Robotic Hand Controlled by Myoelectric Signals

By:
Kyle Staskus
Daniel O’Bryan

Senior Project
Electrical Engineering Dept.
California Polytechnic State University
San Luis Obispo
2014

Table of Contents

Appendix

List of Tables and Figures:

Tables:

Figures:

Abstract

In this project we developed a prosthetic hand that is controlled by myoelectric signals from the forearm. The forearm signals were filtered and amplified to be easier read by a microcontroller. The microcontroller then generated signals to control the mechanical hand based on these myoelectric input signals. This is done by the microcontroller increasing the pulse width sent to several servos making up the hand. The larger the pulse width the more flexed the hand becomes until it reaches the maximum programmed into it. In order to open the hand the high input to the microcontroller must be deactivated and then reactivated for the pulse width to begin decreasing.

Several designs and products are currently available online as complicated limbs and hands for amputees, however many of these can be costly and heavy. This project has taken inspiration from these designs with the goal of reducing cost and weight without sacrificing functionality. One major advantage of our project is the dry reusable electrodes used to capture the myoelectric signals in the forearm. The silver coated cloth functions as an electrode with the help of a pushbutton from a tarp making kit. This electrode is reusable and remains in the same place in the sleeve it is sewn into for ease of use.

I Introduction:

This project captures the myoelectric signals in the forearm, and uses them to control a robotic hand.This capture is done through the use of a silver coated nylon fabric sewn into an athletic compression sleeve. This combination of materials produces a reusable and dry electrode array that the sensor can be attached to, and maintains the electrodes on the same contact point through many uses. The signals from the forearm are amplified to be easier to see and manipulate through the use of a filter. The signals are then passed through a Schmitt trigger to clear up the jumpy signal received from the forearm. The output of this Schmitt trigger is a digital high or digital low to be interpreted by a microcontroller. The 5V high is interpreted by the microcontroller to being changing the pulse width. To have a slow and easy motion the high signal starts incrementing a variable by 1. The variable is bounded by the maximum and minimum values of the modulated pulse. The longer the pulse is high the more the servo closes the hand. This operation maintains the constant period while only increasing the high time of the pulse. In order to open the hand the signal must go low, then return high. This triggers the variable decrementing by 1 until it hits the maximum low point or the input signal returns to the low state. As a replacement to a human hand it must work without inconveniencing the user. The hand must operate from an external battery for portability, and so the user can replace it if needed. By modifying the amplifier before the Schmitt trigger the system can be made to work on exclusively battery power, however this was not implemented in the final test iteration. Finally the hand must mimic the many motions of the human hand. This hand can accomplish fine enough motions to pick up objects and not destroy them.The hand has enough strength to hold a cup upside down, and not too much strength to crush the cup.

The electrical engineering concepts required to finish this project are numerous and cover many areas of the subject. Analog systems are necessary for construction of the driver circuitry for the servos and the filter circuitry for the input. Digital systems exist in the programming of the microcontroller and integration of the sensor. Finally power analysis determines the maximum battery life and linear voltage regulators for the systems power requirements.

II Requirements and Specifications

This project requires that the robotic hand function similarly to the prosthetics currently available to amputees. This hand has the ability to open, close, and grab objects. All while being similar to a normal human hand, without being too complicated to use. This hand is designed to operate with a smaller budget than its more advanced counterparts. As a replacement to a human hand it functions for a large portion of the day, and has a replaceable battery source for the required components. Finally it must not restrict the mobility of the user either in size, proximity to power, or aesthetics. Appendix C contains the engineering specifications related to these requirements and needs of our customer.

The customer for this project will most likely be missing a hand or have use for a mechanical hand. With this in mind the device should only require the use of a few muscle signals, ideally in the forearm or bicep. The user of this device likely won’t have an expert technical knowledge, therefore simple maintenance and operation is required. The device is a prosthetic used for a large portion of the day. Therefore long battery life is a must. The device itself should function as a replacement for the users missing hand without adding additional difficulty to their daily routine.

