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New multichannel bioamplifier for automatic detecting of electromyograms

Novo bioamplificador multicanal para registro automático de EMG

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Abstract

The objective of this paper is to develop bioinstrumentation for the automatic detection of electromyographic biosignals. Currently, detecting bioelectric signals generated by physiological activity of excitable muscle cells is one of the most attractive research topics in the field of Experimental Medical Physics; especially in the field of brain-computer interface in order to control the upper and/or lower ends of prostheses using only the brain. A high-performance four channel bioamplifier was built and calibrated to automatically measurement bioelectrical signals from muscle activity. In order to obtain the acquisition of multichannel myoelectric signals, a computational routine was developed in Labview called BioElectroMiograma v1.0. Experiments performed in a volunteer showed the bioamplifier can satisfactorily measure multichannel EMG biosignals of the biceps and triceps muscle. The bioamplifier operates in LINFIS. The prototype has proven to be capable of measuring biosignals generated by muscle contraction in the order of tens of microvolts. These preliminary results provide the basis for further investigations in bioinstrumentation by studying muscle physiology.

Keywords: bioinstrumentation, biosignals, electromyography, bioamplifier, multichannel.

Resumo

O objetivo deste trabalho é o desenvolvimento de bioinstrumentação para a detecção automática de biosinais de eletromiografia. Atualmente, detectar sinais bioelétricos gerados pela atividade fisiológica das células musculares excitáveis é um dos tópicos de pesquisa mais atraentes no campo da física médica experimental. Principalmente na área da interface computador-cérebro, para o controle de próteses das extremidades superiores e/ou inferiores usando somente o cérebro. Foi construído e calibrado um bioamplificador de quatro bioeletrodos de elevado desempenho para a detecção automática de EMG. Para a aquisição dos sinais multicanais mioelétricos foi desenvolvida uma ferramenta computacional em Labview chamada de BioElectroMiograma v1.0. Experimentos realizados num voluntário mostraram que o bioamplificador multicanal consegue medir biossinais de EMG dos músculos bíceps, tríceps e do antebraço satisfatoriamente. O bioamplificador encontra-se em pleno funcionamento e mostrou que é capaz de medir biosinais gerados pela contração muscular na ordem de dezenas de microvolts. Estes resultados preliminares servem de base para posteriores estudos na área de bioinstrumentação.

Palavras-chave: bioinstrumentação, biosinais, eletromiografia, bioamplificador, multicanal.

Introduction

The number of studies using electromyography (EMG) as a standard technique to analyze the bioelectric activity in the membranes of muscle cells has significantly increased, as well as to diagnose physiological problems related with muscle dysfunctions. Moreover, it has been recently used to help on the functioning of the upper and lower limb prostheses[1-3]. The measured EMG signals over the skin surface are the sum of all bioelectrical signals from a set of cell membranes. Currently, the most promising research in the field of bioinstrumentation is associated with the detection of bioelectric signals generated by physiological activity from excitable cells and their process.

Nowadays, there are increasing expectations for prosthesis implantation (upper and lower), involving multichannel EMG measurement, with man-made devices leading to movement capacity, similar to the natural movement produced by healthy or normal muscles. Considering clinical practice, the measurement of these EMG signals can be extracted from a series of parameters which describe the state of the patients' muscle health. Furthermore, doctors can create proper medical management to treat muscle diseases and traumas.

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In this sense, the main purpose of this experimental study was to build a four channel bioamplifier for the automatic acquisition of electromyography signals.

Materials and Methods

Because the amplitude of signals generated by muscular contraction is very low, registering those signals is far from being straightforward. Biosignals are in the order of tens of microvolts(μV), thus it is difficult to measure them with standards electrical measuring instruments.

On the other hand, in case of EMG biosignals, the frequency range falls exactly in the frequency band dominated by the electromagnetic noise of 60 Hz and its harmonics. Therefore, it is necessary to build bioinstrumentation circuits with high value of common mode rejection ratio (CMRR). This may be achieved by using high-performance integrated circuits in relation to noise and input impedance, the stages of filtering, and data acquisition with high resolution in the analog digital conversion.

In Figure 1, there is the block diagram which represents the functional parts of bioinstrumentation for one channel. It was designed and built to automatically detect EMG biosignals in the Laboratory of Instrumentation in Physics at the Department of Physics of the State University of Feira de Santana. In the same figure, you may see the experimental setup which is basically composed of the bioelectrodes, an AC-coupling stage with fixed gain, differential detection and the stage of high-pass filtering, the amplification step, the low-pass filtering and analog/digital conversion using the data acquisition card niUSB 6009, the acquisition of EMG biosignals using an interface written in LabView program.

