COMPARISON OF DIFFERENTIAL SURFACE EMG CIRCUITS AND INTERELECTRODE SPACING FOR USE WITH REGENERATIVE PERIPHERAL NERVE INTERFACES

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ABSTRACT

Surface electromyography (sEMG) studies how to detect electrical signals produced by muscles from the surface of the skin [1]. However, the noise and crosstalk from nearby muscles are some of the drawbacks to using a surface EMG system [1]. Single and double differential (SD and DD) surface electrode systems were designed to minimize these drawbacks. Still, sEMG systems have not yet been optimized to detect deep and/or small signals from within the body [1]. This is particularly an issue when considering regenerative peripheral nerve interfaces (RPNIs) for controlling a myoelectric prosthesis because EMG signals from RPNIs are usually too small for surface level detection (approximately 100µV – 2mV) [4].

Since interelectrode spacing and pick-up volume have a direct relationship [6] these therefore pose an interesting avenue for designing a surface electrode system that can detect EMG signals from RPNIs. Through a model in Maxwell 3D by Ansys, we aim to explore how varying the interelectrode distance from 8mm-40mm can change the spatial pick-up volume of electrodes, and further examine how the SD and DD circuits process the information to determine the best approach for surface detection of an RPNI. In the future, these results will then be validated through human subject testing.

INTRODUCTION

Surface electromyography (sEMG) studies how to detect electrical signals produced by muscles from the surface of the skin [1]. Passive surface electrodes typically consist of a metal plate and have not changed much in design since 1912 when they were first used by Piper in the detection of EMG signals [1]. Active surface electrodes have been redesigned over the years to increase the input impedance of the electrode to better reduce noise from the body and other power sources (ex. Mains Noise at 60Hz). This improves the quality of the detected signals [1]. One of the biggest disadvantages of surface electrodes is that they can only effectively be used to detect signals from superficial and/or larger muscles [1]. To minimize noise and crosstalk, differential circuits were designed as part of the active electrode. A bipolar or single differential (SD) circuit uses 2 electrodes and a reference electrode. It subtracts, filters, and amplifies the inputs to produce a usable signal for control, as shown in equation 1, where V_a and V_b are the inputs, G is the gain of the system, and V_{out} is the final output.

$$V_{out} = G(V_a - V_b) \tag{1}$$

A double differential (DD) circuit performs similar functions as a single differential circuit, but with 3 electrodes and a reference electrode, giving equation 2, where V_a, V_b, and V_c are the inputs, G is the gain of the system, and V_{out} is the final output. Both SD and DD circuits have been shown to reduce noise compared to a monopolar EMG system, but the DD circuit is better able to reduce noise and crosstalk than the SD system. [2]

$$V_{out} = G(V_a - 2V_b + V_c) \tag{2}$$

The inability to effectively detect signals from smaller and/or deeper muscles is a disadvantage for using sEMG for myoelectric control of a prosthesis as it limits the sites available for control of a device, thereby reducing its potential for control.

Clinical Problem

Regenerative peripheral nerve interface (RPNI) is a surgical technique developed by a multidisciplinary team led by Dr. Paul Cederna and Cindy Chestek at the University of Michigan in 2012. In this surgery, the severed end of a peripheral nerve is implanted into a free muscle graft. This technique can treat symptomatic neuroma formation of the severed nerve [3] while also creating additional sites for myoelectric control of a prosthetic device [4]. Currently these new sites generate EMG signals on a scale of approximately 100µV – 2mV [4]. These signals are too small for normal surface electrode detection so, the signal is collected through needle EMG (nEMG) which requires placing needle electrodes into the respective grafts. This intramuscular placement allows for increased specificity in the control but lacks real world application as these needles are invasive, must be placed by a specialized professional and cause the user discomfort [5].

While RPNI creates new sites for myoelectric control, the ability to detect the signals using sEMG is extremely difficult due to the size of the signals generated by these muscle grafts. Adjusting the active sEMG electrodes to detect deeper and/or smaller signals will allow the surface electrode systems to be used in conjunction with the RPNIs. This could improve control for prostheses by providing additional control sites for a user to operate the device.