III Design

The inputs of this system are the myoelectric signals from the forearm, the outputs are the movements of the hand. The system currently uses multiple 9V batteries to power the microcontroller and the servos. The locations of the signal sensors differ for each customer but stay in the same location without the customer moving them once they are set. As long as the user places their arm in the same orientation and location as when the system was calibrated the sensors and system should work as intended.

Figure 1: Basic Block Diagram

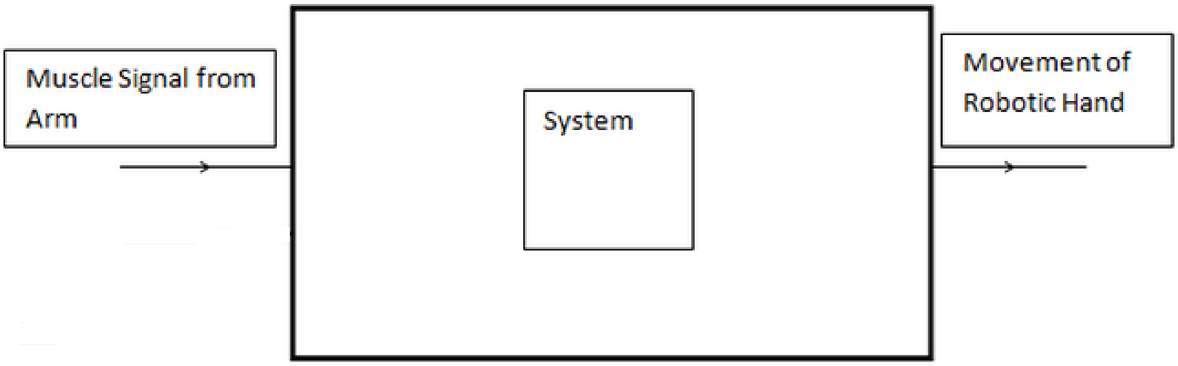
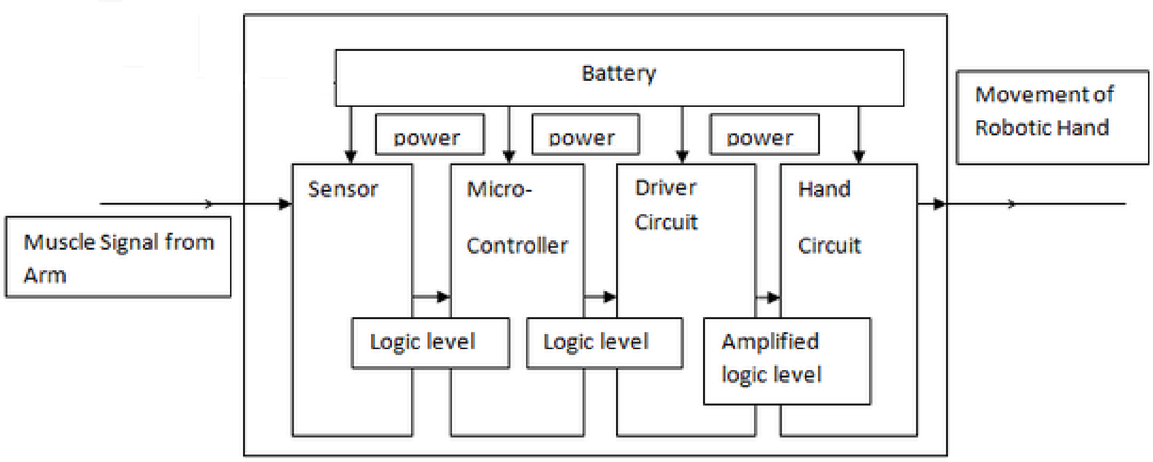


