EMG Driven, Underactuated, 3D Printed Prosthetic Hand

Sonali Carlton, Miles Mellot

Human-Assistive Robotic Technologies Lab
Department of Electrical Engineering and Computer Science
University of California, Berkeley

***Abstract* – The design and description of a 3D printable prosthetic hand which is able to open and close based on the flexing of the bicep muscle on the remaining limb using EMG readings.**

I. Introduction

Nearly 2 million people in the US have amputations, many of whom use prosthetics [1]. Recently, there has been a surge in 3D printed prosthetics. One main advantage of 3D printing prosthetics versus traditional technology is the low costs associated, which is especially good for children who due to their fast rate of growth require new prosthetics to be made often. Additionally, they are extremely customizable to the wearer. The NIH even supports an open-source site for sharing files for 3D printable prosthetics [2].

Given this information and my desire to learn more about 3D printing and coding, I joined as an Undergraduate researcher under Rob Matthew in the Human-Assistive Robotic Technologies Lab at the University of California, Berkeley during the Fall 2018 semester. Working alongside Hope Balatan, from Bioengineering at UC Berkeley, and Gabriela Bravo, from Pontificia Universidad Católica de Chile, we created an orthotic glove, which used 3D printed parts and an Arduino controlled linear actuator to assist with the movement of a single finger on a person's hand based on smaller movements by the user. For my Spring 2019 project, I was joined by Miles Mellot, from the Molecular and Cell Biology Department at UC Berkeley. After discussing my previous experience with the orthotic we decided that our goal was to create an EMG driven, underactuated, 3D printed prosthetic hand.

II. METHODS

A. Initial Design

In doing research we discovered that there were many designs for 3D printable prosthetic hands already available. Based on arbitrary criteria we chose the "Robotics Prosthetic Hand" design by grossrc on the open source website Thingiverse [3]. We printed out the pieces of the hand and assembled it using ⅛ inch paracord to connect the finger segments and fishing wire to connect the fingers to the main hand piece and to the forearm as shown in Figure 1. The paracord provided resistance, while the fishing line controlled the movement. We tied off the fishing line at both ends, the tip of the finger and the base of the forearm, and then melted the ends of the paracord and put hot glue to keep them attached to the main hand.

Fig. 1 Assembled Hand

B. Motor Control

After creating the hand, we wanted to first make the hand move. To accomplish this, we used an Arduino Uno, which was chosen for the wide Arduino code library that exists as well as its ability to support analog and digital inputs. Throughout the experiment, the UNO was connected to my laptop via USB to send data as well as power. To test if the hand would close with the motor, we used the sweep code from the Arduino library [4]. Initially, we tied the ends of the fishing line to PQ12-R Micro Linear Servo [5] and discovered two problems: it was impossible to move fingers individually and there wasn't enough force for the hand to close fully. Using a hanging spring scale, we measured that the force it took to fully close the hand was approximately 49 N. Ultimately, we went with the L16-R Miniature Linear Servo [6] since it had the same wiring system of signal, power, ground but provided more force. We chose an actuator stroke of 50mm, gear ratio of 30:1, and a maximum operating voltage of 6V. Another issue with the Servo was that despite the sweep code working and moving back and forth it wouldn't stop immediately with a key press. We decided that although the default for the sweep function is to go from 0 ° to 180 ° in steps, our motor was hitting its max range before 180° so it would go back to compensate rather than stopping. To fix this problem we attached a potentiometer to the actuator and used AnalogInputpotentiometer code to read the potentiometer values as the servo moved. Using this data, we discovered that the maximum degrees the Servo needed to move was only 140° which then solved the movement problem.

C. Whipple Tree

In order to allow fingers to move separately from each other, we decided to create a whippletree. We used the Whippletree Tensioner design [7] and created a tree as shown in Figure 2. The tensioners were 3D printed and connected with tied fishing line. The last tensioner was tied to the end of the linear actuator. Using the sweep code, we tested that the actuator would pull the fingers completely close and it did. At this point we had a working prosthetic hand which could be controlled using keyboard keys, however, we had yet to implement the EMG driven component.

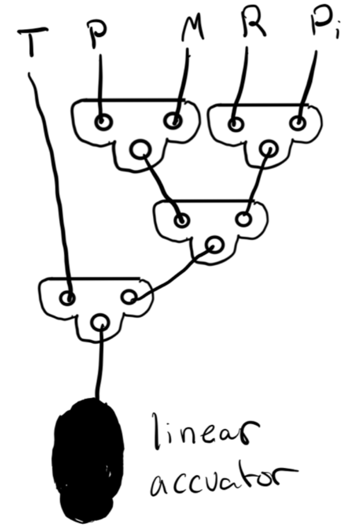
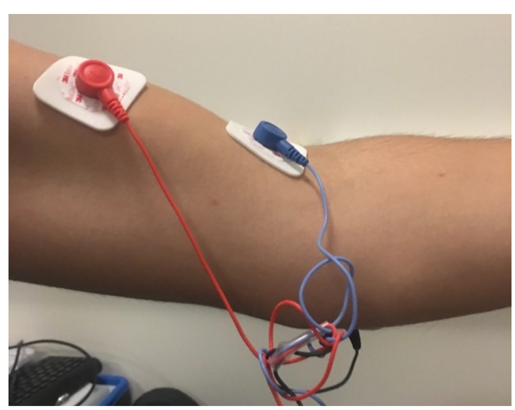


