Biopotential Amplification System Developed for Electromyography with Dry Electrodes

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Abstract*—Electromyography (EMG) provides information about muscle and motor neuron physiology. It is known that pathological conditions in the neuromotor system can affect the characteristics of the myoelectric signals captured by EMG. Although EMG provides important information regarding the characteristics and neuromuscular activity from a subject, it still faces some issues that must be addressed and understood for its proper application, such as the influence of myoelectric signals from adjacent muscles, which contributes to unwanted signals and crosstalk. Additionally, the recruitment of skeletal muscles is complex, and is based on more muscles than necessary for accomplishing a single movement. Consequently, there is an increasing interest for high-quality real-time multichannel EMG signals collection for multiple purposes. In the present work, we show the fabrication of dry electrodes based on chromium and gold with reduced dimensions and its integration to a real-time EMG collection system. The band-pass filter of the system presents cut-off frequencies of 20 Hz and 600 Hz at 34 dB gain. The system uses a PXI chassis with a National Instruments FPGA module that performs a manual selection of amplification gains. A real-time PXI module was implemented in LabVIEW which would allow the use of EMG signal decomposition techniques allowing the study of motion intention identification, prosthesis movements and neuromuscular integrity analysis.

Keywords—Electromyography, dry electrodes, LabVIEW, fabrication.

I. INTRODUCTION

The central nervous system (CNS) sends information to the muscles in the form of electric pulses through alpha-motoneurons. The cellular body of these neurons is located in the spinal cord, and their axons innervate muscle fibres [1]. A motor unit (MU) consists of a group of muscle fibres innervated by the same motorneuron [1]. The CNS can modulate the strength of a muscle either by the number of recruited MUs or by controlling the action potential (AP) firing rate of an MU [1]. One way to study the properties of the neuromuscular system is to investigate the motor unit action potential (MUAP) [2]. The electromyography (EMG) is an electrical signal resulting from the ionic transient from the MUAPs captured by invasive or non-invasive electrodes, and allows inferring on the integrity of the neuromuscular system through the analysis of the waveforms of the MUAPs [2]. Since the EMG signal provides direct information from the neuromuscular system, it is broadly used in studies of the neuromuscular integrity, SNC strategy for muscle recruitment, motion intention identification, prosthetic movements, among others, which motivates the real-time collection of EGM signals.

Invasive electrodes may capture the APs of a single MU. However, the procedure can be time-consuming might bring risks to the patient. Surface electrodes, on the other hand, allow multiple APs to be detected non-invasively. Surface EMG signals are, however, spatiotemporal mixtures of various MUAPs that depend on factors such as the thickness and conductivity of the subcutaneous layers, the depth of the source and the geometry of the electrodes, resulting in a random noise-like signal, making it difficult to analyze [3]. Usually, Ag/AgCl electrodes are considered for surface EMG collection. In such cases, it is recommended the application of a layer of gel of KCl or NaCl to improve contact resistance. This gel, however, creates a half-cell potential at the epidermis-gel interface – that can be modeled electrically through a conductive and capacitive structure with series combinations of parallel RC elements. Fig. 1 illustrates the model with regular electrodes and dry electrodes with different conductance and capacitance model.

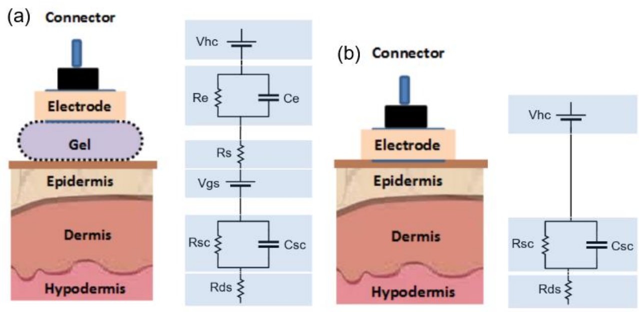

Fig. 1. Electrical model for skin-gel and gel-electrode interface [3, 4].

In the present work, we introduce an in-house, dry electrode to be used in the collection of surface EMG signals. The electrodes were fabricated by depositing metal on a flexible substrate. Two types of electrodes have been tested: Cr/Au and Cu/Cr/Au films. The electrodes were integrated to an EMG system operating in real-time to test and validate the electrodes. The system has embedded algorithms that will be used for further signal processing, such as surface EMG decomposition.

