic of the conditioning board. Block 1 consists of an inverting amplifier formed by a LM741, where the gain can be seen in (3), for being an amplifier in the inverting configuration, it inverts the input signal. In this block there is a coupling capacitor C1, since it is positioned at the signal input, it also functions as a high-pass filter with a cutoff frequency defined by (4).

$$G = -R1/R3 \quad (3)$$

$$F_c = 1/(C1 \times R3) \quad (4)$$

It is in block 1 of Figure 3 that is applied the largest gain in the signal, in the order of tens or hundreds. Thus, R1 and R3 values are not fixed, and the values depend on the signal gain. The resistor R2 is used to minimize the effect of operational amplifier input bias current, so the resistors R2 and R1 must be equal.

Block 2 of Figure 3 shows the Butterworth type active low-pass filter and following the Sallen & Key setting that is applied to the signal, this is a first order filter and can be easily changed to a high-pass filter only inverting the position the capacitor with the resistor. R4 and C2 values were not fixed, as these depend on the value of the cutoff frequency of the filter (5).

$$F_c = 1/(2 \times \pi \times R4 \times C2) \quad (5)$$

4 EXPERIMENT PLANNING

4.1 Objective Definition

The purpose of this experiment is to evaluate, through a controlled experiment, the acquisition platform of biomedical signals using the Brooke systems (1996) usability scale as a measuring tool. This experiment will target two groups of participants, a group with experience and one without experience in electronics.

The goal was formalized using the GQM model proposed by Basili (1984): **analyze** the biomedical signals platform **in order to** evaluate **with respect** to the usability and time prototyping **in the point of view of** students and former students of undergraduate and postgraduate with and without experience in the study area, **in the context of** people interested in the study area.

4.2 Hypothesis Formulation

In this experiment, we want to answer the research questions QP1, QP2 and PQ3:

- QP1: The group with the most knowledge and experience in the area has an average value of usability higher than the group with less experience and knowledge?
- QP2: The platform can be used as a low cost alternative for the acquisition and conditioning of biomedical signals?
- QP3: The group with the most knowledge and experience in the area has the lowest average value of prototyping time than the group with less experience and knowledge?

To assess these questions, three metrics will be used:

- Average usability of each group (SUS_Valor);
- Overall average value of the usability of the experiment;
- Average time prototyping of each group.

With the research questions and metrics defined, the following hypotheses were defined:

a. Hypothesis 1

- H_{0SUS}: The average usability value of the "experienced" group is equal to the average usability value of the "no experience" group.
- H_{aSUS}: The average usability value of the "with experience" group is higher than the average usability value of the "no experience." group.

b. Hypothesis 2

- H_{0tempo}: The average prototyping time of the "experienced" group is equal to the average prototyping time of the "no experience." group.
- H_{atempo}: The average prototyping time of the "experienced" group is higher than the average prototyping time of the "no experience" group.

4.3 SUS Usability Scale

Usability is a quality suitability of any device, for a particular purpose, and their ability to be used in a given context. For being a subjective and complex evaluation, Brooke (1996) developed the Systems Usability Scale (SUS), which is a scale of ten simple, fast and reliable items that provides an overview of subjective usability reviews and is used as a tool to measure the usability of a wide variety of products and systems.

Composed of 10 questions that evaluate the effectiveness, efficiency and satisfaction of the user in relation to a particular product or service, the SUS scale has three characteristics that make it quite attractive in usability measurement. First is a scale with few questions, which makes it quick and easy for both respondents and the research administrator to calculate the values. Secondly, it is a free scale, which can be used without the need for any payment. Third, the SUS is an agnostic of technology, and can be used by a large group of professionals in the evaluation of almost any type of interface or product. Finally, the result is a single score, ranging from 0 to 100, which is relatively easy to understand by people from different study areas (Bangor, Kortum and Miller, 2009).

SUS works as follows: the user reads a statement about the system he wants to evaluate and then immediately must choose from a five-point scale

ranging from strongly disagree to strongly agree of the statement.

With the questionnaire completed, the user's opinion is converted into a score that represents the system usability for that individual.

4.4 Variables

We describe in this section the independent, intervening and dependents variables of the experiment in this paper.

For independent variables, there are the tool used in case the biomedical signals acquisition and conditioning platform YouMake and its electronic components.

For dependent variables, there are two metrics: the average prototyping time, which was obtained by means of a chronometer and the average usability of SUS scale (Brooke, 1996).

As intervening variable, there is the emotional state of the participants, as they might be nervous during of the experiment.