Table 1: Input/Output Table

Input	Muscle Signal from inside arm
Output	Movement of robotic hand out
Function	The system takes signals captured in the arm and outputs them as movement fro the robotic hand mimicking the motion made by the user

The sensor picks up the signals from the user’s arm. This sensor sends the signals it picks up to a microcontroller and the microcontroller interprets the signals it receives. The microcontroller itself does not have the current driving capabilities to move the robotic hand alone. This requires a driving circuit in order for the signals from the microcontroller to drive the servos and moving parts in the robotic hand. Finally, the robotic hand mimics the motions of a human hand based on the input signal. This entire circuit runs off 9V batteries, meaning several 9V are required to source enough current to drive all the parts for an extended period of time.

Figure 2: Detailed Block Diagram



EMG Sensor and Location

In order to get the signals from the wrist that control movement, we needed to find the signal locations in the arm. These can be seen in **Figure 3** below. In order to control each finger, the EMG must be able to pick up each finger movement without too much noise from other fingers moving.

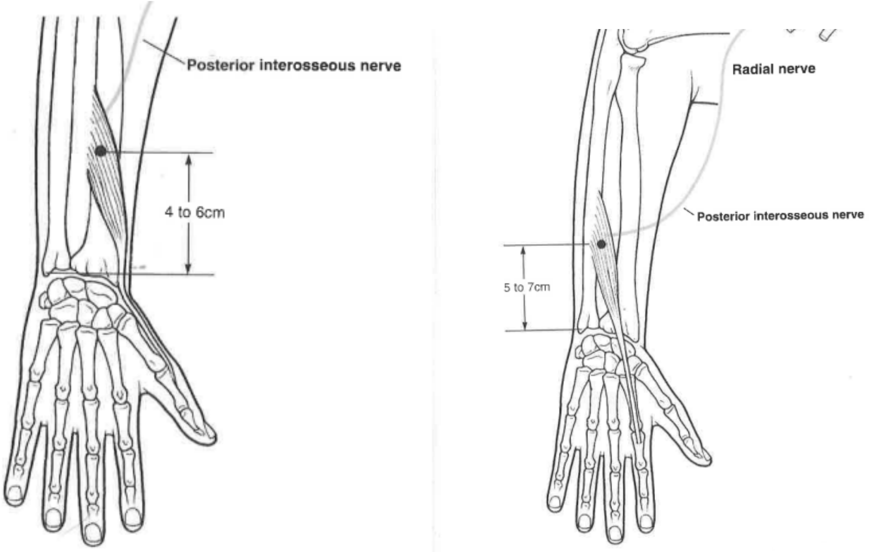


Figure 3. Muscle Signal Locations For Thumb (left) and Index Finger (right).

For this project, only three fingers are desired to get an idea of the possible movement. This means that we want the thumb, index finger, and pinky finger to control the individual fingers. This would involve three sensors placed in the spots of the black dots in **Figure 4.**