Fig. 2 Whipple Tree
Connections between the fingers going from thumb on the left to pinky to the right, using four tensioners tied by fishing line.

D. EMG Control

Once the linear actuator component was set up, the EMG component was relatively easy to add. I wrote an Arduino code that combined the existing sweep code with another Arduino library code readAnalogVoltage [7] so that when the Arduino got a certain voltage it would trigger the servo instead of the keyboard controls we previously used. To test the EMG part, we disconnected the motor from the hand in order to see if we could get just the motor to move based on EMG signals. We connected the MyoWare Muscle Sensor and Cable Shield [8] and placed the electrodes on the skin. I tested the EMG on my left arm bicep because this was an easily definable and accessible muscle. I placed the red electrode on the middle of the bicep and then the blue electrode on the end of the muscle and then the black ground on the boney part of my elbow as shown in Figures 3 and 4.



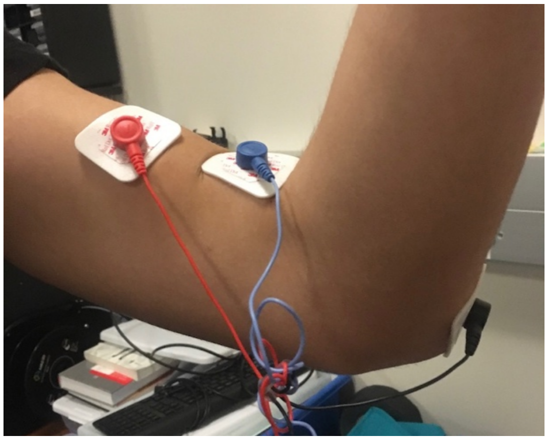


Fig. 3 & 4 Electrode Placement
Electrode placement on the middle and end of the bicep as well as ground on the elbow.

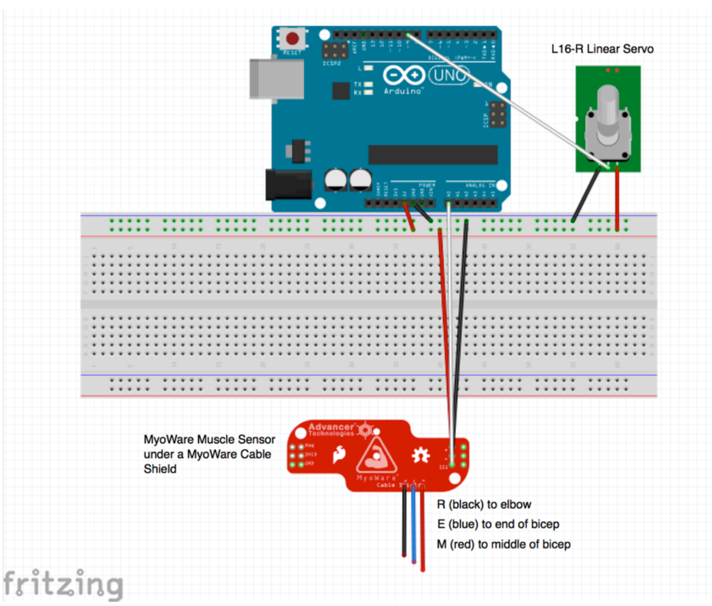


Fig. 5 Wiring Diagram
Final breadboard and Arduino wiring diagram with EMG connections.

III. RESULTS

The hand was initially designed as a voluntary close, where the base position is that the hand is opened, however since that required flexing the entire time the user wanted the hand to be closed, we changed the hand to be a voluntary open. It would easier for the user to flex when they wanted to open the hand and release a held object than flexing while holding an object. After correcting the code for this, we attached the motor back to the hand to make sure that the hand would open when the bicep was flexed and would close as the default or when the bicep was not flexed.

After visually evaluating the graph outputted by the EMG readAnalogVoltage, we decided to set the triggering voltage to open the hand at greater than .55 V, because it a voltage which was easy enough to reach by flexing but wouldn't be triggered by the relaxed hand accidentally. To fully test the hand with the EMG driven actuator, the fishing line between the hand and the motor to be completely tensioned so I clamped the hand and motor to the table to test the prosthetic and it performed the correct action a majority of the time. The hand successfully held various objects; however, it needs further testing on the force applied.