4.5 Participants

Tullis and Stetson (2004) claims the use of SUS scale permit to obtain a system usability mean with a small sample number (8-12). Besides that, the authors assert this sample number has a confidence enough of a good evaluation of how people see your system or product. Thus, it was chosen twenty four participants for the study.

The question P1 was asked at twenty-four participants, mixed among students and former students of undergraduate and postgraduate in UFS, with the sole purpose to classify the participants into more experienced or less experienced in the study area.

• P1: Have you ever studied electronics?

Thus, the participants were divided into two groups, the group G1, with experience, represented by the people who answered yes and the second group G2 that have only basic knowledge of circuits, represented by those who answered no.

4.6 Pilot Study

Before the experiment, a pilot study was conducted with student with a master in electrical engineering and a degree in electrical engineering. This student has experience in electronic circuits and is currently a Professor of in the Electrical Engineering Department of the Federal University of Sergipe - Campus São Cristóvão (Sergipe, Brazil). This study was conducted in a laboratory at the Federal Institute of Sergipe - Campus Itabaiana (Sergipe, Brazil). It was given to the participant a user guide and a video showing how to prototype ECG, EMG and EOG. Soon after, the participant performed the experimental work described in the following sections.

The participant got a 12 minute prototyping time and 95 points in SUS usability scale. The pilot study was used to better understand the study procedures. It also helped to assess the usability obtained by a person with considerable experience, and the time required to perform the task.

Thus, the pilot study was useful to show that it was possible to prototype the experiment in a timely manner. It also showed that people with enough experience possibly will feel easily in prototyping.

4.7 Experiment Design

4.7.1 ECG Acquisition and Conditioning

For acquisition and conditioning of the ECG, which is the potential heart rate, it is needed to position the surface electrodes that will acquire the signal of the first derivation of the ECG in the chest, just below the shoulder and the reference in the right arm, as shown in Figure 4. This figure also shows the acquisition circuit using the AD620. Since, with the LM324 it is similar.

In this paper, the ECG is detected through surface electrodes, which requires a passing frequency range between 0,67-40Hz (Prutchi and Norris, 2005). Also, one needs a high gain, since the ECG signal amplitude is around 1 mV (Babusiak and Borik, 2013).

As has already been performed several tests in this work, commercial values of components that enable the display the ECG with a good degree of acceptance were found. They are:

• Gain of 6.26 in the acquisition board in case of using the AD620 circuit, also possible with a gain resistor of 6,8KΩ;

• Gain of 7.26 in the acquisition board in case of using the circuit LM324, this gain is also possible with a gain resistor of 15KΩ;

• Gain of 150 in the conditioning board through the inverting amplifier in block 1 of Figure 3, using R1 = R2 = R3 = 1KΩ 150KΩ;

• High pass filter of about 0.5 Hz with a 2200uF capacitor C1 shown in block 1 in Figure 3;

• Low pass filter of about 34Hz through a 47K resistor in R4 and a 100nF capacitor C2 in block 2 in Figure 3.

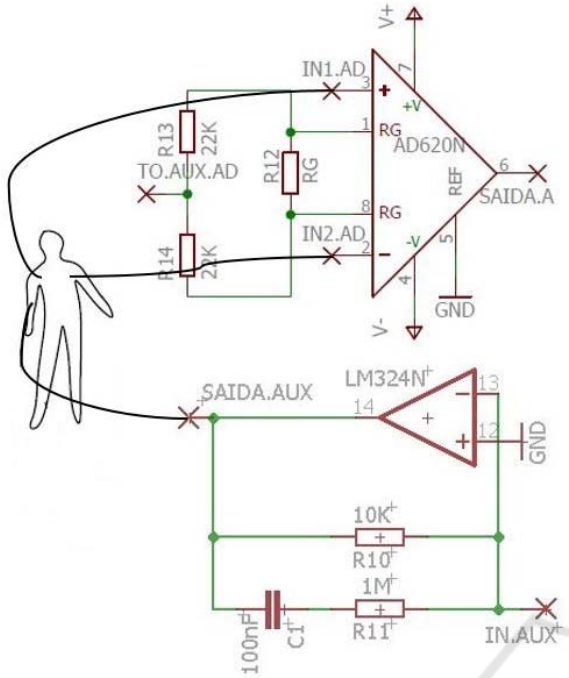

Figure 4: ECG acquisition schematic.