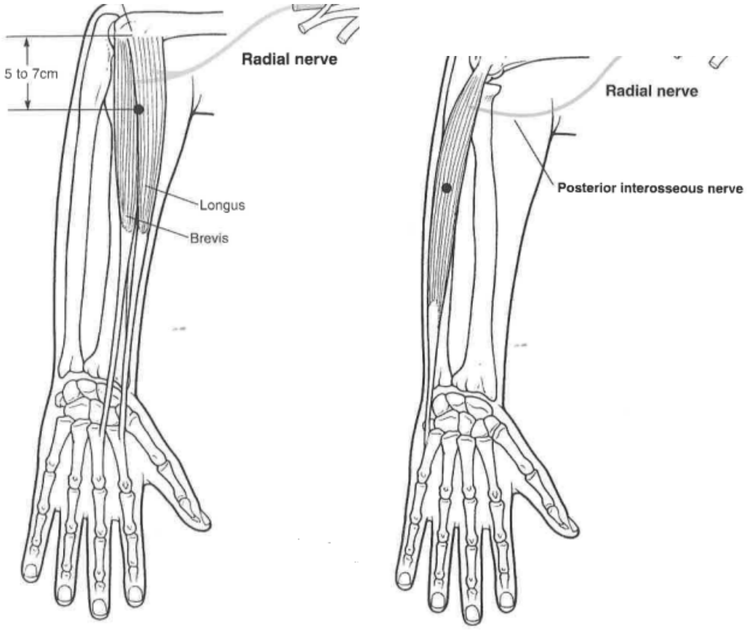


Figure 4. Muscle Signal locations for Index and Middle Finger (left) and Pinky finger (right)

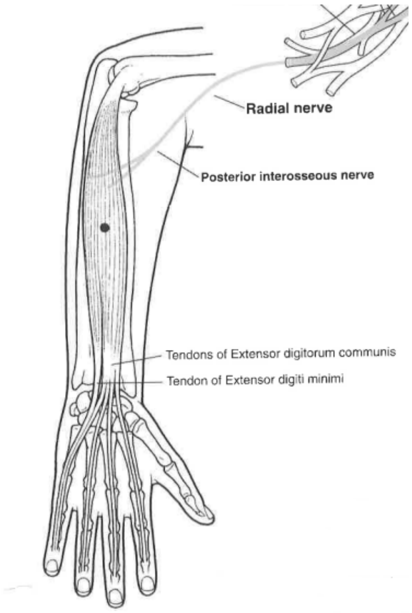


Figure 5. Muscle Signal location for Multiple Fingers and Wrist

Wet EMG sensors are sticky and only usable until they lose their sticky underside. This is an impractical design for a product that will be worn daily. Ideally, a reusable EMG sensor is desired. We attached a metallic cloth to an armband, which holds the cloth to the skin and works as a sensor, reading electrical signals from the muscles on the skin. This works as a dry electrode that is machine washable and more user friendly than the wet sensor counterparts.

Amplifier

The signal coming out of the sensor was at too low of a voltage to be of use to the microcontroller input from initial testing. The minimum voltage level for the Arduino microcontroller input was 3.3 V, with the sensor voltage reaching a maximum of about 1.5V peak and holding at around 500 mV. An amplifier with an amplification of 3 amplifies the signal so it is more useful and easier to discern the high’s from the low voltages.

Schmitt Trigger

The amplifier was not enough to get a clean signal to the Arduino, so a Schmitt trigger was used so the Arduino either got a high signal of 5 V or a low level of 0V. The Schmitt was designed to trigger a high at around 4 V. This meant the Arduino got the high signal of 5V until the amplifier output reached below about 1 V, which set the schmitt trigger low and gave the Arduino a low signal. This helps to clear up the signal so the noise from the sensor would not affect the Arduino's performance.

Microcontroller

The microcontroller used was an Arduino Uno due to the availability, known power required(1 9V battery for 3 hrs), and ease of use. The microcontroller takes in the Schmitt trigger output to an input pin. The microcontroller then used whether or not the signal was a digital high or a digital low to decide on the width of the pulse width modulation output on an output pin. This pulse width varied from 600 us to 1.2 ms over a period of 20 ms. The code for the microcontroller can be found in Appendix B.

Driving Circuit

The microcontroller is unable to power 9 servos by itself since it can only output 40 mA per pin. A driving circuit is required for each servo, meaning a buffer between the microcontroller and the servo. So we sent the signal to multiple buffers and each then sends the signal and the current required to the servo. A simple op amp buffer is the current design and accomplishes this task.

Servos

The servos are what open and close the hand. They are small mechanical motors that take an input from the microcontroller, power from the driving circuit, and move based on that input. We built the fingers of the hand with the servos as a different method from other hands which function off of strings. This makes the hand stronger and more durable and the design as a whole a bit less messy. However a design objective was to not have the motors be too strong that they crush objects, but strong enough to not drop them either.