Research Rationale

In practice, surface EMG systems use an interelectrode spacing of 10mm-20mm depending on the system used. With the direct relationship between pick-up volume and interelectrode spacing [6], our research aims to study how changing the interelectrode spacing may allow for detection of EMG signals from deeper within the body or detection of smaller signals without introducing excessive noise or crosstalk that could render the EMG signal useless in a control paradigm.

METHODOLOGY AND PRELIMINARY DATA

Preliminary testing was conducted using a DD circuit designed by Federico N. Guerrero et. al. using 4 operational amplifiers, shown in figure 1 [7]. An instrumentation amplifier was added to the end of the circuit to allow for the collection and processing of the EMG Data. Figure 1 also shows the red boxed area of the circuit that was removed as a modification to create a SD circuit from the proposed DD circuit.

Pilot testing was conducted on 3 individuals under the CU Denver Weir Biomechatronics Development Laboratory covered under COMIRB No. 14-0838. The SD and DD circuits were tested in tandem. The electrode array in figure 2 was affixed to the subject's dominant arm using a tie bandage. The array was placed over the wrist flexor muscles in the forearm. The subjects performed 2 tasks for each interelectrode spacing. The tasks were conducted as follows:

Task 1: Wrist Flexions

1. 10s lead in – Rest
2. [2s Wrist Flexion, 3s Rest] – repeat 10x
3. 10s lead out – Rest

Task 2: Individual Finger Movements

1. 10s lead in – Rest
2. [2s Flexion, 3s Rest] for each of the following movements in this order
   a. Wrist Flexion
   b. Index Finger Flexion
   c. Middle Finger Flexion
   d. Ring Finger Flexion
   e. Pinky Finger Flexion
   f. Index + Middle Finger Flexion
   g. Middle + Ring Finger Flexion
   h. Ring + Pinky Finger Flexion
   i. All 4 Fingers Flexion
   j. Wrist Flexion
3. 10s lead out - Rest

The EMG data was collected, filtered, and analyzed to determine the Signal-to-Noise Ratio (SNR) and the appearance of crosstalk. The data from the three individuals was inconclusive regarding the trends in the SNR due to multiple sources of error. This is thought to be a result of the circuits being tested in tandem and the common-mode rejection ratio (CMRR) affecting each system differently when the systems were tested in tandem. Due to these results, an electrode simulation model is being developed using Maxwell 3D on the Ansys Electronics Desktop Program. After the results of the simulations are processed, the results will be validated through human subject testing.

The model is currently designed as an idealized cylinder to provide a simplified representation of an arm. Later, the model will be updated to better reflect the actual geometry of an arm using real-life scans if an arm. These models are based on two papers by Madeline Lowery et. al. from 2002 and 2004 with all material parameters matching the models described in these references [8, 9]. Figure 3 shows the idealized cylindrical model with the three electrode bars for reading out the EMG signal, two electrode disks to act as excitation electrodes in the model, and a muscle fiber currently located 14.5mm below the surface of the skin. The muscle fiber will have a sinusoidal wave passed through to simulate a muscle signal in the body. Using finite-element analysis, the EMG signals will be analyzed to determine the expected spatial pick-up volume for each scenario and how this changes with different interelectrode spacing. The muscle fiber depth is also variable to allow for analysis of the depth of the pick-up volume in each scenario.

