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Myoelectric Control of Prosthetics and Robotics

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Abstract

Prosthetic limbs improve mobility and give people the power to perform otherwise arduous tasks. In our research, we have developed a functional, 3D printed prosthetic hand. This hand detects and interprets the myoelectric signal from healthy muscles to control motors that move the prosthetic fingers and wrist, mimicking the functionality of a true hand. Prior work has accomplished basic movements, but due to the processing power needed to interpret the myoelectric signal, prosthetic hand movements are far from the fluidity and quickness of a real human hand. The focus of our project is to decrease the signal processing response time thereby increasing the speed of the prosthetic hand. In order to detect a myoelectric signal, we use three electrodes attached to the arm-two across the muscle of interest and another on the elbow acting as a ground reference. The signal from the two electrodes on the arm are sent into an instrumentation amplifier where the differential voltage across the muscle is found and amplified. The signal is then sent into a twin t-notch filter to remove the large, parasitic 60 Hz noise. We also send the signal through a high pass RC filter to remove any DC offset induced by the electronics. Finally, the signal is amplified and sent to a microcontroller, which uses a simple threshold algorithm to decide if the hand should be opened or closed. The open and close action is accomplished via servos attached to the prosthetic fingers. In conclusion, we were able to create a functional, low cost 3D printed prosthetic hand controlled via myoelectric sensing and interpretation. We have significantly improved the signal to noise ratio thereby increasing the speed of operation. These results are an important step forward for open source prosthetics and will give amputees the opportunity to perform otherwise difficult tasks.

Keywords: Prosthetics, Myoelectric, Open Source

1. Introduction

The loss of a limb has a significant impact on a person's ability to perform essential functions. Prosthetics have been developed to help restore these functions, providing people the power to perform tasks that they otherwise could not. Although much progress has been made by private corporations, prosthetics from these companies are often times not a viable option financially for amputees. Alternatively, open source prosthetics are often readily available but lack the functionality of a human hand. In order to bridge the gap between functionality and cost in a prosthetic, this project seeks to develop a functional, 3D printed, open source prosthetic hand.

It is estimated that there are 40 million people worldwide in need of prosthetics[1] . However, commercial upper prosthetic devices are often prohibitively expensive, costing tens of thousands of dollars[2,3]. Currently, only about 5% of the people in the world who need a prosthetic have access to one[1], leading many people to continue using basic hook type prosthetics. The high cost of prosthetics is particularly acute with children as they quickly outgrow their prosthetics[4]. Additionally, people in remote and poor areas of the world lack access to

Figure 1. A 3D printed hand showing the palm of the hand and the back of the hand. This is a version of e-NABLE's open source Flexi Hand that we modified to accept servo motors.

more advanced medical care[1]. Highly functional, open source, low cost, 3D printed prosthetic device will significantly improve access for those who otherwise would be unable to obtain such a prosthetic.

Currently, one of the leaders in open source plans for 3D printed prosthetics is the e-NABLE organization[5]. They provide plans for prosthetic hands that work on a body powered model of operation, meaning that the hand is opened or closed by movement of the wrist. While this method of operation is simple and easy to implement, it leaves much to be desired in the way of functionality. Specifically, the user must retain use of their wrist, and there is no control of individual digits.

For this work, we propose a system that combines the high functionality of expensive, commercial, myoelectrically controlled prosthetics with the low cost of e-NABLE's open source prosthetics. Our solution is the production of a 3D printed prosthetic that uses non-invasive surface mounted electrodes to control the prosthetic hand. This prosthetic is easily assembled and provides a highly effective and low-cost prosthetic that is easily manufactured in places of need.

There are also many important applications of myoelectric control beyond prosthetics. For example, many industrial and scientific operations would greatly benefit from reliable and naturally controlled robotics. For instance, NASA spends many millions of dollars sending astronauts into orbit to perform maintenance on high value equipment. If these operations could be conducted from Earth using human controlled robotics, this would save many resources as well as eliminate the risk to the astronauts. This technology could also be deployed in many other dangerous environments in place of a human worker; such fields might include mining, bomb disposal, etc. A final application of this technology is in the augmentation of human strength (i.e. Iron Man technology). The user could wear a robotic glove, for instance, that was controlled by his own muscle's electrical signals but possesses much greater strength.

This project has succeeded in producing a 3D printed prosthetic hand that can mimic basic user movements. This hand detects and interprets the myoelectric signal[6], an electrical impulse triggered as muscles contract or relax, from healthy muscles to control servos that move the prosthetic fingers and wrist, mimicking some of the functionality of a true hand.

2. Experimental Method

The 3D printed prosthetic hand developed in this work is based on the e-NABLE Flexi Hand (see Figure 1) and uses the myoelectric effect[6] in order to control the opening or closing of the hand. In order to detect a myoelectric signal, three electrodes are attached to the arm. Two of these electrodes are placed across the muscle of interest, and the third electrode is placed on the elbow and connected to a ground reference (see Figure 2).

