EMG/EEG Controlled Prosthetic

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***Abstract*—**This project study focuses on a variation of a prosthetic design using a combination of electromyography (EMG) and electroencephalography (EEG). This set-up primarily covers prosthetics that limb loss that begins below the elbow, such that the individual still has their bicep. To cover different issues that arise with prosthetic device control that use one or the other, the complement of both procedures can be set up to provide more precise signals. The project design encompasses receiving outputs from both filtering circuits to process using Arduino hardware. From there, the filtered signals will pass through specific logic gates before being sent to a motor-controlled prosthetic device.

Keywords—prosthetic, EEG, EMG, Arduino, filtered signals

I. INTRODUCTION

Nearly two million people in the United States alone live with limb loss. Vascular disease accounts for about 82% of limb loss, which includes blood vessel disease (known as peripheral vascular disease), diabetes, blood clots, and osteomyelitis. 22% of limb loss is due to trauma, with trauma also causing 75% of upper extremity loss. 4% of limb loss is due to congenital disease and another 4% is due to tumors [1]. 70% of upper limb amputations are below the elbow, which is the area of focus for the prosthetic design.

A long-standing goal of neuroprosthetic research is the optimization of prosthetic control. The two main methods of obtaining the biological signals for control are electroencephalography (EEG) and electromyography (EMG) coupled with machine learning. EEG tests the electrical activity of the brain by using electrodes. The output is the summation of the electric field generated by synaptic potentials. EMG tests the electrical activity of skeletal muscles caused by their activation.

Current issues of EMG controlled prosthetic devices include noise that arises from movement, changing electrical activity due to muscle fatigue, and the fact that each amputee has different muscle characteristics. The major issue with EEG control is the lack of spatial resolution that can be attributed to the ex vivo collection of data. To address these problems, the P300 potential recorded from EEG will be used to confirm the intention of movement that is indicated by the contraction of muscle. As previously observed between separate trials and individuals, the P300 is a stable and consistent enough input to control the Brain Computer Interface (BCI) of a prosthetic [2].

The P300 is an event related potential that arises due to one's intention to make a movement. It is a positive-going potential that occurs one to two seconds before the physical onset of an action [3]. The P300 component is isolated from the beta frequency band of brain activity.

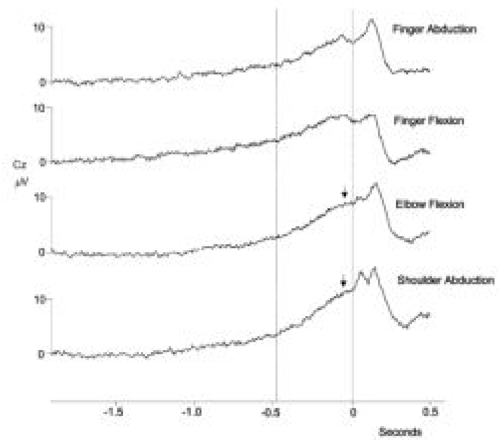

Figure 1. P300 Component: The positive-going potential can be seen starting between t = -1.5 and t = -0.5 with reference to when the action is initiated (t=0). [3]

To minimize the cost and maximize the ease of use, non-invasive methods are preferred.

II. EMG

A. *Overview*

The EMG signals are the electric potentials generated by the activation of muscle fibers in neuromuscular activities, and the patterns of EMG signals are recognized to control the prosthetic devices for the lower arms in this case. The EMG data serves as the basics to the analysis of correlation between muscular activity and central nervous system control. The process designed for the EMG part is: raw data collection, amplification, filtering, and digital processing.

B. *Electrode placements*

The triceps and biceps muscles control the position and movement of the forearm, and the triceps connect the shoulder and the joint to enable the slightly bent flexion of the forearm, which is considered to be the common status after the loss of forearm. Therefore, this experiment will focus on the main muscle groups of the triceps brachii: long-head, medial-head, and lateral-head. In the experiment that is referenced, the researchers applied 8 electrodes on one arm: 2 electrodes on the belly of each head, and the reference electrodes at elbow joint and shoulder joint.

