EMG Prosthetic Finger

“GoGoFinger”

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Abstract

For our project we decided to make a prosthetic finger for the owner's personal use. This project was originally designed for use by one of our own senior project members and because of this we were able to design a product that best suited his needs. Although our partner has learned to live his life without three of his fingers he admitted that having a prosthetic finger would allow him to do many normal tasks with either hand he chooses. The prosthetic provides assistance in his daily activities by functioning as a normal index finger. The prosthetics can move in a complete range of motion comparable to an actual human finger while operating on its own power source. In addition, everything that is necessary to operate the prosthetic finger is stored in a single compartment allowing for ease of transportation and usability. Although originally intended for our customer, we hope our product will include a larger population in the future and continue to be improved down the line.

Chapter 1: Introduction

Accidents can occur to anyone, and sometimes people receive serious injuries such as losing a limb because of one. Losing a limb can affect the patient's everyday life and their autonomy. Nowadays, different medical companies provide numerous solutions for those who have unfortunately gone through one of these accidents including different kinds of prosthetics. Most of these very in aesthetics, range of movement, and change extensively depending on the quality of performance (i.e. speed, durability, choice of material). Prosthetics can also use different approaches to mimic the movement of human fingers and the conditions that cause them to move [5]. However, prosthetics that include more functions or have better performance prove more expensive and sometimes require surgery to attach to the patient, only increasing the overall cost even more [4]. Most prosthetics can cost up to thousands of dollars not including all of the fees associated with purchasing one (i.e. doctors, tutorials), which some patients in the United States and in developing countries can't afford.

Prosthetic fingers can provide patients with the ability to pick up a pencil and write, play piano, hold up a glass of water, type on a keyboard, and much more. Using electromyography to evaluate signals generated in the muscles by brain activity and 3D printing for the design of a prosthetic, one can create an affordable yet durable and fully functioning prosthetic. This would give patients another opportunity to perform activities on a regular basis that may have become more difficult as a consequence of a limb-severing accident.

We hope to work on and add later developments to the GoGoFinger in the future in order to improve sensitivity to the finger (i.e. better movement performance), more degrees of freedom, amplified strength of brain control, smaller components, and a quicker response time between sensors and servos. Furthermore, the use of removable fingertips with this prosthetic adds to the overall functionality. The tips can help perform other tasks easily; a removable screwdriver could help the user tighten or loosen screws, a laser pointing device for use during presentations, a bottle opener to open soda pops, a flash drive to keep important files anywhere, or a blade to open new packages. These removable tips resemble innovative additions to a regular prosthetic targeted to those who want to have the extraordinary and prepare to do even more tasks than explained above. However, these additions may also come as options for the patient in order to maintain affordability, and would result in differently priced products.

The Problem:

Many people have lost their fingers during accidents and as a result would greatly benefit from prosthetics or any of the other sources provided from a medical institution. However, as discussed above, these solutions can be extremely expensive and a lot of the times are unaffordable to the people who need them. Some agencies offer payment aid for these services, but often have strict restrictions or do not cover enough of the cost. In the case of the patient studied during this project, the index and middle finger of his left hand got severed in an accident at a young age, and he would like to be able to use affordable prosthetics that can give him back the motion in at least one of his fingers in order to learn how to assist with daily tasks such as holding a glass of water. The second image from left to right in *Figure 1* below shows, in yellow, the prosthetics that our patient would need.

Two companies, Touch Bionics and Otto Bock, focus on the market of prosthetics; one focuses on the function of the prosthetic while the other prioritizes on aesthetics. While Touch Bionics does offer i-Limb Digits, a fully functional finger-partial hand prosthetic (refer to *Figure 1*), the i-Limb hand can cost a total of $100,000 including fitting and training, making it extremely unaffordable to most. A few other companies also focus on finger prosthetics like RCM Enterprise, and Didrick Medical, however most of them provide mechanical solutions to finger prosthetics. This would allow for an affordable EMG finger prosthetic to enter the market in a positive and accepted manner by either adding this design to a company like Touch Bionics or beginning a startup.

For our project, our primary goal was to create a product that was affordable to the average consumer while also maintaining full functionality as well as looked pleasing to the eye.

The Solution:

In order for us to complete this senior project and successfully reach all of the goals we set, we needed to have a set timeline and then stick to it as best as possible. Throughout the design process we would meet up and brainstorm ideas until we agreed upon the best way to implement that part of the project. We knew early on that we would utilize a 3D printer to print all major components of the actual prosthetic finger. We also agreed upon using an EMG sensor kit as well as servo motor's found online that weren't too expensive, but still allowed for a complete range of motion as well as acceptable performance (i.e. signal strength, motor speed, response time, etc.).

Although we got the majority of our work done together as a team throughout the time this project was completed, but we still had to be individually productive and work on our own respective tasks as well. This meant that in order to be the most efficient, we had to split up tasks based on our strengths. Omar primarily handled the coding portion for this project while also spending a lot of time on determining positioning of the EMG sensors. Ernesto spent a big portion of his time tuning the servomotor and making sure it could handle the necessary load. Shane took lead on designing the housing for the electrical components as well as how the prosthetic secures to the user's hand.

We also received assistance from a couple of ours friends who had experience using Solid Works and had access to 3D printer. Thanks to this help we designed the prosthetic finger in much less time and we could print necessary components right when we needed them. Although we worked on our own respective parts at time, we couldn't have completed each task without the collaboration and ideas of all group members.

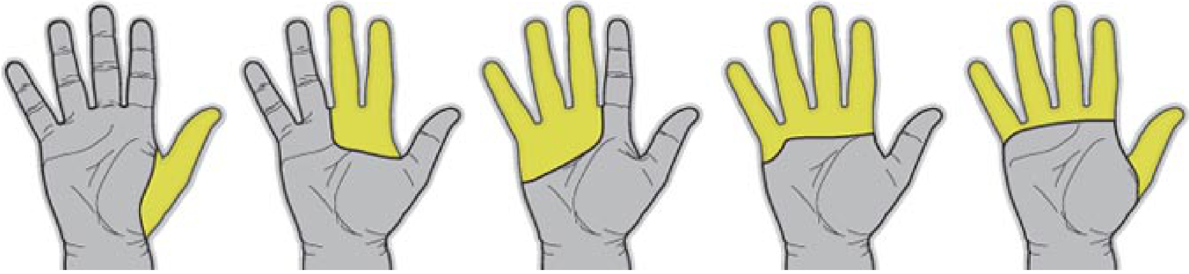

Figure 1: i-Limb Digits possible prosthetic options

Chapter 2: Design

Customer Needs Assessment

After speaking with our customer, we determined our customer's needs. The user needs two prosthetic fingers that assist with daily living by performing all of the same major motions that a normal finger would make [7]. Our project also needs to demonstrate affordability as it's number one priority and therefore requires careful selection for each individual part. In addition to affordability, the prosthetic must operate in a safe manner without exposing the user to danger. Since our customer intends to use this device on a daily basis for multiple hours at a time, both comfortableness and usability largely shape the design of our project. Lastly, our customer would like the ability to quickly change the fingertips with other tools in order to perform various tasks such as changing out screws or using a laser pointer.