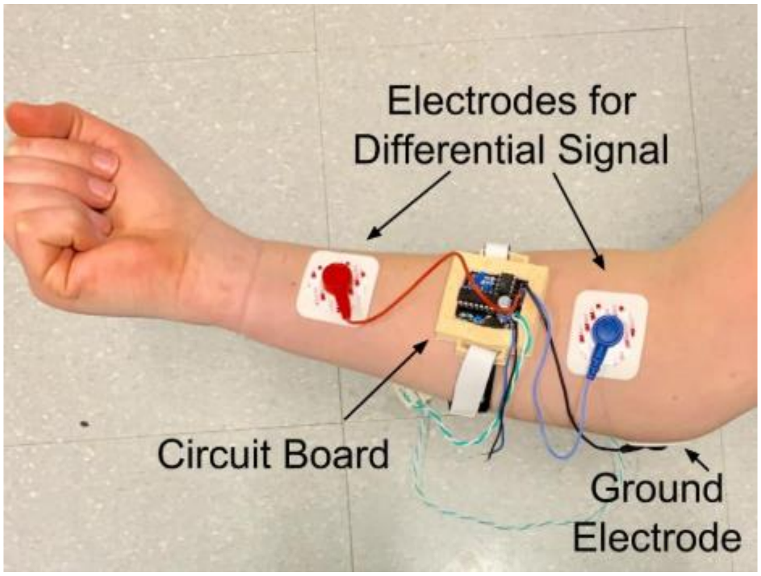

Figure 2. Diagram of the electrodes' placement and the wearable circuit board.

To maximize the amplitude of the signal, the muscle system in the forearm was analyzed and the placement of the electrodes was optimized[7]. It was found that the flexor digitorum superficialis and the flexor digitorum profundus in the anterior forearm are the muscles most involved in the movement of the fingers. Therefore, the electrodes are placed across these muscles in order to significantly strengthen the myoelectric signal detected as the operator of the prosthetic moves their fingers or wrist.

Once the myoelectric signal is picked up by the electrodes on the arm, it cannot be used as is; it must be pre-processed. The need for this preprocessing is twofold. First, the signal that comes directly off of the arm is very small, on the order of a micro Volt or less. At first glance, a simple amplifier would seem to overcome this problem. However, there is a second problem, that is, the human body acts as an antenna, effortlessly picking up noise, primarily 60 Hz, from abiding electromagnetic radiation and coupling it to the signal from the electrodes. In fact, our initial test circuits showed a signal to noise ratio of about 1:100 i.e. the signal was being completely buried beneath the noise. Therefore, we designed and fabricated a pre-processing circuit that filters and amplifies the signal ultimately producing a usable signal to noise ratio of approximately 10:1 (see Figure 4).

The pre-processing circuit, shown in Figure 3, performs the following operations in order to pull the signal out from below the noise. The first stage of the circuit differentially reads the output of the two electrodes that are placed across the muscle group of interest. Reading the signals differentially is essential to remove a majority of the large parasitic common mode noise that is picked up by the antenna action of the human body. However, this differential signal, while less noisy, still contains a large 60 Hz noise component which is filtered out using an active twin-t notch filter. Finally, the signal is amplified and sent to a microcontroller for final interpretation and actuation of the prosthetic.

Once the microcontroller has decided that the hand should be opened or closed, it activates servos connected to strings in the hand attached like tendons, making the fingers open or close (see Figure 1). The microcontroller commands an angle of turn to the servo motor that then turns the servo horn to that angle. To increase the speed of the fingers, 3D printed custom servo horns were printed that are longer than ordinary servo horns. As well as custom servo horns, a case for the circuit board that attaches to the arm (see Figure 2) was also custom printed to lower noise from movement on the surface of the arm.

3. Results and Analysis

Once the myoelectric signal from the arm has been appropriately amplified and filtered by our circuit and sent to the microcontroller, the signal must be interpreted to decide whether or not to open or close the hand. Towards this