Compared to the experiment focused on the speed variations above, this experiment proceeds in the relatively stationary status with only two available inputs to the processing circuit, so the number of electrodes is reduced to match the designed circuit. Since the long-head of the triceps brachii extends all the way from the scapula to the elbow joint, and it functions in the extension of the forearm, it is assumed that patients with prosthetic will have higher activity here because they may find easier to begin practice with the help of shoulders. Hence, both the positive and negative input electrodes will be placed on the long-head of the triceps and a reference electrode placed below the elbow.

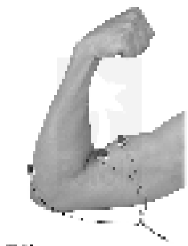

Figure 2. Simplified placements of electrodes: on the long-heads of biceps. [20]

For both measurements of EMG and ECG, the Ag/AgCl wet electrodes will be used because they are low-cost and generate low noise levels, and the skin should be shaved and cleaned to have better contact with the electrodes.

C. *EMG Signal Acquisition*

EMG signals were recorded from the long head brachii of a 20 y/o female. Data was collected with an Arduino Mega 2560, 3M 2560 Red Dot ™ Monitoring Electrodes with Foam Tape & Sticky Gel, and 3 standard electrode leads. Using C++, the speed of data acquisition was set to 9600 bits per second. The arduino reads the signal input and outputs it onto a serial monitor in units of µV. Three trials: No Flex, High Flex, and Low Flex, which refers to the strength of tricep tension, are recorded. The three trials are repeated for two sets of data with each set having the signal transduced by the Arduino recorded from either the proximal or distal electrode and the results are shown in Table 1.

Trial	Signal Electrode	Average Voltage (mV)
No Flex	Distal	332 ± 34
No Flex	Proximal	311 ± 13
Low Flex	Distal	305 ± 10
Low Flex	Proximal	306 ± 11
High Flex	Distal	309 ± 13
High Flex	Proximal	306 ± 12

Table 1. Average and Standard Deviation of EMG trials

D. *Circuit design*

The circuit shown in Figure 3 is the one used for EMG simulation.

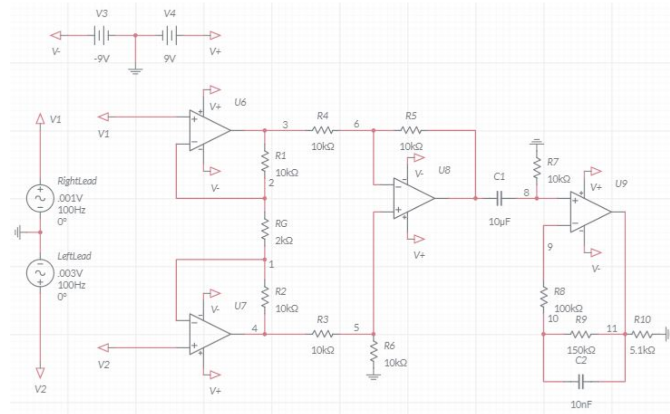

Figure 3. Simulation circuit for EMG.

The three operational amplifiers on the left form a standard biopotential amplifier with a high gain as shown in Equation 1, a high input impedance, and a high common-mode rejection ratio.

$$Gain = 1 + \frac{2R}{RG} = 1 + \frac{2(10k)}{2k} = 11 \quad \textbf{(1)}$$

The rest of the circuit from C1 onwards forms an active bandpass filter where the high pass filter has a cutoff frequency of 1.6Hz (Equation 5), the low pass filter has a cutoff frequency of 106Hz (Equation 6), and has a gain of 20.6 (Equation 7).

$$f_{c,low\ cut} = \frac{1}{2\pi \cdot C1 \cdot R1} \quad \textbf{(5)}$$

$$f_{c,high\ cut} = \frac{1}{2\pi \cdot C2 \cdot R3} \quad \textbf{(6)}$$

$$G = 1 + \frac{R2}{R4} \quad \textbf{(7)}$$

The final output would then be inputted into an Arduino to interface with a computer where an appropriate computer program would be used to confirm the intention to make a prosthetic move. After this confirmation, the program would make the prosthetic move with a motor to perform a function.