If the signal appears inverted, there is no problem, since the voltage difference between the inputs is acquired to observe the signal, reverse the electrodes on the chest, placing what was on the left side goes to the right, and what was on the right side goes to the left side. This will make the signal before appeared inverted and it will shown correctly.

In addition to these values, it is possible to vary both the gain and the frequency passband and special care should be taken with the 60Hz interference from the power grid. For this, it is interesting to acquire the signal away from wires connected to the electricity grid and, if necessary, apply a band pass filter to eliminate the interference (this was not applied in this paper).

4.7.2 EMG Acquisition and Conditioning

For acquisition and conditioning of the EMG, it is necessary to position the electrodes that will acquire the muscle signal. For this, one electrode is placed in the middle of the muscle and other electrode in muscle base as shown in Figure 5. These positions serves for both the AD620 and for the LM324, simply connect the electrodes wires as in ECG.

The procedure is equal to ECG, but the passband of the EMG signal with surface electrodes is generally between 2-500Hz frequency and amplitude between 50µV and 5mV amplitude (Cohen, 2006).

So the cutoff frequency of the low pass filter was changed to 498Hz and the high pass remained the same, in 0.5Hz, which had a good answer. The gain in the conditioning board in Figure 3 was changed to 56, since the EMG signal has higher amplitude than ECG.

4.7.3 EOG Acquisition and Conditioning

For acquisition and conditioning of EOG, one needs to position the electrodes that will acquire the small signal of the eye movement. The positioning depends on which parts of the eye movement is wanted. If it is the signal from moving to the left or to the right, the electrodes are positioned at the side of the right eyebrow and the other at the side of the left eyebrow. If it is the signal from moving up, down, or blinking, the electrodes must be placed as in configuration 2 in Figure 6. The reference electrode is always at the bone behind the left ear. Such placement serves for both AD620 and LM324, simply connect the electrode wires as in ECG.

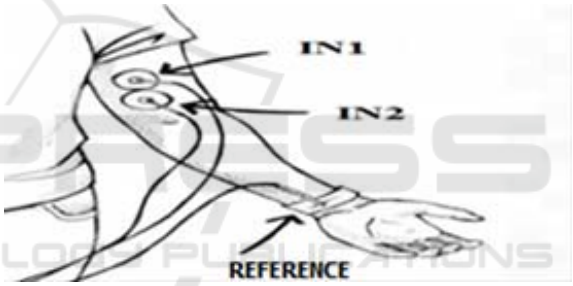

Figure 5: EMG electrode positioning. SOURCE: adapted from (Backyard Brains, 2016).

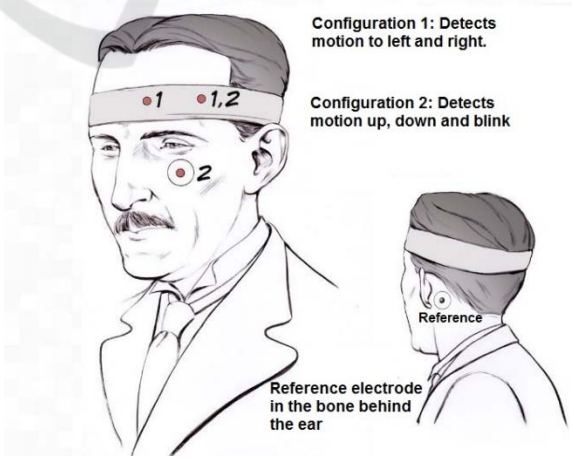

Figure 6: EOG electrode positioning. SOURCE: adapted from (Backyard Brains, 2016).

The value of the EOG signal varies from 50 to 3500μV with a frequency range between 0.001-100Hz (Barea et al., 2002). The procedure is the same as the ECG, but the low pass filter passband changed to 1.5Hz and the gain to 220 times in the conditioning board in Figure 3. Although there are frequencies up to 100Hz in EOG, a 1.5Hz filter exhibits an acceptable signal.

5 EXPERIMENT STEPS

In the following sections, the steps for the operation of the experiment are presented, ranging from preparation and implementation to validation of data.

5.1 Preparation

To prepare the participants for the experiment, a quick assembly guide and a video showing how to prototype EMG, ECG and EOG were provided. Furthermore, a framework with the components (the fixed ones) and connectors at the locations of the variable components were provided already welded.

5.2 Execution

The experiment was conducted in the hardware laboratory of the Federal University of Sergipe - Campus São Cristóvão and in the electronics laboratory at the Federal Institute of Sergipe – Campus Itabaiana. After watching the video, reading the user guide and answered some questions from the participants, the experiment was started. It was the prototyping of the acquisition and conditioning of EMG, ECG and EOG signals, it is worth mentioning the electrodes were placed on the body of the author of this paper.