Requirements and Specifications

After reviewing our customer's needs, my team came up with the necessary requirements and specifications to deliver a quality product that covers everything he asked for. Making our product affordable falls as our number one requirement. We must choose cheap sensors, mechanical components, and mold materials in order to not drive up the cost [8]. In addition to an inexpensive mechanical motor of some sort, this part must also function in a complete range of motion. To assist with the range of motion, two myoelectric sensors detect all types of movements in the hand. Lastly, additional molds created for interchangeable fingertips assist with various tasks and swap out easily. The entire prosthetic receives power from a self-contained battery power source to make our product both portable and efficient. Overall, we must ensure the safety of our user by properly testing the types of materials, the power source, and the mechanical components. Table 1 below provides a detailed list and description of all specifications as well as the requirements that drive each of these specifications.

TABLE I

GOGOFINGER REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
1-5	Total production cost less than $300	After researching potential parts for the motor, 3D printing/material, and sensors, our project doesn't exceed $300.
1,2,4	Material that can withstand 13N of force and weigh no more than 7oz.	A cheap durable plastic that lasts throughout daily use and outdoors conditions. This material gives the molds a finger like appearance.
3	Fingers bend in complete 90 degree motion [9]	Must have a mechanism that operates in a complete 90-degree motion.
1,4	Two sensors account for a complete range of movements [10]	One sensor measures the muscle twitches form the flexor while the other measures the extensor. [11] These twitches correspond to actual movement of the fingers.
1,4,6	Utilizes a 9 V Battery to power the device	The battery powers the device for up to 12 hours. Each finger requires a battery [12].
1,3,4,5,6	Interchangeable tips such as screwdrivers (Regular, Phillips), bottle opener, laser pointer	The ability to swap fingertips allows the user to perform various tasks right from the tips of their fingers. For example the user may switch between a screwdriver, pointer, or bottle opener.
1,2,3,4	A glove secures the prosthetic fingers to the user's hand.	The user wears a comfortable glove that securely connects the prosthetics to the hand while impacting their operation.
1,2,3	1.5x1/3x1/4 (inches) fingertip dimensions	Carefully sized fingertips represent proportionality to human fingers.
1.		

The requirements and specifications table format derives from [1], Chapter 3.

Level 0 & 1 Black Box Diagrams

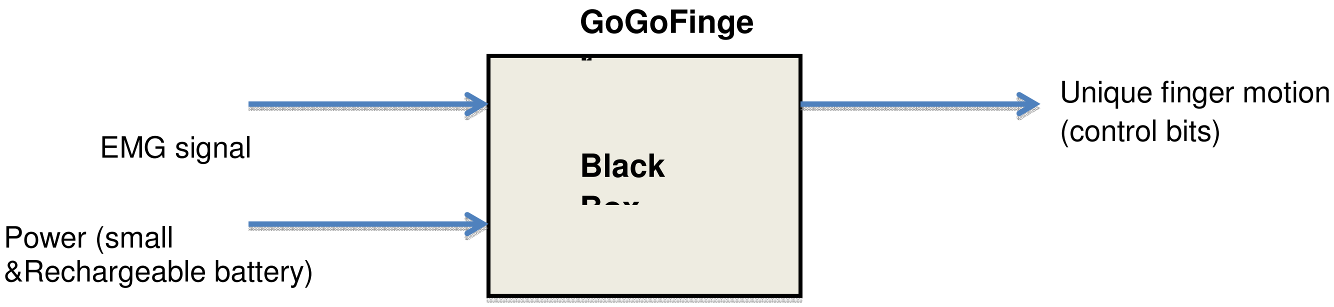

Figure 2: Level 0 Black Box Diagram for the GoGoFinger

TABLE II

Module	GoGoFinger
Inputs	- Brain signals responsible for flexor and extensor hand motions - Power, small & rechargeable battery
Outputs	- Movement of one or both prosthetic fingers
Functionality	Process brain signal to relay a unique motion to one or both prosthetic fingers.

GOGOFINGER FUNCTIONAL REQUIREMENTS LEVEL 0

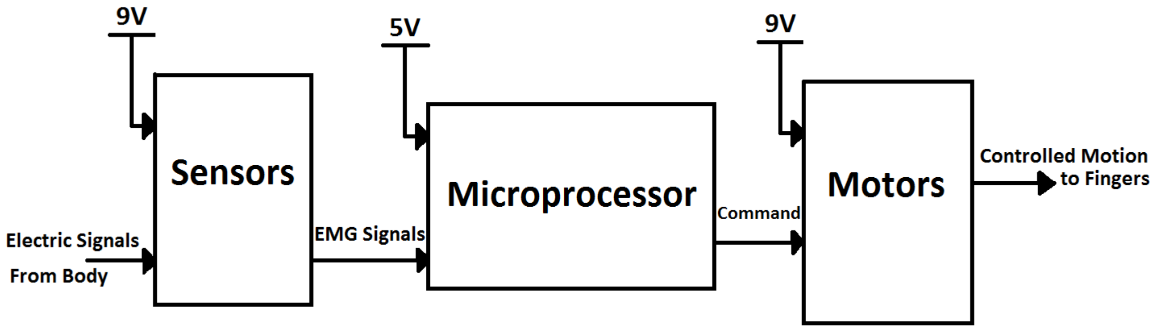

Figure 3: Level 1 Block Diagram for the GoGoFinger

TABLE III
GoGoFinger Functional Requirements level 1

Module	Sensors
Inputs	-9V from battery -Electric signals from body
Outputs	-EMG signals
Functionality	The sensors detect electric signals from the body and transfer these signals to the microprocessor
Module	Microprocessor
Inputs	-5V from battery -EMG signals
Outputs	-Digital Output to SG90 servo
Functionality	The microprocessor receives EMG signals and assigns a predetermined that is sent to the motors to set a specific shaft angle for the prosthetic fingers.
Module	Motors
Inputs	-9V from battery -Specific command
Outputs	-Motion to fingers
Functionality	The motors receive a specific command from the microprocessor, which controls how the motors produce the output motion.

Overall Design

For the overall design of our project there was a lot of brainstorming that took place. One of the references that helped us solidify the direction we wanted to take with our project is shown in Figure 4.