E. *Results*

When the circuit in Figure 3 was tested with an AC voltage of .001V in the right lead (green) and .003V in the left lead (light blue) and 100Hz frequency for both leads in Multisim, the graph produced is shown in Figure 4. As expected, it shows significant gain of the final output signal in dark blue and an offset caused by the bandpass filter.

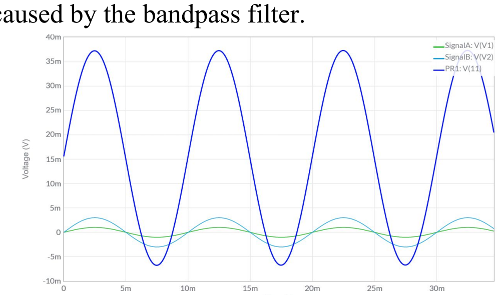

Figure 4. Test simulation for EMG using AC inputs.

When the same circuit was simulated in Multisim, this time with the data acquired from EMG part C, the right lead (green) and the left lead (light blue) produced the right image in Figure 5 and the final output is shown in the left image. Similar to the AC test, this final output shows significant gain of the original signals. The output spikes mirror those of the inputs and some filtering occurs.

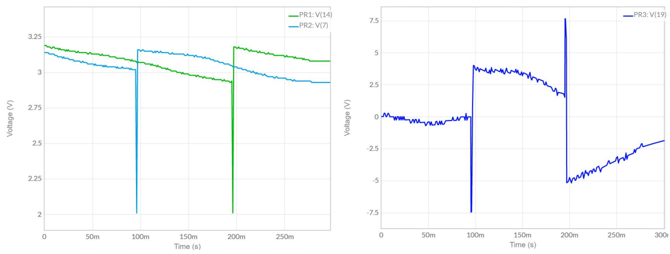

Figure 5. Simulation for EMG using raw EMG electrode data.

III. EEG

A. *Overview*

An EEG recording as mentioned, is a way to understand brain activity. This is a great advantageous point to the project proposal as it supports the EMG reading in verification that the brain is processing the muscle movement of one's biceps to start the control of the prosthetic limb of the lower arm. From an electrical circuitry standpoint, the outline to design the EEG part of the circuit is as follows: raw data collection, amplification, noise reduction, filtering, and finally computerized processing of signal.

B. *Electrodes placements*

First, it is necessary to point out which type of brain wave the circuit should be reading. There are many types of waves to analyze, depending on what type of activity is being observed. Since the target raw data from the body is more muscle movement along with spatial awareness, alpha, or a frequency range of 14-30 Hz is exactly what is needed. *Table X* shows the possible types of brain waves that exist.

EEG wave type	Frequency range (Hz)	Amplitude (mV)
γ	30-100	<50
β	14-30	<50
α	8-14	30-50
θ	4-7	50
δ	0.5-4	~100-200

Table 2: EEG brain wave signal types (frequency ranges may vary due to multiple experiments done in measuring such an array of signals).

Typically, researchers use an EEG electrode cap with the 10-20 electrode placement system for EEG recording. The cap ensures the Ag/AgCl wet electrodes fix precisely on the scalp during the recording without additional markings. The placement system divides the brain into 5 areas, F(frontal), C(central), T(temporal), P(posterior), O(occipital), proportionally to the surface of the head for recording.