• Data Collection

After the experiment, the participants answered the platform evaluation questionnaire (SUS) (Brooke, 1996). In the end, the authors performed the calculations for the SUS usability score (SUS_Valor metric) of each participant.

5.3 Data Validation

For the experiment, it was considered a factor (prototyping of the acquisition and conditioning platform of biomedical signals), and a treatment (prototyping by the participants with more and less experience). Given this context, the average prototyping time and the mean of SUS usability scale (Brooke, 1996) were computed.

To aid the analysis, interpretation and validation, four types of statistical tests were used: Kolmogorov-Smirnov (K-S), Shapiro-Wilk (S-W), Student's t-test (for independent samples), and Levene. K-S and S-W tests were used to verify the normality of the samples. The Student's t-test was used to compare the average of two independent samples, and finally, Levene's test was used to evaluate the homogeneity of variances.

All statistical tests were performed using the SPSS - IBM (2013) tool.

6 RESULTS AND DISCUSSION

With twenty four samples obtained at the end of the experiment, the SUS score properly calculated, and the classified participants, the experiment resulted in G1 "with experience" with twelve samples and G2 "No Experience" with twelve samples. According to Lopes et al. (2013), a great number of statistical tests assume that the data follow a normal distribution to be applied. Therefore, the Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) tests were applied to assess the normality of the sample through the Statistical Package for Social Sciences (SPSS) (2013).

The K-S and S-W tests provide the p-value, which according to Lopes et al, (2013), can be interpreted as the degree of agreement between the data and the null hypothesis (H0) and H_0 being the hypothesis that the distribution is normal. Figure 7 shows the result of normality test conducted in SPSS with a confidence level of 95% (significance level $\alpha = 0.05$). Note that the group with experience obtained a p-value (sig) larger than the alpha in both K-S (0.171> 0.05) and S-W (0.425> 0.05), which means that there is no evidence to reject the H_0. This also happens to those without experience, sig is greater than the alpha in both K-S (0.062> 0.05) and S-W (0.081> 0.05). So the normal distribution is a possible distribution for this sample set and thus the T-student statistical test can be applied. This test evaluates the hypothesis that two population means are identical, in which case, H_{0SUS} claims the G1 average is equal to G2 average.

Figure 10 shows the result of the T-student test in the SPSS with a confidence level of 95% ($\alpha = 0.05$). Note that the value of sig on Levene's test is greater than alpha (0.107> 0.05), which means that there is homogeneity of variance, and in this case one uses the 0.954 sig which is greater than the alpha and so there is no evidence to reject the H_{0SUS}. Thus, there is not enough significance for the group means to differ.

From this, it can be concluded that the average usability from the "experienced" group does not differ

from the "no experience" group, which answers the research question QP1. Thus, there is evidence that a person with no experience in the field makes the prototyping with the same ease of a person with experience, due to the platform's usability.

To answer the research question QP2, the overall average of usability of the platform this paper was compared to BITalino platform (Silva et al., 2014), which is a framework that works by fitting sensors blocks in the main control block and has an overall average of 84.62 and rated A+ for usability by the rating scale of Sauro and Lewis (2012). It is also characterized, according to the authors, as a user-friendly platform.

Regarding the platform of this experiment, figure 8 shows the average from the "experienced" group and "inexperienced" group and from it we can identify the average overall usability of the experiment, which is 84.479. According to figure 9, the correlation of the SUS score is performed with the note from the scale built by Sauro and Lewis (2012) and it shows that, from a scale F to A+, the system note is A +. Comparing these values, it can be seen that both YouMake and BITalino, have grade A+ and a general average of 84.479 and 84.62 respectively. Thus, to have similar values, we can infer that YouMake can be used as a low cost alternative for the acquisition and conditioning of biomedical signals, answering QP2.

To answer QP3 focused on the prototyping time for each group.

Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
SUS_Value	With Experience	,206	12	,171	,934	12	,425
	Inexperienced	,237	12	,062	,877	12	,081

a. Lilliefors Significance Correction

Figure 7: Sample normality test of SUS.

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
SUS_Value	With Experience	12	84,583	9,3440	2,6974
	Inexperienced	12	84,375	12,8419	3,7071

Figure 8: Groups' averages of SUS.