We used five bioelectrodes Ag/AgCl for heart monitoring from MAXICOR® with conductive gel and cellulose solid blade with protective PVC. In order to eliminate the possible offset voltage created in the contact between bioelectrodes-skin, and in order to improve the CMRR of all instrumentation, four bioelectrodes were used in the surface to direct measure EMG signals, and the remainder was used as a body reference electrode. In the initial phase, an AC-coupling using a network of passive components (resistors and capacitors) that couple inputs and joins them together (Figure 2) was conducted. During the same stage of circuit configuration, a fixed gain differential of 927 was used, performed by a high-performance instrumentation amplifier, model INA 2128P.

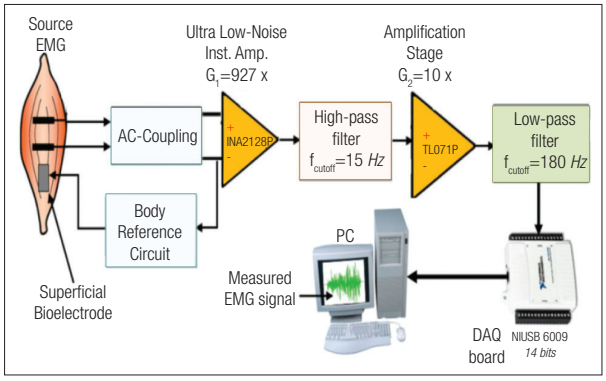

Figure 1. Schematic diagram of the proposed bioamplifier for the automatic measurement of electromyography biosignals. The main stages are: EMG sources, bioelectrodes, amplification, high-pass filter (HPF), low-pass filter (LPF), and data acquisition.

The circuits for high pass and low pass filtering were built with high-precision passive components (1%). For the amplification stage, a low-noise operational amplifier TL071P was used. Furthermore, the filtered biosignals were connected to a 14-bit resolution data acquisition card (NI6009) and used a differential configuration of its 4 input channels.

Finally, the data acquisition device was connected to a laptop via USB port. Using the programming language Labview® 2010, we were able to write a routine in order to record multichannel electromyography data.

In the process of measuring bioelectrical signals, it is very important to pay attention to the initial stage of the measuring system. The value of skin impedance at the interface of the electrode-skin contact is a critical parameter in commercial devices used to measure EMG.

The optimal impedance should be in the order of kΩ. Another important element is the length and the kind of wire used in bioelectrodes. In our case, 0.9 m long sound stereo cables were used to shield the electromagnetic noise. The local region in which the bioelectrodes was placed was washed with alcohol, and then the measurement of the skin impedance value of the biceps muscle was approximately 1,100 kΩ (Bench 390 digital multimeter).

One-channel bioelectrode circuit

The device consists of four copies of the analog conditioning circuit from which the biosignal was processed through one surface electrode. In Figure 2, we illustrate the circuit used for conditioning EMG signals for one channel. The initial stage of the circuit is the differential preamp. It was essentially composed of the instrumentation amplifier from INA 2128P BURR-BROWN. This chip was chosen because it works in a wide frequency band and allows large gains. The high-rate of common mode rejection (120 dB for gain ≥100 is one of its main features), besides having an input noise density of 8 $nV/\sqrt{Hz}$ in the frequency band of 10 to 300 Hz. The noise is approximately 0.2 μV peak to peak at low frequencies and has an input offset voltage of 50 μV. In the preamplifier circuit, the body reference circuit can be observed. The function of this stage is reducing the offset voltage generated by body. The main part of body reference circuit is a dual operational amplifier model TL072CP.

Filters were applied at the output of the preamplifier to help reduce the noise amplified by the preamplifier. They also help to eliminate any DC current which could cause bias for biosignal. In the bioamplifier, we used two passive RC filters, one high-pass with cutoff

frequency (f_{cutoff}) of 15 Hz and another low-pass with cutoff frequency of 180 Hz.

The energy of dominant frequency band in EMG signals is inside the pass-band of the filters, that is, 50 Hz to 150 Hz. Furthermore, we ensure that any information necessary to contribute to EMG signal is not lost.