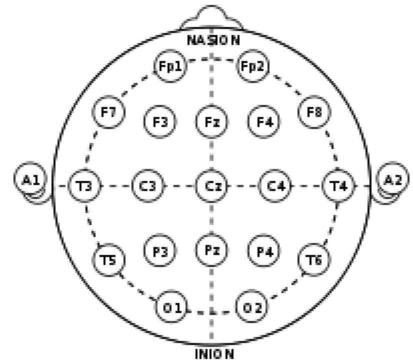

Figure 6. Labels for points according to 10-20 electrode placement system [15]

Due to the limitation of the instrumentation amplifier only allowing two inputs at a time, if multiple parts of the brain were to be examined, then multiple electrode pairs need to be connected to their own instrumentation (IA) amplifier. For the purposes of experimental analysis of motor function, the central region of the brain, electrodes F3 and F4 are utilized as an electrode pair as shown in Figure 6. If possible, all areas should be tested to see the relative activities during different behaviours to choose the best electrodes placement. Both electrodes can be isolated to measure the lateralized readiness potentials, which is the preceding potentials occurring at the motor cortex in response to the contralateral limb movement, very similar to P300 component mentioned. For instance, the move of the left arm will cause a more negative potential on the F4 area and a less negative potential on the F3 area and vice versa. Taking the average of differences in both left and right limb movement and this value is known as the lateralized readiness potential. So in this simplified 2-channel EEG recording, the positive and negative electrodes are placed at F3 and F4 respectively, and the reference electrode is placed on the right ear, commonly known as A2 (not pictured on Figure 6).

C. *Circuit design*

The electrodes are wired up to a protection circuit. This region of the EEG circuit allows for the prevention of overvoltage or overcurrent to happen, or rather the user bearing consequences of malfunctioning circuitry. This portion consists of an array of diodes and resistors to allow for that overvoltage/overcurrent prevention. In this case, instead of a numerous number of diodes and resistors to keep track of, just resistors are used. The CMRR of a typical EEG circuit ranges from 10,000 - 100,000 (80dB - 100dB). This design utilizes the typical 80dB CMRR to help minimize noise from other objects that may interfere with the raw signal acquisition. Voltage outputs of the protection region will then be fed into an instrumentation amplifier.

The CMRR, or the common-mode rejection ratio and the corresponding value in decibels are calculated by the following equations:

$$CMRR = \left|\frac{A_d}{A_c}\right|$$

$$CMRR_{dB} = 20log_{10}(CMRR)$$

where A_d is the differential gain and A_c is the common-mode gain.

Once the raw signal passes through the IA, it will travel through a bandpass filter to extract the target frequency ranges to pass through, which is the 14-30 Hz frequency band. The filtered EEG signal, along with the output of the filtered EMG signal, will feed as inputs to the Arduino Mega 2560 microcontroller for digital processing and be able to output a voltage to the servo that will also be connected to the Arduino board.

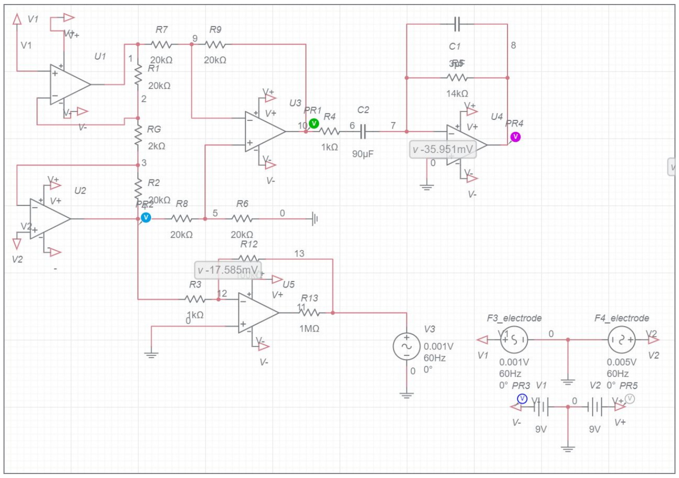

Figure 7: Multisim schematic of EEG circuit with three probes for output voltage reading..

The Arduino Mega 2560 has analog pins to allow for digital conversion of the raw signal that was filtered by way of an ADC or an analog to digital converter feature the board has. The Arduino will be connected via USB 2.0 A to B cable to a computer for digital processing and eventual output.