Hand

To design the hand, we took a model mannequin hand for a base and built the fingers from the structured palm of the hand. To save in cost, we have only three fingers, each with three joints, to close and grab objects. This build is not as aesthetically pleasing as was anticipated however functions as a prototype.

IV Integration and Testing

Parts List
6 LMC662
6 LM 317
6 Battery clips
6 batteries
9 Tower Pro MG90S
1 Mannequin Hand
1 CMOS Hex Core Inverter Chip
1 Compression Sleeve
1 ft Silver Coated Nylon Cloth from lessEMF.com
1 Sparkfun EMG Sensor
1 Arduino Uno
1 Dual Power supply

Before the system was integrated, each component was tested individually to make sure it worked and to limit the difficulty of finding a problem. Once each component was tested, it was integrated into the whole system and tested again with the other parts. This was done with each individual part to find problems early and quickly.

EMG Sensor and Location
During testing, it was concluded that the Electromyography (EMG) sensor chosen for this design was not sensitive enough to pick up only the individual fingers for movement. This lead to a design change to only use one sensor since we were able to get a strong and distinctive signal when only monitoring the extensor digitorum communis. The figures shown below in **Figure 6 and 7** show the muscle used and the sensors placed on the forearm. The red sensor is the high sensor, meant to find the high part of the voltage difference, with the blue being the low voltage sensor, and the black sensor on the elbow is the reference node, or ground node.

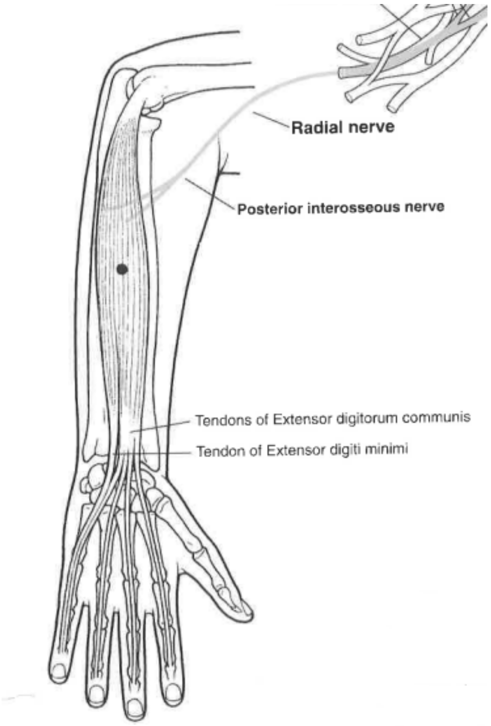


Figure 6. Muscle Signal location for Extensor Digitorum Communis

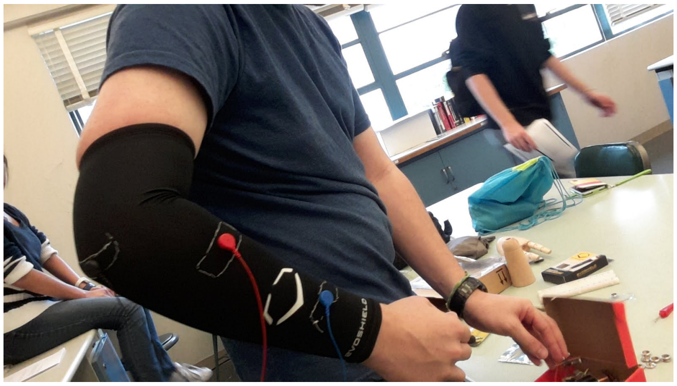


Figure 7. Locations Used During Project

With this setup, we were able to get a stable and repeatable useable signal that we had control over. For the reusable sensors, we were able to use a compression sleeve with silver coated cloth used underneath to make contact with the skin.