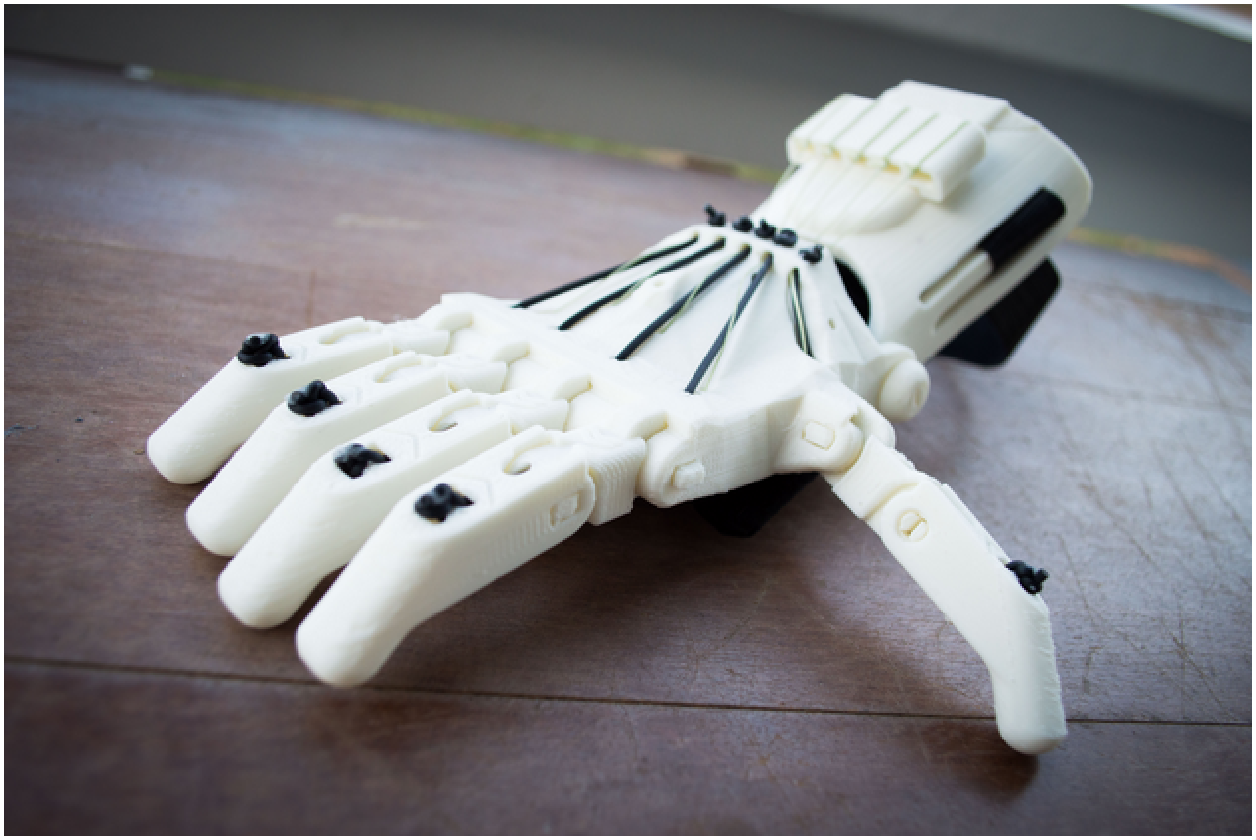

Figure 4: Artificial hand serves as model for our project

As shown in the above figure, we wanted to incorporate moving joints and strings as the primary mechanism to move our artificial hand. This image served as an example of the type of model we wanted to make.

The Finger Modeling and Printing

The first thing we had to decide upon was how to make the model for the finger that we planned on using. We brainstormed and experimented with various methods while reaching this determination, in the end, it came down to cost, viability, and availability as factors that affected our decision.

We decided on using a 3D printer to make the actual model. To create the mold that the printer would read we thought about using a mold of the customer's hand. This would work by using a molding kit that would leave the impression of a person's hand in a type of putty and then hardening clay was used to fill in the mold and create the figure. After attempting this several times, we came to the realization that this method was ineffective because the hand did not form properly many of the times. Since we felt that this would lead to noticeable inaccuracies later on, we decided to try another method instead.

Another method we considered was using a 3D scanner to create the model of the human hand and use that as the file the 3D printer would use. Unfortunately we had trouble with the availability of a scanner and we also felt there were better options to explore.

Finally, we decided to use the modeling software SolidWorks to create the file of the hand we desired to use. This would entail the team learning the basics of SolidWorks to gain an understanding of how the program worked and how we could alter files to fit our specifications. We found a file that we felt would be perfect for our needs, and proceeded to alter this file to fit our desires.

This is where our knowledge of SolidWorks came in handy to be able to alter the file and certain parameters such as orientations, lengths, diameters, etc. Figure # shows the file we altered and used for the project. We also used SolidWorks to create other objects such as enclosures.

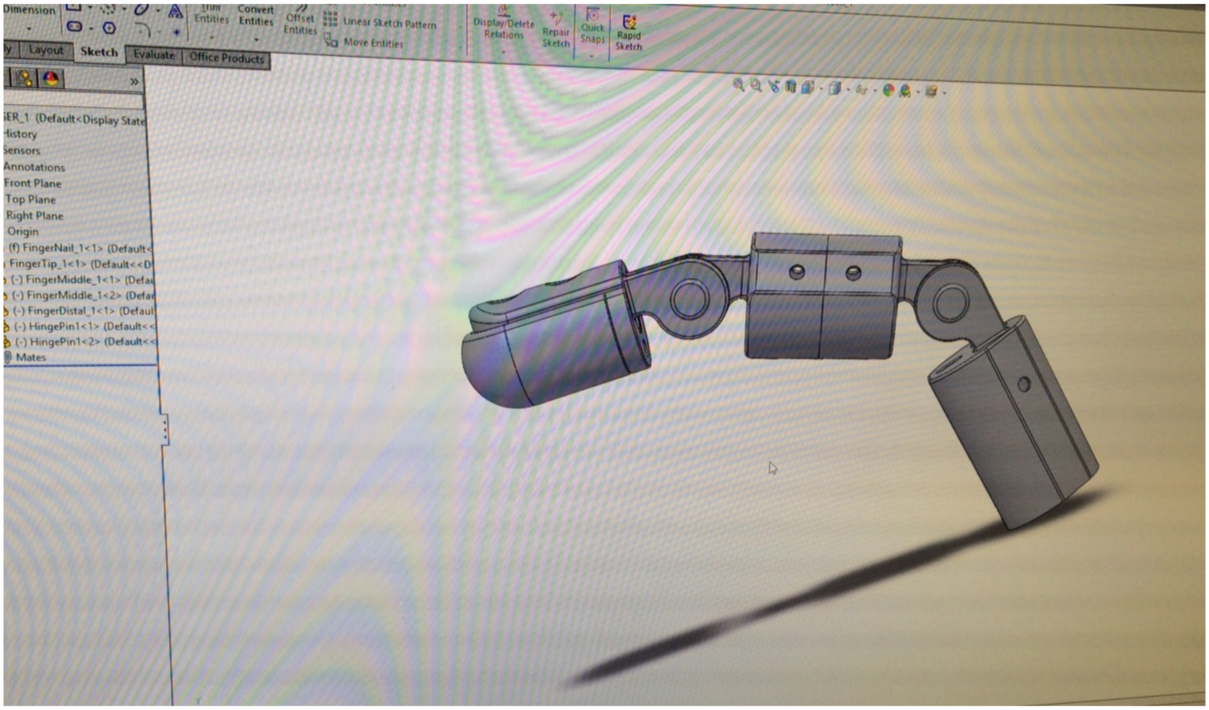

Figure 5: SolidWorks file of the hand used for the 3D printer

Controlling the Fingers

After we had an idea of what type of model we were going to use for the finger, we needed to decide how we were going to control the movement of the finger. We thought this would be best accomplished through servo motors, as they offered decent size and strength for these purposes. The also offered two directions of motion, which would allow for the flexing and extending of the finger.