Both types of cutoff frequency filters were calculated by the following equation:

$$f_{cutoff} = \frac{1}{2\pi RC} \quad (1)$$

To design a high-pass filter, the values of C=0.22 μF and R=47 kΩ were chosen. On the other hand, to design a low-pass filter, we chose the values of C=1 μF and R=470 Ω. In Figure 2 it is easy to identify the high-pass and low-pass filters.

At the top of Figure 2, we may see the low noise power supply circuit. All instrumentation was powered by two 12V-batteries connected in series, forming a symmetrical configuration and generating an electrical voltage of ± (5.01±0.01) V. The ground line is located at the junction point between the two batteries.

In order to obtain theses values for the source voltages, the par 7805 and 7905 voltage regulator IC was used. The aim of the capacitors in the power circuit is to stabilize the current, thus avoiding dramatic changes. This became necessary since the electric current in the circuit tends to oscillate when electronic components are distant from the power supply, and such fact is not advisable when it comes to integrated circuits.

The bioamplifier is composed of four measurement channels, and so there four identical circuits, as shown in Figure 2. Each preamplifier provides a gain close to 1,000 times given by:

$$Gain = 1 + 50k/R_G \quad (2)$$

R_G is the resistance gain placed between pins 3 and 4 of CI INA2128P. For a 1,000 time gain, according to equation (2), the value of R_G is equal to 25,025 Ω. We chose a resistor of 27 Ω as this is the closest R_G value we had in our laboratory. Therefore, the voltage gain for each preamplifier was approximately 927 times.

Biosignal measurement automation

The automatic control of the experimental system was performed by using the programming language Labview 2010 from National Instruments.

In Figure 3, we illustrate the graphic interface of the routine called BioEletroMiograma v1.0. The windows or panel can be seen in which the waveform of the EMG multichannel biosignal will be displayed. Using this interface, we introduced some data or input parameters,