II. Methods

Our system is based on a signal conditioning circuit to be used with the dry electrodes. Using the RC model shown in Fig. 1b, the system was designed and developed based on a resistor of 1 MΩ in parallel with a capacitor of 10 nF as circuit input requirements. The circuit has two stages of amplification: the first stage has a fixed gain and the second stage has a programmable gain via LabVIEW. The circuit has seven differential channels and its total gain varies from 10 to 10,000 V/V.

A. *Dry Electrodes*

The electrode was fabricated through a thermal deposition process performed at the Information Technology Center Renato Archer. One type of substrate was used to manufacture the electrodes: Kapton®. Fig. 2 shows the Cr/Au deposition system that uses thermal evaporation to deposit the metal in the substrate.

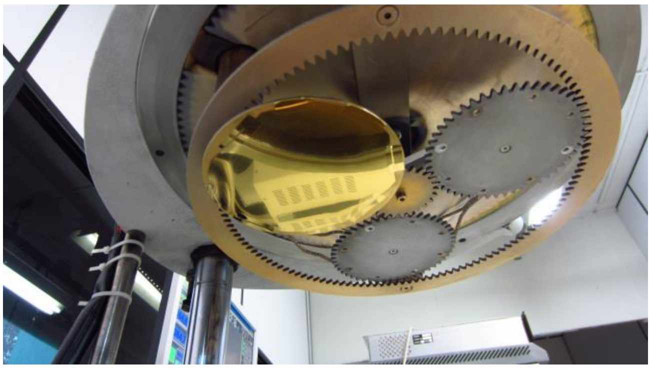

Fig. 2. Thermal deposition system from Information Technology Center Renato Archer.

The substrate was cut in cleanroom and washed with Extran® liquid. After that, the substrate was dried at the furnace at 50° C for, approximately, two hours.

The next step includes to fix the substrate at sample holder, fix sample holder at the planetary system, insertion of metal (Cr and Au) on tungsten boat and close vacuum chamber. The vacuum was made until pressure achieves 10^{-7} Torr to start deposition process. During the process, the temperature inside the chamber was around 194 °C.

The thicknesses of the Cr and Au films were respectively 5 nm and 200 nm.

B. *Measurement System*

The measuring system was designed and developed to operate with dry electrodes (Fig. 3). The circuit has a first amplification stage with fixed gain, the second stage of amplification with programmable gain and a band-pass filter [2]. Gain control can be adjusted through a dedicated program in LabVIEW Real-Time that commands the FPGA module model PXI-7851R (National Instruments). The LabVIEW RT was used due to low latency data transmission through Gigabit Ethernet protocol between chassis PXI and computer.

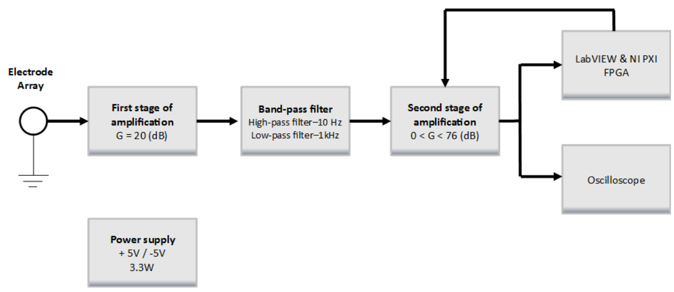

Fig. 3. Block diagram of the measurement system (modified of [2]).

C. *Test Protocol*

The test protocol includes two steps:

i. Frequency response of circuit through the relation between output and input signal as shown in Fig. 7;

ii. Test with commercial wet electrode using Noraxon system and developed system.

The test with wet electrode using Noraxon system and developed system were performed following the sequence: Tests only on the right forearm, cleaning the skin for electrodes contact, positioning electrodes with a distance of 40 mm from each other and connection of electrodes with the circuit.

III. Preliminary Results

The Desktop DTS and wireless sEMG amplifier from Noraxon were utilized on initial tests to compare a commercial and the developed system using conventional wet Ag/AgCl electrode.

Fig. 4. (a) Receptor module. (b) Wireless surface electromyography sensor.

The acquisition system can be seen in Fig. 5. Observe the main information of the setup and the image of the equipment.