Our next decision was how we were going to connect the motor to the finger. We knew it would require a material that would be flexible but also have a lot of strength so as not to snap when trying to move the finger. In the end we reached the conclusion that a string would be the best option to accomplish this task. It was light and small enough so that it would not add unnecessary weight yet could still handle the stress the motor would place on it.

Controlling the Motor

One decision we had to make early on was how the motors would be controlled. We knew early on that a microcontroller would be used to collect signals and instruct the motors how much to move and in what direction.

The kit we ordered contained a microcontroller and included software to program it. We felt this was the best course to take since it was already supplied and the software was tailored for the purpose for which we were using it.

Sending the Signals to the Microcontroller

The first part of this puzzle was how we would obtain the signals from the body to be able to decipher them via the microcontroller. We decided from the beginning to use the EMG sensors to obtain the electric impulses from the human body.

The kit we looked into and ultimately purchased contained the EMG sensors we needed as well as the necessary hardware and software to make them function within our project.

Attaching it to the Customer

After understanding how the individual parts would work, at least in theory, it was time to think of how they would come together and what would be used to hold all these pieces. At first we had considered a type of harness, but soon realized it was more difficult and time consuming than originally planned.

We finally decided on using an external glove to hold the printed finger together. The glove’s purpose would be to hold the finger steady yet not impede any movement. We also wanted to make sure it would not get in the way of the strings when the flexing or extending was taking place.

Another thing we wanted to take into account was where the motors and the microprocessor would be placed. Using SolidWorks we decided to create an enclosure that could sustain these items without providing too much bulk to the entire contraption.

Chapter 3: Build and Test

The Prosthetic Finger

The first step in building the finger that we were going to use for our project was to produce the file that would be sent to the 3D printer. As explained in the design section of this report, we obtained a file that was similar to what we needed and then modified the necessary parts to fit our needs. After we were satisfied with our design it was printed using the 3D printer shown in Figure 6.

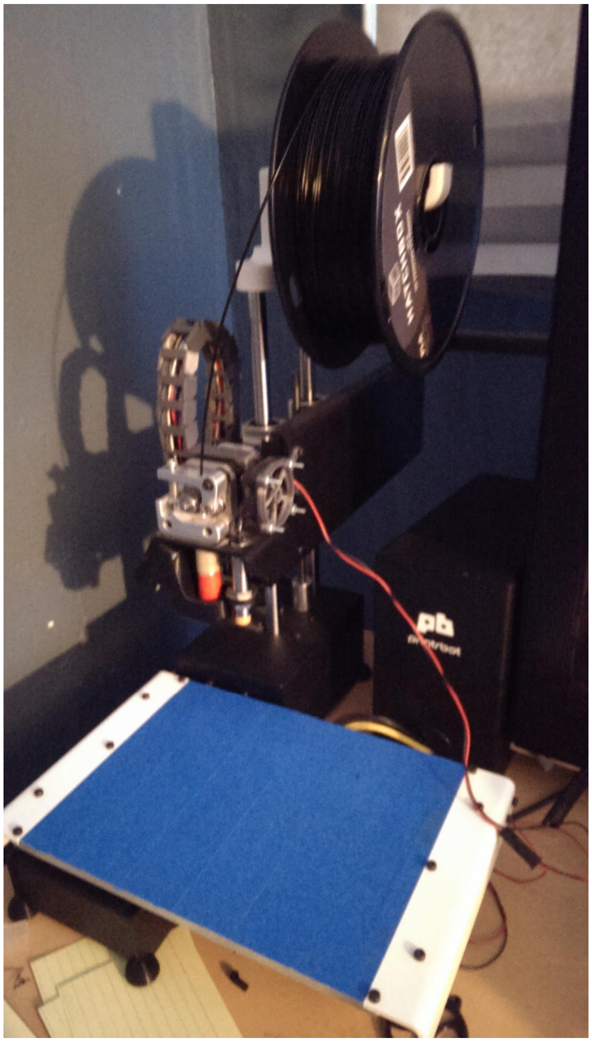

Figure 6: 3D Printer used to print the components of our project

There were multiple printings that needed to be made before we were satisfied with the results. Some of the problems had to do with the printer itself, such as deformed parts and parts that cracked during the process due to the thinness of the initial design.

We also had to reprint the bottom joint of the finger after realizing that the overall finger was too large. Using SolidWorks, we modified the distal and middle joint to a shorter length and reprinted this piece again.

Figure 7 shows the SolidWorks model of one of the joints that attaches directly to the finger stub on the human hand.

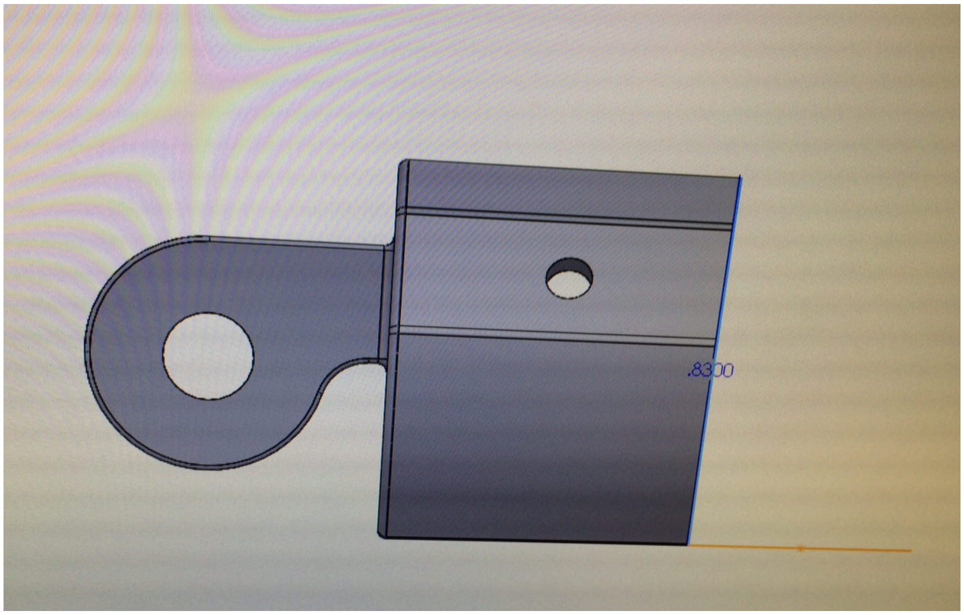

Figure 7: SolidWorks design of a finger joint

A complete representation of all the joints and how they connect are shown in Figure 9.