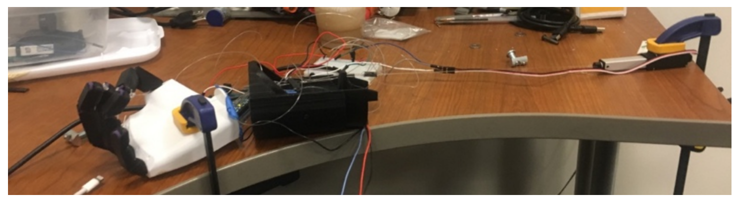


Fig. 6 Testing Setup
Hand and motor clamped down while using EMG control to trigger the motor movement

IV. DISCUSSION

Through this project, I was able to develop many skills. I had already had some experience with using Arduino however I hadn't used an Arduino in conjunction with a linear actuator as well as a commercial sensor. I further developed my coding skills by combining two open sourced codes I could see how to create things from existing sources but adapt them to our needs. Additionally, I discovered the benefits of open source since a lot of our device was created by combining multiple open source designs. I also learned more about how to use Cura and Solidworks software to 3D printed the pieces for the prosthetic. I had never before done any work involving EMG, so I learned about the applications of that technology.

V. NEXT STEPS

Although this version of the hand fulfilled our goal there were some changes that could improve it. If I had had more time, I would have tried to rebuild the hand but using a wire other than fishing line. The fishing line was hard to tie and got extremely kinked and knotted as shown in Figure 7. Perhaps using colorful wire to distinguish each finger or using a different method of attaching the fingers to the tensioners.

Fig. 7 Inner Forearm
Tangled fishing line connecting the whippletree.

For future versions of the hand the EMG control could be placed on different muscles, however, the triggering voltage would have to be adjusted based on individuals and their muscles capacity. If a muscle other than the bicep was used, a similar set up of electrodes would be required with one in the middle of the muscle and one at the end, but with a different ground that is closer to the location of the muscle being used, which doesn't have much muscle movement. For our scenario, the bicep was the easiest. The triggering value would have to be tested and set as the individual and muscle group changed. Various changes could be made in terms of the force of the hand. If a thicker paracord or wire that had more resistance was used the hand could have more force as it was flexed which would be useful in daily activities. Additionally, using multiple motors could allow individual control of each finger, however, it would require more power and would be less portable. To allow for more control the EMG could trigger different amounts of movement based on a lower or higher triggering voltage so if the user only wanted to halfway release, they could flex slightly and to release the hand fully flex their muscle more. The most important changes I think would be replacing the fishing wire and testing the EMG control on different muscle groups.

Acknowledgment

Thank you to my mentor Rob Matthew and faculty advisor Professor Ruzena Bajcsy for supporting my independent research through Bioengineering 196. The BioE and EECS Departments both provided resources for this project that made it possible in addition to the HART Lab. Additionally, thanks to Hope and Gabby for working with me on the initial orthotic device and Joel Leza for mentoring us on that project.

SOURCE CODE AND DIAGRAMS

github.com/deertastic/prosthetic-hand
Relevant Files:
Final Code: combo_hand.ino
Wiring Diagram: emg wiring.fzz
Contains STL files for whippletree tensioner and the robotic prosthetic hand.

REFERENCES

[1] Siek, Stephanie. "New Prosthetic Limbs 'Celebrate' Bodies, Personalities Instead of Hiding Lost Limbs." CNN, Cable News Network, 4 May 2012, inamerica.blogs.cnn.com/2012/05/04/new-prosthetic-limbs-celebrate-bodies-personalities-instead-of-hiding-lost-limbs/.

[2] "3D-Printable Prosthetics." National Institutes of Health, U.S. Department of Health and Human Services, 3dprint.nih.gov/collections/prosthetics.

[3] grossrc. "Robotic Prosthetic Hand." Thingiverse, www.thingiverse.com/thing:1691704.

[4] "Sweep." Arduino, www.arduino.cc/en/tutorial/sweep.

[5] "PQ12-R Micro Linear Servo | Actuonix." Www.actuonix.com, www.actuonix.com/Actuonix-PQ12-R-micro-linear-servos-for-RC-p/pq12-r.htm.

[6] "L16-R Hobby Linear Actuator For RC." Www.actuonix.com, www.actuonix.com/L16-R-Miniature-Linear-Servo-For-RC-p/l16-r.htm.

[7] "ReadAnalogVoltage." Arduino, www.arduino.cc/en/Tutorial/ReadAnalogVoltage.

[8] Adafruit Industries. "MyoWare Muscle Sensor." Adafruit Industries Blog RSS, www.adafruit.com/product/2699?gclid=EAIaIQobChMI-r2nts-Z4gIV0iCtBh3nHAVBEAQYASABEgK_jvD_BwE.