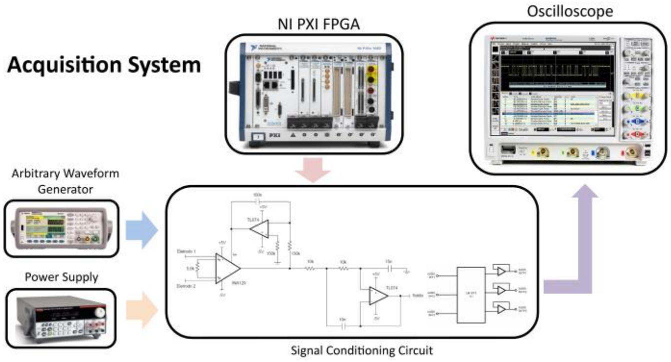

Fig. 5. Block diagram of acquisition system [2].

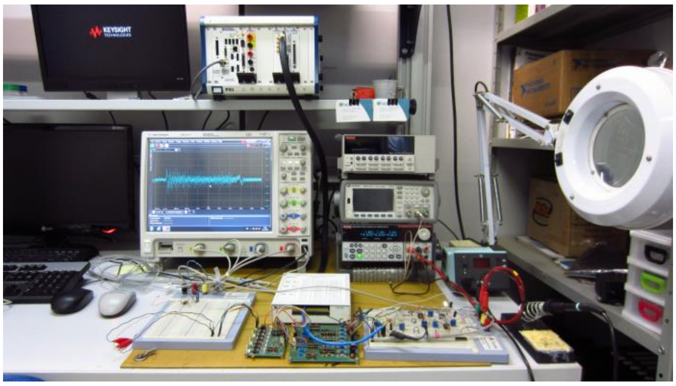

Fig. 6. Experimental setup used for frequency response analysis.

The following gains are programmable via LabVIEW: 20. 26. 34. 40. 46. 54 and 80 [dB]. The frequency response of the acquisition system was measured for three gains (20, 40 and 54 dB) as shown in Fig. 7.

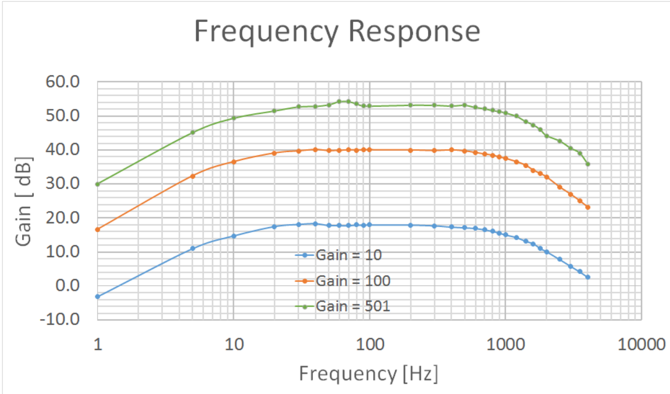

Fig. 7. The frequency response of the two-stage amplifier for three gains (20, 40 and 54 dB).

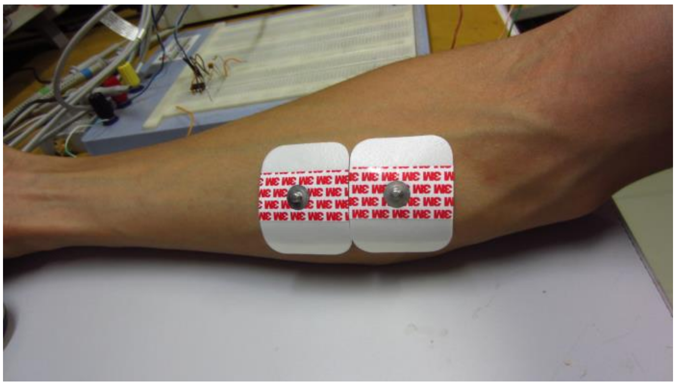

Fig. 8. Conventional pre-gelled Ag/AgCl electrode used to compare both systems.

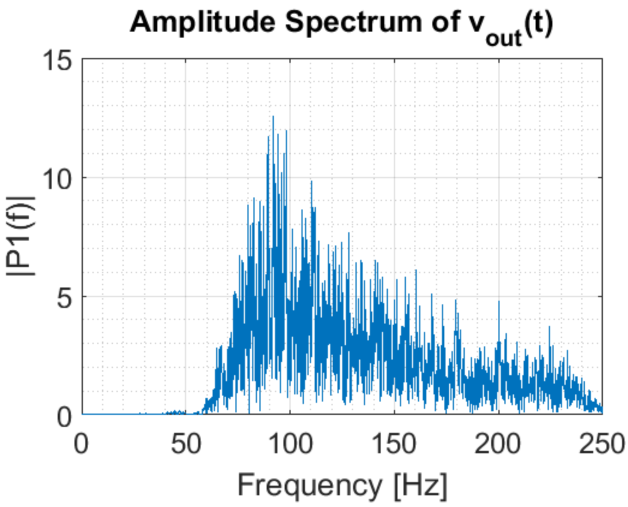

Fig. 9. The amplitude spectrum of the conventional wet electrode and Noraxon Desktop DTS.