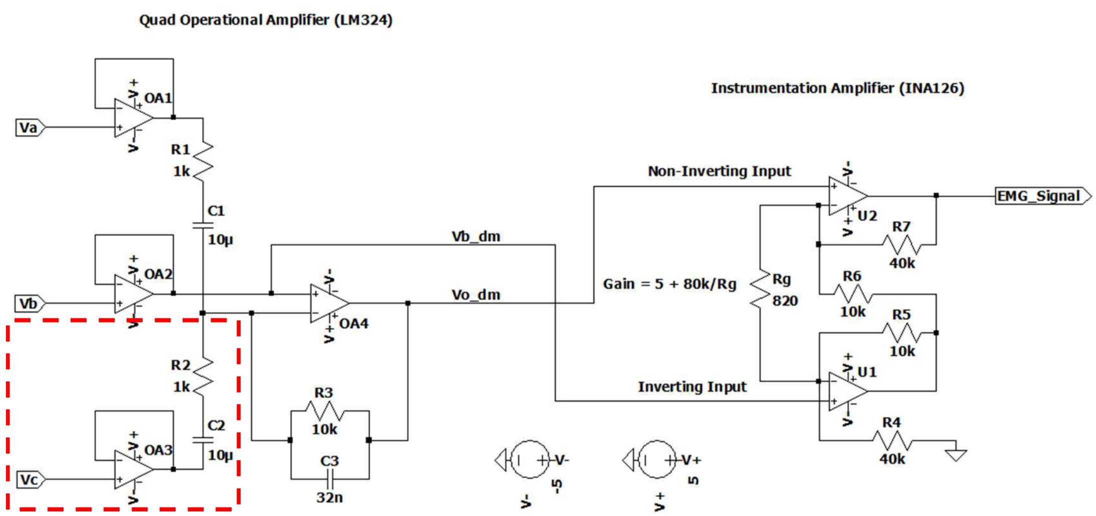

Figure 1: DD Circuit built in LTSpice. The circuit is based on the design provided by Guerrero et. al. in 2016 [7]. The circuit also includes the addition of an instrumentation amplifier at the end to collect the EMG signal and further amplify it before processing. The red dotted line box indicates the section of the circuit that is removed to change the proposed design from a DD circuit to a SD circuit.

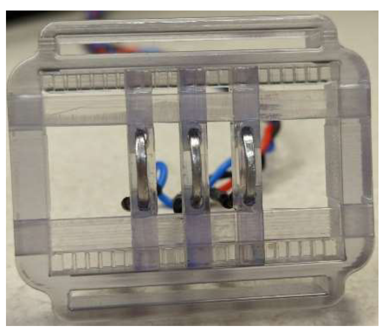

Figure 2: Electrode array designed by Amber Bollinger to adjust electrode spacing by 4mm at a time from 8mm to 40mm. The DD circuit used all three electrode bars. The SD circuit only used the two outer electrode bars, not the center one.

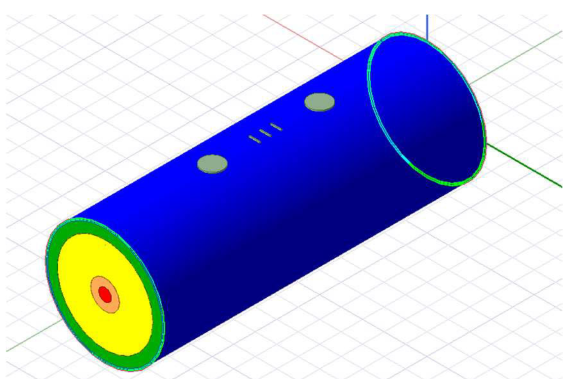

Figure 3: Idealized cylindrical model built in Maxwell 3D of an arm with two disk excitation electrodes and three bar recording electrodes. The model has cancellous and cortical bone, muscle (and a muscle fiber), fat, and skin. All parameters of these materials are described in the two articles by Lowery [8, 9].

CONCLUSION

From the pilot testing, it is clear there are specific benefits to each type of EMG detection circuit. The DD is more focal and so it can detect surface signals more readily; however, it cannot detect signals from muscles deep in the body. The SD circuit is less focal allowing for detection of signals deep in the body; however, too much crosstalk renders the surface EMG data unusable. From the data collected in pilot testing, suggestions to detect deeper or smaller signals from RPNIs could be through a combination of increasing pick-up volume through interelectrode spacing, increasing CMRR in the circuit design, and increasing gain to make the small signals more easily detectable. Further research will be done to elaborate on trends for these testing areas.

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