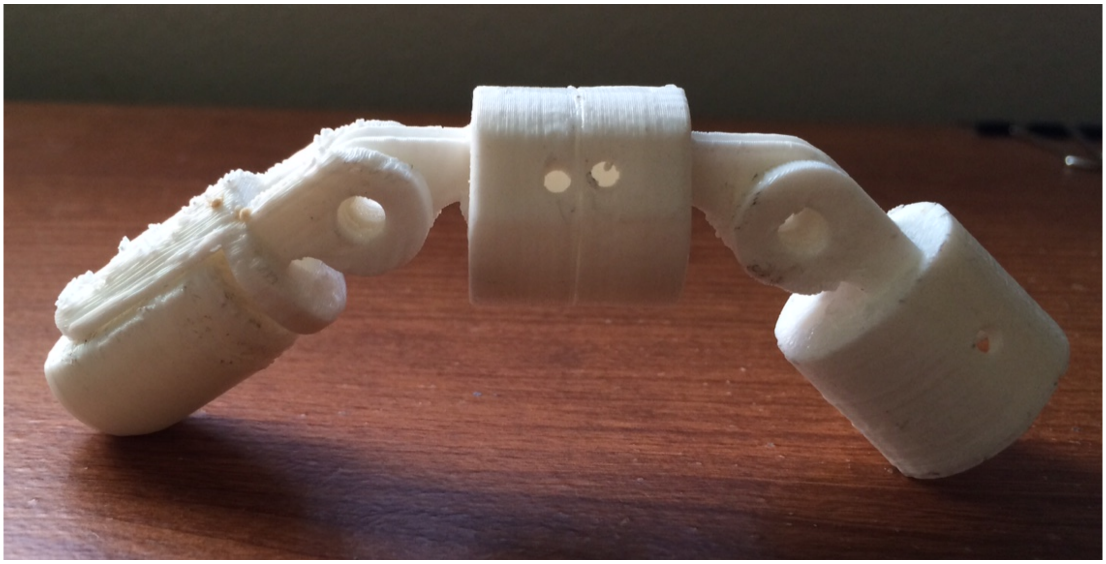

Figure 8: The finger joints and the layout of the finger

After having all the correct and desired pieces, it was time to assemble the finger. We found that metal screws worked adequately for this and used two large screws for the joints and two smaller screws to hold the removable tip.

The next step was to thread strings through the joints that when pulled would control both joints in one direction. In theory we wanted to have two strings: one going under the joints to control bending the finger and one above the joints to control extending the fingers.

We realized that when extending the finger the string did not generate enough torque, and we solved this problem by using another string over the joints to provide more leverage. This seemed to fix the problem. Figure # shows what the assembled finger looks like.

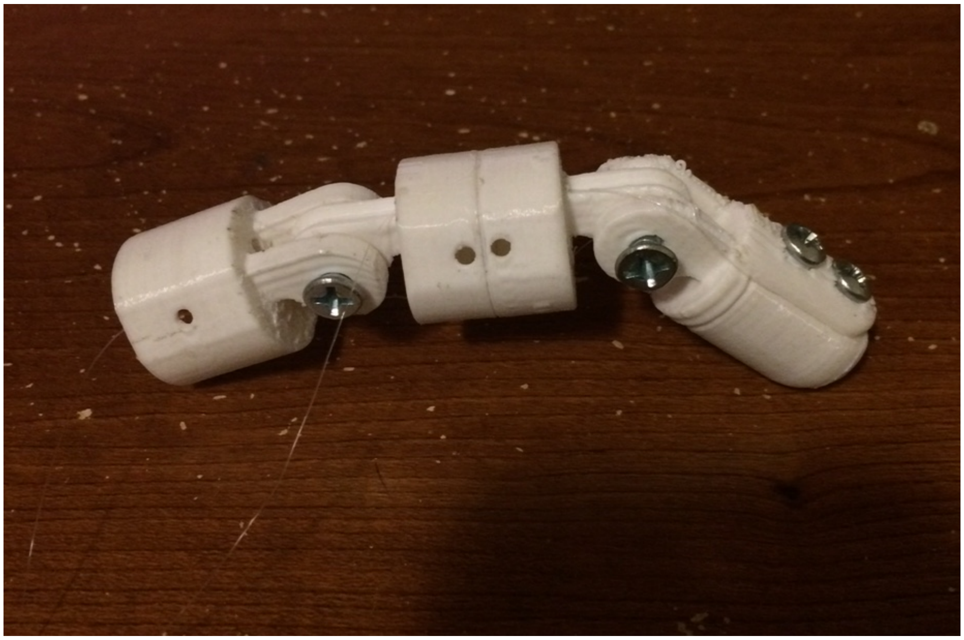

Figure 9: Assembled finger with metal screws and strings

EMG Sensors

The EMG sensor that we decided to use for this project was ordered from Sparkfun and created by Advancer Technologies. The reason for selecting this exact sensor was due to the good reviews that people gave it online and after talking with people who had experience working with it, we decided it would be a good fit for our project. This EMG sensor also had a great price compared to many of the high-end sensors on the market. We originally planned on using an EMG sensor from BITalino, but ran into several problems that made it difficult to interface with our microcontroller.

Figure 10: DSP display of EMG showing relaxed state (low digital value)