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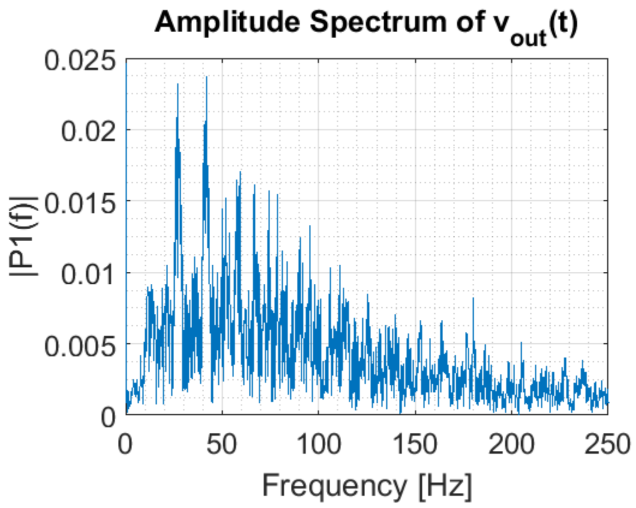

Fig. 10. The amplitude spectrum of the conventional wet electrode with developed acquisition system.

After tests with pre-gelled electrodes a process of thermal deposition was initiated.

Initial result showed that it is possible to deposit Cr/Au film on Kapton and copper tape. The thickness of the Cr layer is 5 nm and the Au layer is 200 nm.

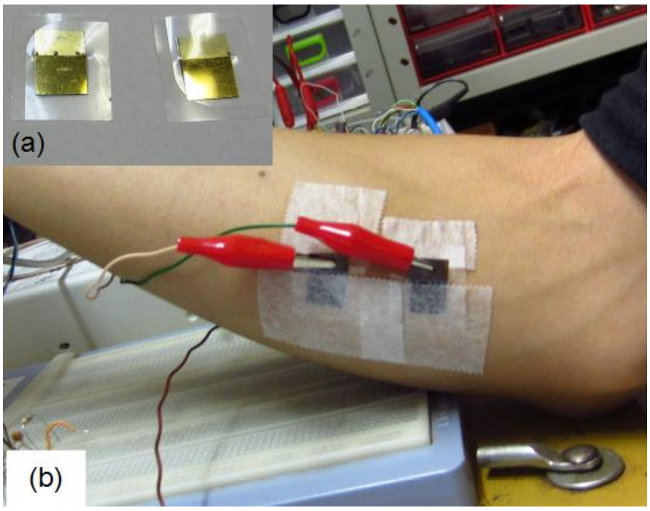

Fig. 11. Kapton with Cr/Au film tested with developed system. (a) Detail of dry electrode with sheet of polyester to limit skin-metal contact area. (b) The interlectrode distance was 40 mm and the contact area with skin was 78.5 mm^2.

IV. Discussion

The experimental setup of Fig. 6 was utilized to plot the frequency response of the developed system. The cut-off frequencies were 20 Hz and 600 Hz.

The measured signal with commercial and developed systems was decomposed into its frequency domain via MATLAB script. In the commercial system the spectrum includes frequencies of 50 Hz until 250 Hz. In the developed system the spectrum includes frequencies of 10 Hz until 250 Hz.

A wet Ag/AgCl electrode was used to validate the developed system and a manufactured electrode at CTI Renato Archer was used to acquire the signal. The Cr/Au electrode showed signal with amplitude lower than Ag/AgCl electrode.

The preliminary results show that the system can be used to design an array of dry electrodes for signal processing application.

V. Conclusion

The developed measurement system obtains the same signals from commercial equipment using conventional electrodes and dry electrodes. The dry electrode has the advantage of it does not need to apply gel in the skin. In addition, the dry electrodes obtained with Cr/Au by evaporation deposition provided similar signals to conventional equipment using the developed circuit. Therefore, the system is validated and operational.

Acknowledgment

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