SUS RANGE	GRADE	PERCENT RANGE
84.1–100	A+	96–100
80.8–84	A	90–95
78.9–80.7	A–	85–89
77.2–78.8	B+	80–84
74.1–77.1	B	70–79
72.6–74	B–	65–69
71.1–72.5	C+	60–64
65–71	C	41–59
62.7–64.9	C–	35–40
51.7–62.6	D	15–34
0–51.7	F	0–14

Figure 9: Grading scale interpretation table for SUS score. SOURCE: Adapted from table 8.6, page 204 from (Sauro and Lewis, 2012).

Figure 11 shows the result of the normality test conducted in SPSS with a confidence level of 95% ($\alpha = 0.05$) and with H_0 the hypothesis that the distribution is normal. Note that the "experienced" group got a higher sig than alpha in both K-S (0.200> 0.05) and S-W (0.597> 0.05), which means that there is no evidence to reject H_0. This fact also happens with the "no experience" group, the sig is greater than alpha in both K-S (0.200> 0.05) and S-W (0.110> 0.05). Then the Normal distribution is a possible distribution for the set of samples and thus the t-student statistical test can be applied.

Figure 12 shows the result of the t-student test in the SPSS with a confidence level of 95%, with H_0 which states that the prototyping time of G1 is equal to G2. Note that the value of sig on Levene's test is greater than alpha (0.155> 0.05), which means that there is homogeneity of variance, and in this case one uses the sig 0.201 which is higher than alpha and, therefore, there is no evidence to reject the H_{0tempo}. Thus, there is not enough significance for the groups prototyping time to differ.

From this, it can be concluded that the prototyping time from the "experienced" group does not differ from the "no experience" group, which answers the research question PQ3.

Independent Test Samples

		Statistics								
		Levene Test for Equality of Variances		t-test for Equality of Means						
									95% Difference Confidence Interval	
Dependent variables	Assumptions	F	Sig.	t	df	Sig. (2 extremities)	Average difference	Error Difference Pattern	Lower	Upper
SUS_Value	Equal Variances Assumed	2,832	,107	,045	22	,964	,2083	4,5846	-9,2996	9,7163
	Equal Variances not Assumed			,045	20,097	,964	,2083	4,5846	-9,3521	9,7687

Figure 10: T-student test for independent sample of SUS.

Tests of Normality

	Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Time	With Experience	,199	12	,200*	,947	12	,597
	Inexperienced	,193	12	,200*	,888	12	,110

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 11: Normality test for the time variable of time.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Time	Equal variances assumed	2,174	,155	-1,317	22	,201	-1,333	1,013	-3,433	,767
	Equal variances not assumed			-1,317	19,897	,203	-1,333	1,013	-3,446	,780

Figure 12: T-student test for independent samples of time.

7 THREATS TO THE EXPERIMENTAL STUDY VALIDATION

7.1 Internal Threat

The internal threat defines if the relationship between treatment and result is casual, without the influence of other factors that may not have been measured. Participants answered the usability scale without supervision, so there is the possibility of them not having understood well some of the issues and may have marked wrongly, besides the scale subjectivity. However, care was taken so that the participants didn't talk among themselves, mitigating the insider threat.

7.2 External Threat

The external threats are the conditions that limit the ability to generalize. The experiments were performed in two different laboratories because the samples have been collected at the IFS and at the UFS and, therefore, in different environments. Moreover, the oscilloscopes (equipment used for signal viewing) used in each laboratory were different in brand and model. Thus, there is the possibility of users answering the questions differently. Although the overall number of samples are sufficient according to Tullis and Stetson (2004), a larger number of samples could better represent the general population of students interested in biomedical signals.

7.3 Construction Threat

The construction threats are related to the design and human factors. Such threat can be characterized by the participants time spent. Perhaps the time is not the best metric, because some users spend more time just viewing the signal than others that are more objective.

7.4 Conclusion Threat

The conclusion threats are related to the ability to reach a correct conclusion about the relationship between about the treatment and the outcome. To avoid hypotheses infringement, we used the normality test, Shapiro-Wilk, and a parametric test, t-test, for data analysis. To reduce the confiability impact to the implementation of the treatment, we followed the same experimental setup in both cases.

8 CONCLUSION AND FUTURE WORK

From the results obtained in the experiment, we can see that the platform YouMake can be used as a low cost alternative for the acquisition and conditioning of biomedical signals, in addition to showing that a person with no experience can use the platform with equal ease, and same prototyping time a person with experience in the field.

As future work, we intend to integrate the capture platform with the interfacing and digitalization

platform that is being developed in another research.

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