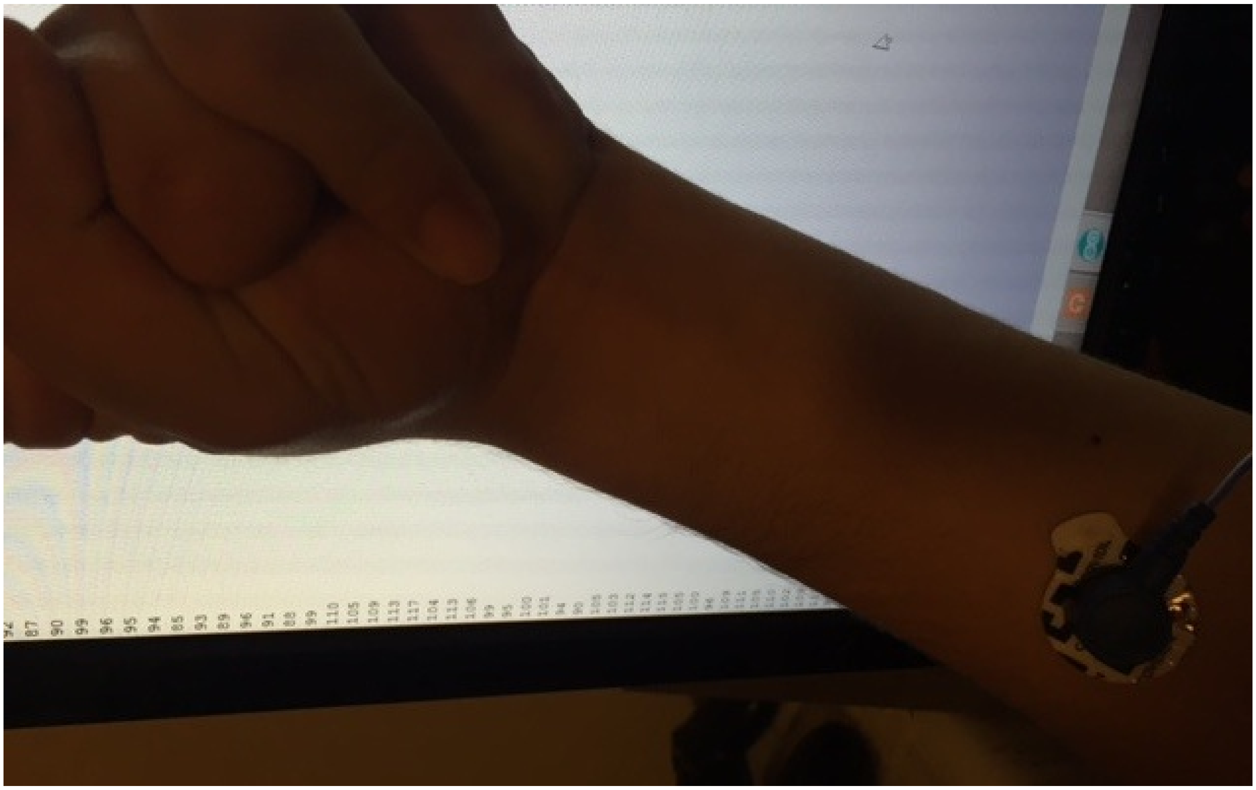

Figure 11: DSP display of EMG showing muscles being flexed (high digital value)

The EMG sensor was tested using the DSP software that is provided by Arduino. Figures 10 and 11 above show two different readouts of the DSP software. One shows the user's arm as relaxed showing no digital input, while the other shows the user clenching his fist and the digital readout shoots to a high value. The software is used to see a digital representation of the analog signals we would be using to communicate with the microcontroller. Once we properly connected the sensor to the software we were able to clearly see the signals coming from the body. The toughest part about using the EMG sensor is figuring out the most precise location for placing the three electrodes in order to ensure the strongest signal with the least amount of noise. One of the three electrodes used during testing can be viewed in Figure 12 below. The software greatly assisted with the location of the electrodes because we could clearly identify which parts of the arm strengthened or added noise to the signal.

Figure 12: Sample electrode used to receive EMG signals

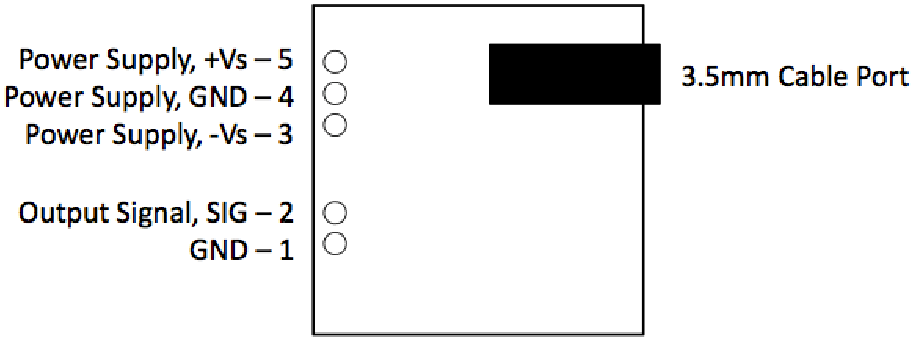

Figure 13: Pin layout for EMG sensor from Sparkfun

Figure 13 above shows the relatively simple pin layout used to configure the EMG sensor. This sensor receives power from two 9V batteries with their negative terminals being connected to the reference pin on the chip. The use of two 9V batteries can also be used to power the microcontroller and therefore requires us to only need a single power source for our prosthetic finger.

Testing the Motor

To test the motor, we first simply connected it to the Arduino to make sure we could control the movement. Once we were assured we could power it correctly and that it was moving according to the commands provided with the code, we then incorporated it to the whole project.

The actual movements of the motor did not give us too much trouble, and instead we spent much of the testing time adjusting the movement of the motor so that it corresponds to the appropriate rotation of the gears and the appropriate pull of the strings.

Figure 14: Servomotor used to control the string movement

One of the issues we ran into was that the motor and the strings produced mixed results sometimes. Sometimes it worked fine and other times the motor could not generate enough torque to pull the string. After adding two strings this problem was minimized.

Coding

The Arduino Pro Mini used in this project communicates with the EMG via UART at the analog pin A1. The SG90 servo was controlled using digital pin 0 of the board. The Arduino IDE software for coding was useful to us as it has a servo.h library saved, which included helpful functions to attach the servo to a certain pin, and write to the servo the angle of the shaft to which we want to move it towards.

The shaft angle was determined by looking at the serial monitor, available in the Arduino software, and matching the baud rate at which the UART serial is set to in the code, in this case 9600, as the speed seemed to work best with the response time of the servos. Furthermore, the length of the strings leading to the prosthetics from the servo were modified to improve the flex and extend process and make it flow with the code. A delay was also used to make sure that the processing speed did not mismatch with the time it takes for the SG90 servo to receive the signal and the time it takes for the shaft to reach the appropriate angle.

Since the servo’s period is 20ms and the duty cycle is 1-2ms, as shown in *Figure 15* taken from the SG90’s datasheet, the delay chosen was set to 20ms to give the shaft enough time to adjust too. These delays can be reduced through a lot more testing to minimize the response time of the prosthetic.