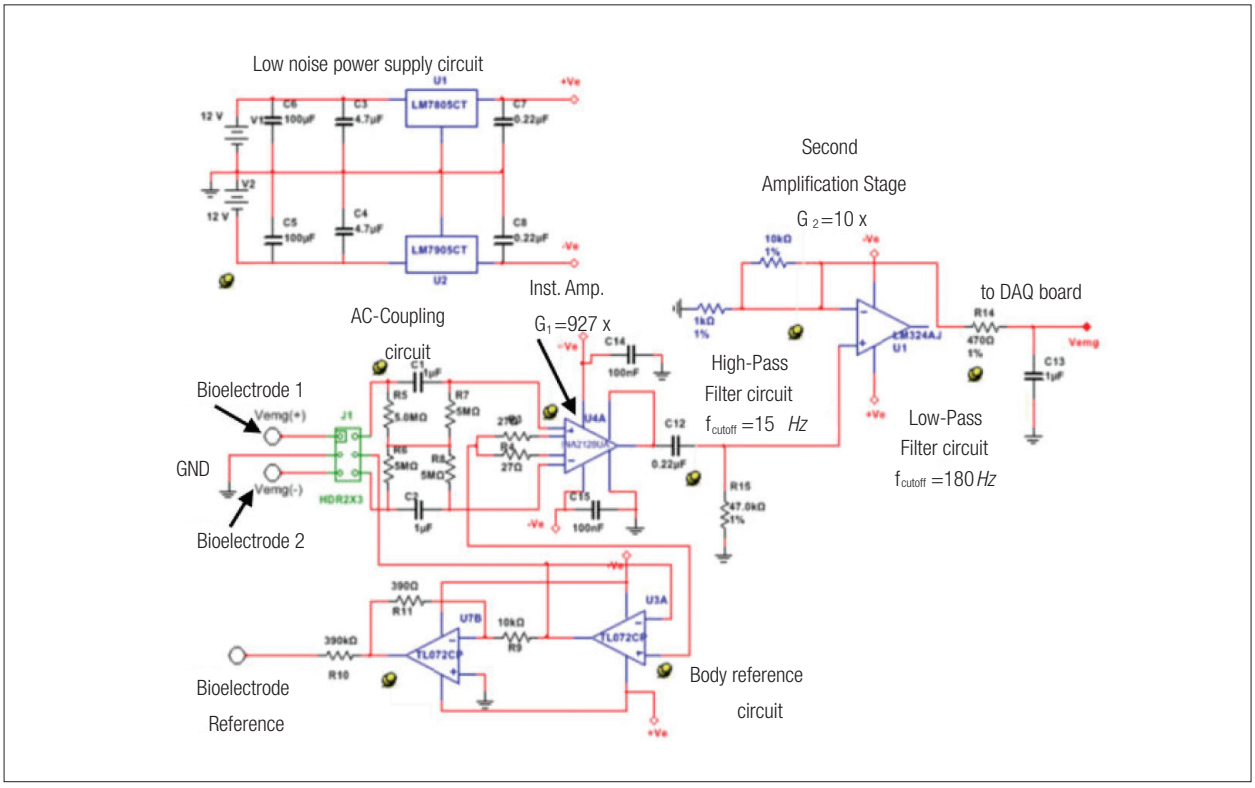

Figure 2. Analogical conditioning circuit to record electromyography (EMG) signals corresponding to one channel. The values of electronic components were C1=C2=1μF; R5=R6=R7=R8=5MΩ; R3=R4=27Ω; C14=C15=100nF; R10=R11=390 Ω; R1=1kΩ; R2=10kΩ; C3=C4=4,7μF; C5=C6=100μF and C7=C8=1μF.

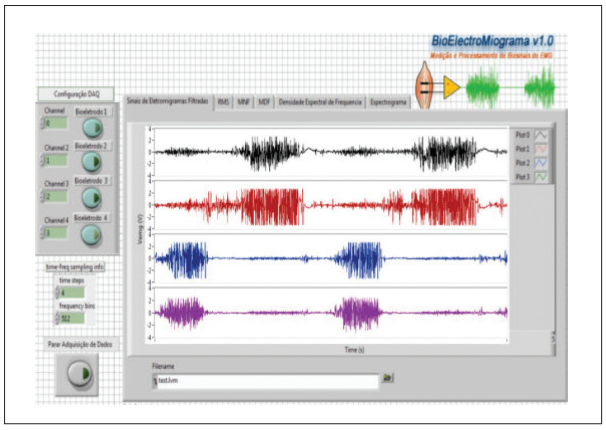

Figure 3. Front panel of the graphic interface of the routine BioEletroMiogram v1.0 used to control the automatic measurements of electromyography.

such as the rate of acquisition, digital gain control, filter parameters, and the addressing of the data acquired for storage for subsequent analysis. Finally, we clicked on the run button to begin the measurement process.

Bioamplifier calibration

The calibration procedure of the bioamplifier is quite basic. The idea of calibration is to compare the value of the output voltage in each channel of the bioamplifier and the value of input voltages.

In Figure 4, we show the scheme of the calibration procedure. A separate calibration is required for each channel. As observed, the calibration method uses a function generator in order to generate input signals for each bioamplifier channel. A 100 mV amplitude and 60 Hz frequency sine wave was chosen. Hence, the signal is reduced 1,000 times via voltage divider, thus producing amplitude signals of ±100 μV, which simulate biosignal EMG.

Figure 5 shows the four channel output biosignals from the bioamplifier during the calibration procedure. We may clearly observe the waveform of these sinusoidal signals. This means that the bioinstrumentation device can measure signals in the order of 100 μV. The measurement was made using a 2 kHz sample rate.

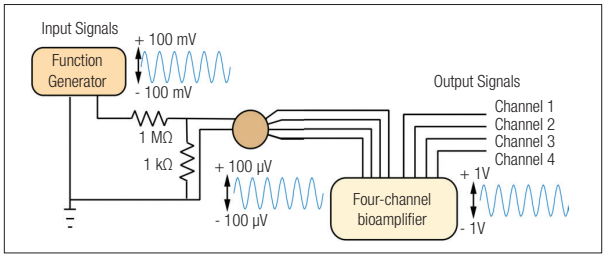

Figure 4. Schematic diagram of the calibration procedure of the multichannel bioamplifier.