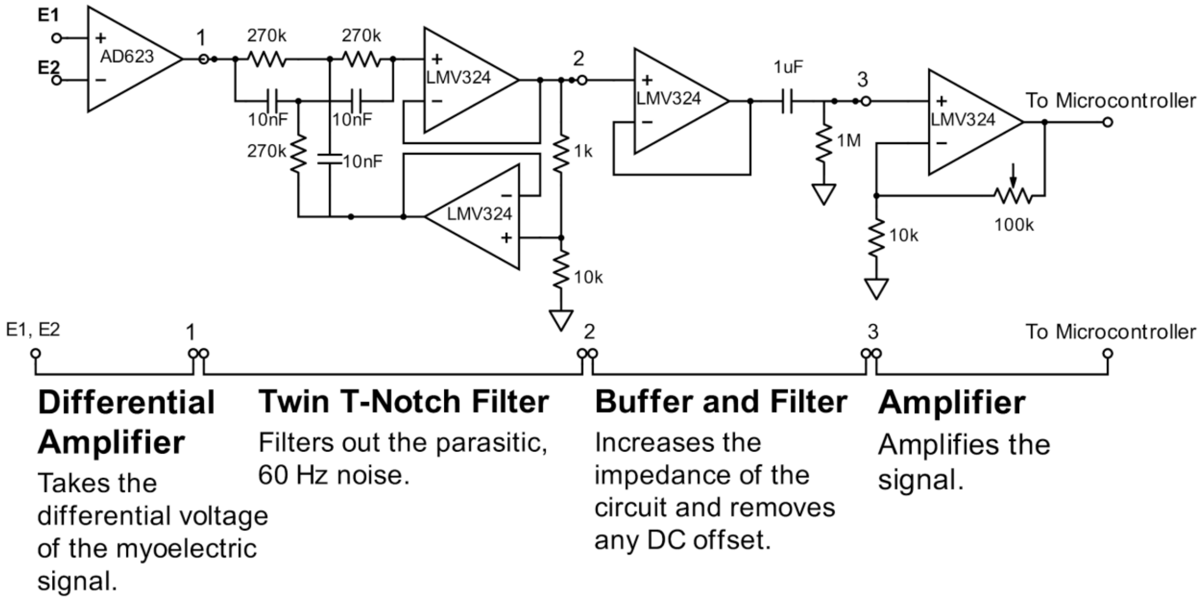

Figure 3: The circuit diagram of the pre-processing circuit.

end, a simple thresholding test on the signal is performed as shown in the flow chart in Figure 5. First, the microcontroller checks to see if the voltage is greater than some threshold (see Figure 4); a threshold of 3.5 V is used in this work. Second, once the threshold voltage is exceeded, the microcontroller checks to see whether the hand is in an open or closed state. Finally, if the hand is open, the microcontroller activates the servos to close the hand and vice versa. This method of decision making has the advantage of being very simple and computationally cheap. The computational costs of any analysis done must be carefully weighed against the size and speed of the microcontroller, with this method giving us a good balance of speed and a small profile. To watch a video of the prosthetic hand in operation, visit the following url: https://youtu.be/ljKoZNYS_Rw.

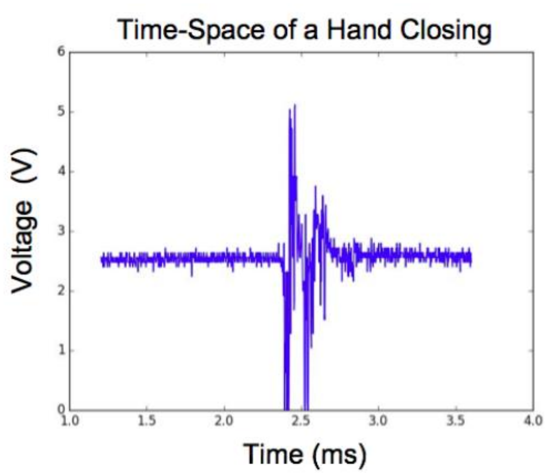

Figure 4: A sample voltage vs time for a single squeeze of the user's hand.

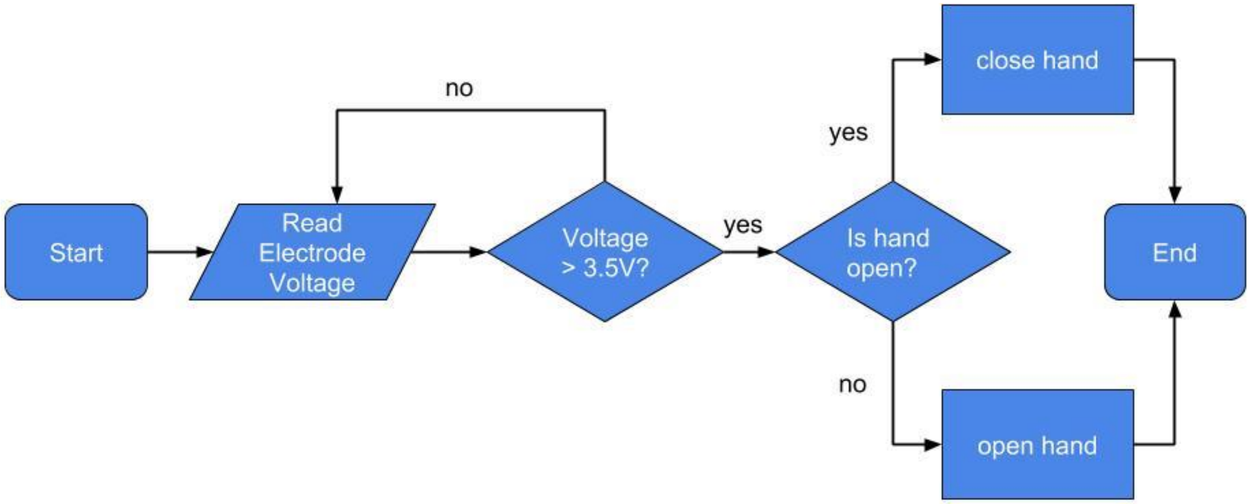

Figure 5. A flow chart

4. Conclusion

In this work, we were able to create a functional, low cost 3D printed open source prosthetic hand controlled via myoelectric sensing and interpretation. These results are an important step forward for open source prosthetics and will give amputees the opportunity to perform otherwise difficult tasks.

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6. References

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