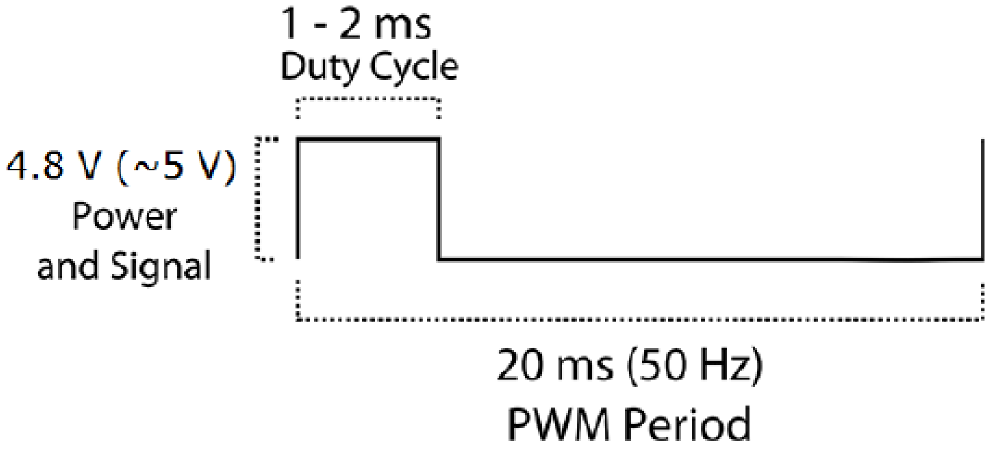

Figure 15: SG90’s period and duty cycle

To begin the code, it was appropriate to check each component separately to make sure everything worked independently before moving into the whole system. Using the serial monitor on Arduino, we were able to observe the digitized signals coming from the forearm and to the EMG. Once were able to observe a good flex response on the monitor and close to 0 when at rest, and got the code to sweep the shaft back and forth or get to a certain position, the system was put together by writing “if” statements to set the shaft of the servo to a certain angle according to the analog signal received from the EMG. To set the limits on these, minimum and maximum values were found and testing was needed to see which ranges of signals could be controlled more accurately by the patient. In this case four limits were used; below 20, 20 to 70, 70 to 130, 130 to 200, and above 200. Each range was set so that as the patient increased the amount of flex force used, the prosthetic fingers would be able to flex as well.

```
#include <Servo.h>
const int analogInPin = A1;  // Analog input pin
int EMGValue = 0;        // value read from the sensor

Servo servo1;

void setup() {
  // Tells Arduino a Servo is connected at Pin 9, Digital Pin 0 on the board
  servo1.attach(9);
  // Initialize UART comm at 9600 baud rate
  Serial.begin(9600);
}

void loop() {
  // read the analog in value:
  EMGValue = analogRead(analogInPin);
 // Relaxed State
  if (EMGValue<20) {
   servo1.write(0);
   delay(20);
   }
 // Level 1 Flex
  else if (EMGValue<=70) {
   servo1.write(45);
   delay(20);
   }
 // Level 2 Flex
  else if (EMGValue<=130) {
   servo1.write(90);
   delay(20);
   }
 // Level 3 Flex
  else if (EMGValue<=200) {
   servo1.write(135);
   delay(20);
   }
 // Level 4 Flex
  else {
   servo1.write(180);
   delay(20);
   }
  // print the results to the serial monitor:
  Serial.println(EMGValue);
}
```

Chapter 4: Results

Right from the start we learned that were would be multiple aspects to this project. In looking at the overall design of our product we had to consider how it was going to look, how it was going to function, what type of materials to use, what were its limitations and so much more. We also quickly learned that it is the design process that takes up the majority of our time devoted to this project. The more effort we put into brainstorming ideas and thinking of every possible way we could go about doing something, the more it paid off when it came down to the build and test stages. When one thing suddenly stopped working or we couldn't figure out what went wrong, it was very helpful to have other ideas to fall back on instead of remaining stuck on one. Another major takeaway was being able to efficiently use our time and being able to split up tasks and work independently, but also knowing when to rely on our group members for help.

By the end of this project we were able to successfully create a product that fulfilled what it was originally intended to do. Our two primary goals were to keep it cheap and affordable and also ensure that the user's daily living would be improved by the use of this prosthetic finger. We also were successful in creating a prosthetic that could be easily transported and also remain in use during transportation. In order to do this we had to come up with a way to self power the device and make sure the power source lasted long enough during continuous use. Although we originally agreed to use a lithium ion battery, we decided upon two 9V batteries that were more compatible with both the sensor and microcontroller after modifying the EMG component of our project. We were also very happy with the range of motion for our prosthetic finger, even though the result is not highly consistent and varies on the position and other movement of the hand. We were originally worried that the hinges in our design would inhibit the finger from extending out all the way. However, after numerous printings and adjustments made in SolidWorks, we made a product that moved exactly how we intended it. Overall, this was a great project because it tied together multiple areas of our electrical engineering coursework as well as even introduced us to things we had yet to see.

Bibliography

[1] R. Ford and C. Coulston, *Design for Electrical and Computer Engineers*, McGraw-Hill, 2007, p. 37

[2] *IEEE Std 1233, 1998 Edition*, p. 4 (10/36), DOI: 10.1109/IEEESTD.1998.88826

[3] Yuanqing Li; Zhu Liang Yu; Ning Bi; Yong Xu; Zhenghui Gu; Amari, S.-I., *"Sparse Representation for Brain Signal Processing: A tutorial on methods and applications,"* Signal Processing Magazine, IEEE , vol.31, no.3, pp.96,106, May 2014

This source comes from an IEEE scholarly magazine regarding various brain signal processing methods and applications. Our project must process various brain signals, but we do not exactly know how to go about doing this yet. This article gives us a good insight into brain signal processing and various ways of doing so. Because this article came directly from an IEEE journal, it has enough credibility for use in this assignment.

[4] Wikipedia contributors. "Electromyography." *Wikipedia, The Free Encyclopedia*. Wikipedia, The Free Encyclopedia, 14 Sep. 2014. Web. 21 Oct. 2014.

-This Wikipedia article gave us a fundamental overview and understanding about electromyography, which we plan on using to develop our project.
-The article cites 25 references and the body uses technical and professional wording.

[5] Yunhui, Liu. "Systems and methods for reproducing body motions via networks". U.S. Patent 8 738 122, May 27, 2014.

- In this patent the authors reproduce body motion using a system that contains sensors used to capture electromyography signals. This system resembles the work we plan to do with sensors should we choose EMG sensors. The patent provides another example of how to go about our project.
- An officially issued patent. Also, professors in the subjects of Computer Science and Mechanical Engineering and Robotics designed this method.

[6] Shurr, Donald G.; Michael, John W. *Prosthetics and Orthotics*, 2nd ed. Bergen County, Prentice Hall, 2001.

- This textbook serves as a reference for us on the topic of prosthetics. It describes the various mechanics that go into this topic.
- The author presents this textbook in a professional, detailed, and informative manner.

[7] Prochazka, A., *"Comparison of natural and artificial control of movement," Rehabilitation Engineering, IEEE Transactions on,* vol.1, no.1, pp.7,17, Mar 1993

This article, published in an IEEE magazine, discusses a study that received a patent for its work comparing the similarities and differences between artificial and natural control of movements. This article helps us explore how the human brain interacts with movements of limbs and how to reciprocate those interactions for an artificial application. This publication includes numerous references as well cited by 24 different articles.

[8] N.A.A. Razak, N.A.A. Osman, H. Gholizadeh, S. Ali, **"***Development and performance of a new prosthesis system using ultrasonic sensor for wrist movements: a preliminary study"* BioMed Central Ltd, 23 April 2014

Although this article explains prosthetic developments and performances for a wrist instead of a finger, the methods still apply. The method discussed in the article known as mechatronics relies on using ultrasonic sensors along with two servomotors to control the motions of the wrist. A well-known biomedical journal magazine known as BioMed Central published this article as well as international recognition gives this article credibility.

[9] Goldfarb, Michael, Skyler A. Dalley, Huseyin A. Varol, and Tuomas E. Wiste. *"Control System for Jointed Mechanical Device."* Vanderbilt University (Nashville, TN), assignee. Patent 8,840,680. 23 Sept. 2014.