Some details of the digital processing part of the circuit logic that are beyond the scope of the class. However, they are important to consider. The following explanation outlines the rough idea behind what should be happening in digital processing. The filtered signal from both the EMG and EEG circuits travels to the Arduino and then to the computer for processing. It is reasonable to assume that within the code, one must have a way to recognize both EMG and EEG filtered signals to check if the wave will show that upward infliction of voltage, or P300 component. Once that threshold voltage is achieved, the code will need to send a value that can equate to a voltage value to be sent to the appropriate pinout for the servo motor that is attached to the prosthetic.

One crucial fact to point out in the circuit design is that some sort of active grounding needs to be established. This is where the driven right-leg (DRL) circuit is integrated. Instead of the DRL directly being implemented, a version of that concept is applied with a reference electrode acting as that active ground for the purposes of the EEG raw data collection. That is where the A2 electrode is utilized.

D. *Results*

Pen and paper calculations based on the concept of output voltage of an instrumentation amplifier should be the following:

$$V_{dark\ blue} = \frac{R_9}{R_8}(1 + 2 * \frac{R_1}{R_G})$$

where $R_1 = R_2 = R_7 = R_8 = R_9$.

With countless trial and error, the output of all probes from Figure *8* mostly validates paper calculations. Due to the nature of not being able to have readily available EEG electrode data to filter out necessary beta waves, the simulated AC voltage that would be picked up by the electrodes must suffice. The blue graph is reading the voltage right at the intersection of the midway point of the IA and the DRL component. The green graph measures the IA output and the pink shows output voltage of the entire circuit after the signal passes the bandpass filter.

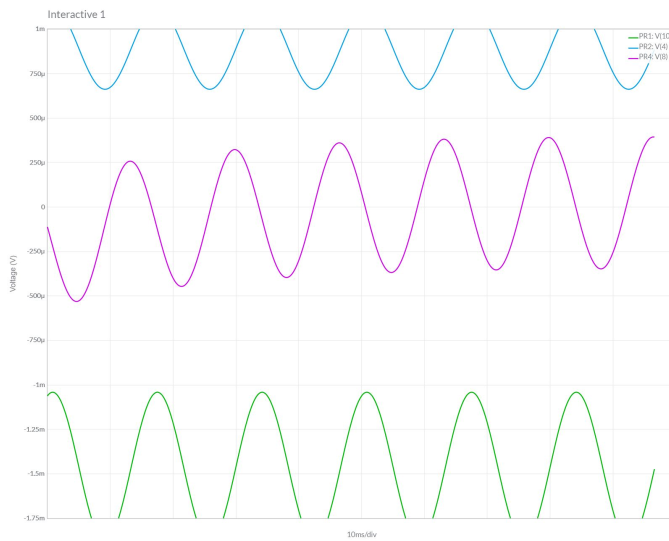

Figure 8: Graphical voltage output behavior from probes

It is clear that the voltage outputs oscillate due to the sinusoidal input. What can also be observed that the output is measured in mV and uV due to the fact that the beta waves are relatively less than $50\,\mu V$ in amplitude. It is obvious that this is not a perfect representation of the model, but it gives a relative image of what the design was attempting to accomplish based on concepts from lecture.

Because the frequency band needs to be accounted for, the following equations will allow for that expectation to be integrated in the band-pass filter before signal heads to the Arduino:

$$f_{low} = \frac{R_4}{R_5}$$

$$f_{high} = \frac{C_2}{C_1}$$

IV. Conclusion

For overcoming various issues that are encountered with prosthetic devices and their control, the EMG/EEG combination prosthetic has been proposed and analyzed. The processed signals through the Arduino and servo-motor confirm that the physical implementation of the design would be valid. The findings of this project design represent a proof of concept for this expansion of bioinstrumentation. The advantages of this design are present in its noninvasive properties and accessibility. The combined medical procedures would synthesize together to form precise and accurate signals for prosthetic control.

Further research can expand with experimenting for signals with more reliable environment conditions and lab equipment. From there, continued development would move to prototyping and optimizing the circuit layout for reduced noise and outside interference. Prototype designs can be adjusted to maximize comfort for the user through trial designs and tests. Progress into the concept of combining EMG and EEG signals could provide other opportunities to increase prosthetic control and lead to more accurate prosthetics that could expand to account for other types of limb loss.

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