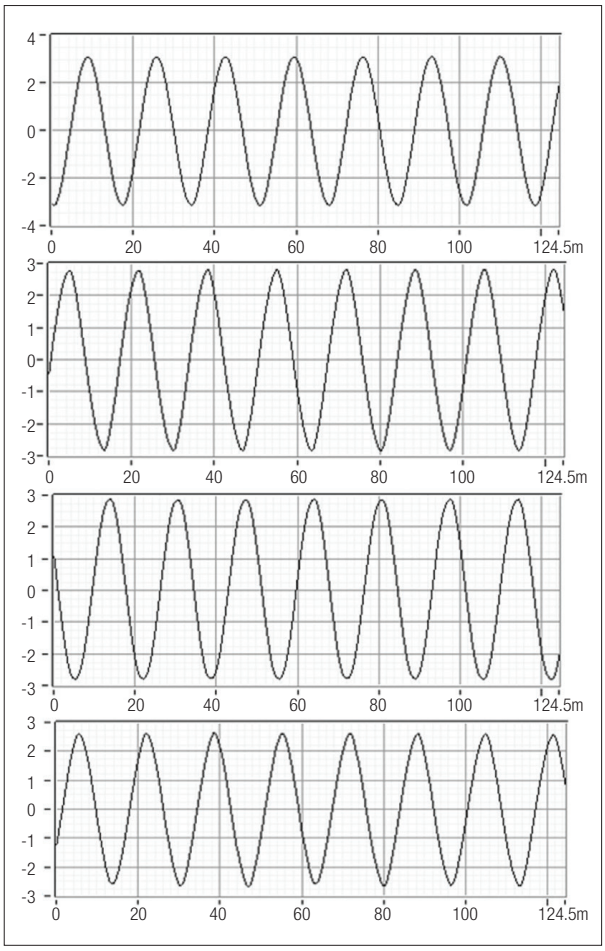

Figure 5. Output signals on four bioamplifier channels, from top to bottom, channel 1 to channel 4.

Results and Discussion

With the objective of evaluating the feasibility of the proposed four channel bioamplifier, we have measured muscle EMG signals of the biceps and triceps in a healthy volunteer. The fitting parameters of the experimental system, which was common for all experiments, were the 2,000 Hz acquisition frequency, and the number of collected samples. Two hundred samples were processed by sampling points. The configuration data acquisition board was customized to the differential mode with full scale ±5 V and the bioamplifier gain of 10^4 x.

Figure 6 presents the EMG biosignal of four superficial bioelectrodes measured by the proposed bioamplifier. The first two signals were detected in the biceps (top) and the other two in the triceps (bottom). The waveforms for all channels represent the EMG biosignal from these muscles working simultaneously. It may also be observed that the signal content is higher in the first two ones, corresponding to the biceps EMG, in comparison to the signal content of the

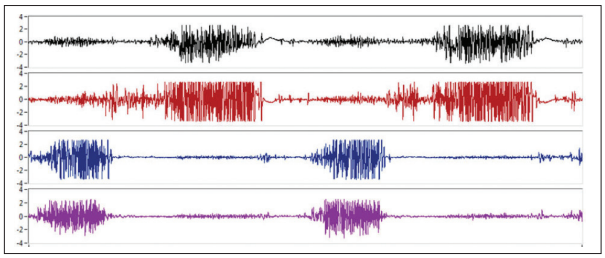

Figure 6. Electrical voltage of electromyography multisignals vs time in seconds. On top: two measured electromyography signals generated by muscle contraction of the biceps. In bottom: two measured electromyography signals generated by muscle contraction of the triceps, all from an adult volunteer.

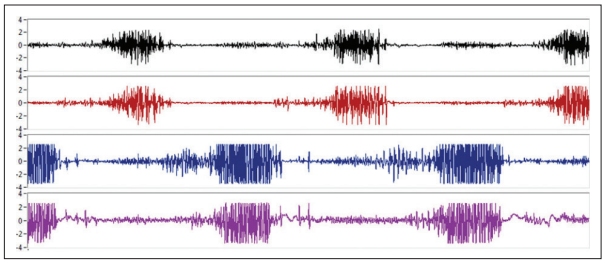

Figure 7. Electromyography signals generated by muscle contraction of the triceps (upper) and biceps (bottom) recorded with the proposed bioamplifier.

triceps muscle, which is lower. In Figure 7, we show the EMG signals generated by triceps (top) and biceps muscles (bottom) recorded with the bioamplifier. In this case, bioelectrodes were exchanged against the EMG as shown in Figure 6. We obtained the same results. These experimental results demonstrated the feasibility of measuring EMG signals using the proposed bioamplifier. Also, this work can be used as reference to development news experimental setup to research on experimental medical physics to measure biosignal generated by excitable cells.

Conclusion

A high performance four channel bioamplifier was build and calibrated for the automatic detection of myoelectrical biosignals generated by muscle contraction. Experiments carried out showed that the proposed bioinstrumentation may be able to measure EMG signals generated in the biceps and triceps muscles in a healthy person. The experimental setup showed to be feasible for other research activities in the bioinstrumentation area.

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