This US patent details one method for a control system application for Jointed Mechanical Device. Our senior project requires the ability to operate in a large field of motion and using a control system may represent one way of doing so. This US patent reflects a quality source not only because it provides technical support for each claim, but also gives references to verify their claims.

[10] Advancer Technologies, *Three-lead Differential Muscle/Electromyography Sensor for Microcontroller Applications,* 4 February 2013

This datasheet for an EMG Sensor directly relates to our project. One idea of ours includes using two EMG sensors to track the brain signals corresponding to muscle movement. This datasheet provides early insight into the limitations and capabilities that come with using an EMG sensor. Because this specific datasheet came from Advancer Technologies, it holds as a credible source. Advancer designs and sells biomechatronic technologies and other sensors.

[11] Lichter, P.A.; Lange, E.H.; Riehle, T.H.; Anderson, S.M.; Hedin, D.S., *"Rechargeable wireless EMG sensor for prosthetic control,"* Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, pp.5074,5076, Aug. 31 2010-Sept. 4 2010

The artice provides in depth analysis of an EMG sensor for use in prosthetic control including both advatnages and disadvantages for this specific sensor. Since we have considered using two EMG sensors for processing brain signals this article provides us with helpful information regarding these types of sensors. This article, cited one time, also includes plenty of professional references to verify the information.

[12] D. Gow, M. MacLachlan, C. Aird, "*Chapter 9 – Reaching with electricity: externally powered prosthetics and embodiment"* Churchill Livingstone, 2004 p. 155-168

Our original plan included a self-contained battery that powered the device. However, this chapter from an academic textbook provides alternative methods for powering prosthetics including external methods. Churchill Livingstone publishes numerous academic textbooks and proves as a credible source for this particular application.

[13] Wikipedia, *Acrylonitrile butadiene styrene,* 15 October 2014

A Wikipedia webpage for ABS plastic applies to our prosthetics. We have contemplated using ABS as one possible material for our prosthetic fingers. This webpage gives detailed information regarding all aspects of ABS and backs the information by providing plenty of relevant sources.

[14] M. Singh, *"Ceramic integration and joining technologies: from macro to nanoscale,"* Hoboken, NJ: Wiley-American Ceramic Society, 2011

This book covers various techniques for joining and integrating ceramic and ceramic-based materials covering all sorts of applications including a section on prosthetics. Our project requires interfacing between multiple parts including ceramics, motors, and sensors. This book provides insight and design ideas for integrating our necessary project components. This book demonstrates credibility through the credibility of its publisher as well as the extensive experience and background of the author.

[15] "Three□lead Differential Muscle/Electromyography Sensor for Microcontroller Applications" *Advancer Technologies*. February 2013. http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Biometric/Muscle%20Sensor%20v3%20Users%20Manual.pdf

- This details a sensor that poses potential use in our project. The datasheet and manual present the information concerning the sensor.
- Manufacturer of the sensor produced the document.

[16] Duque, G.J.E.; Munera, P.A.; Trujillo, C.D.; Urrego, H.D.A.; Hernandez, V.A.M., *"System for processing and simulation of brain signals,"* Communications, 2009. LATINCOM '09. IEEE Latin-American Conference, pp.1,6, 10-11 Sept. 2009

This article from an IEEE conference explains a specific method used for brain signal processing. In order for our prosthetics to move, they receive instruction in the form of a brain signal. This article provides us with a good start in how to process brain signals and apply it to our project. This article, published through the IEEE website, also comes from an IEEE conference. This document also includes plenty of references to support its claims as well as referenced by another article.

[17] Villegas, J.M.; Rodriguez, J.L.; Vega, Y.; Mejia, D.A.; Medina-Santiago, A., "Real time simulation of arm prosthetics through a myoelectric sensor," *Information Systems and Technologies (CISTI), 2014 9th Iberian Conference on* , vol., no., pp.1,4, 18-21 June 2014

- This article specifies work using myoelectric sensors to simulate arm prosthetics, which resembles our senior project and offers lots of helpful ideas. It also includes information on using SolidWorks for the modeling.
- Article comes from an IEEE conference and the authors include professors in relevant areas of study.

[18] Dermitzakis, K.; Arieta, A.H.; Pfeifer, R., "Gesture recognition in upper-limb prosthetics: A viability study using dynamic time warping and gyroscopes," *Engineering in Medicine and Biology Society,EMBC, 2011 Annual International Conference of the IEEE* , vol., no., pp.4530,4533, Aug. 30 2011-Sept. 3 2011

- This article deals with ways to recognize gestures in prosthetics, which we use for our project and thus this provides lots of helpful information.
- Article comes from an IEEE conference by authors working in a research lab.

[19] Van der Riet, D.; Stopforth, R.; Bright, G.; Diegel, O., "An overview and comparison of upper limb prosthetics," *AFRICON, 2013* , vol., no., pp.1,8, 9-12 Sept. 2013

- This article provides information about the current commercial products involved with upper-limb prosthetics. It provides useful information on current technologies in the field.
- Article comes from an IEEE conference by authors working at the School of Mechanical Engineering at a university in South Africa.

[20] Eleni, A., "Control of medical robotics and neurorobotic prosthetics by noninvasive Brain-Robot Interfaces via EEG and RFID technology," *BioInformatics and BioEngineering, 2008. BIBE 2008. 8th IEEE International Conference on* , vol., no., pp.1,4, 8-10 Oct. 2008

- This article provides information about neurorobotic prosthetics and how brain signal processing works. This helps us to better understand our own project's use of brain signals and how we incorporate it to our sensors.
- Article comes from an IEEE conference by authors working at the Department of Biomedical Information at University of Central Greece.

[21] Andersen, R.A.; Burdick, J.W.; Musallam, S.; Scherberger, H.; Pesaran, B.; Meeker, D.; Corneil, B.D.; Fineman, I.; Nenadic, Z.; Branchaud, E.; Cham, J.G.; Greger, B.; Tai, Y.C.; Mojarradi, M.M., "Recording advances for neural prosthetics," *Engineering in Medicine and Biology Society, 2004. IEMBS '04. 26th Annual International Conference of the IEEE* , vol.2, no., pp.5352,5355, 1-5 Sept. 2004

- This article simply provides interesting information on neuron technology and new methods for improving the recording of this information. It gives us information on the internal workings of our EMG sensors.
- Article comes from an IEEE conference by authors working at various departments at Cal Tech. It also has 12 citations.

[22] Xu Zhang; Xiang Chen; Yun Li; Lantz, V.; Kongqiao Wang; Jihai Yang, "A Framework for Hand Gesture Recognition Based on Accelerometer and EMG Sensors," *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on* , vol.41, no.6, pp.1064,1076, Nov. 2011

- This article describes a project dealing with hand gesture recognition. This describes the use of EMG sensors, which we may use, as well as an accelerometer we think may prove itself as a useful addition to our project.
- Published in an IEEE journal article by authors working in the field. It also has 17 citations.