Amplifier

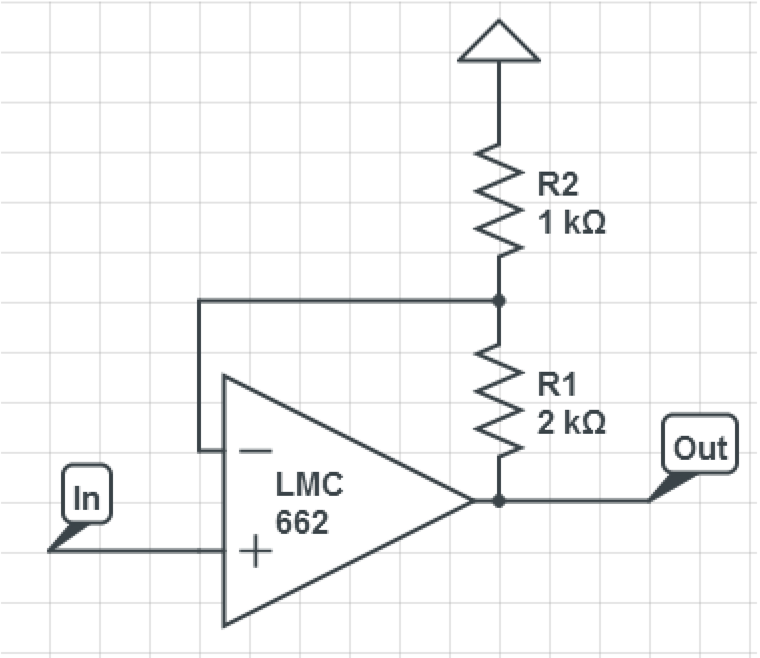


Figure 8. Amplifier Circuit

This amplifier circuit was designed to amplify the input signal by 3 times through the resistor divider connected to the negative terminal of the op amp.

Schmitt Trigger

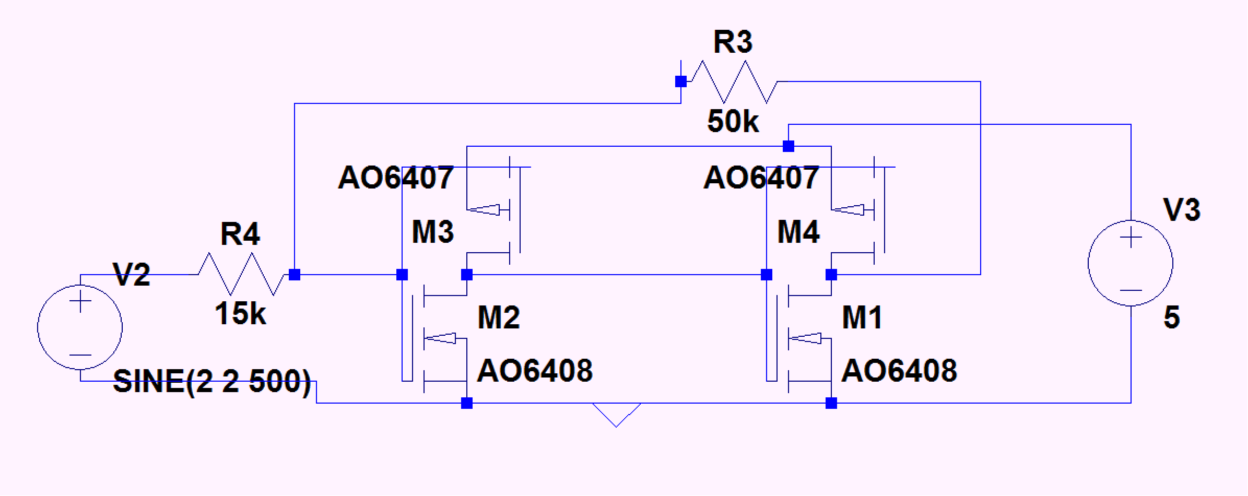


Figure 9. Schmitt Trigger Circuit

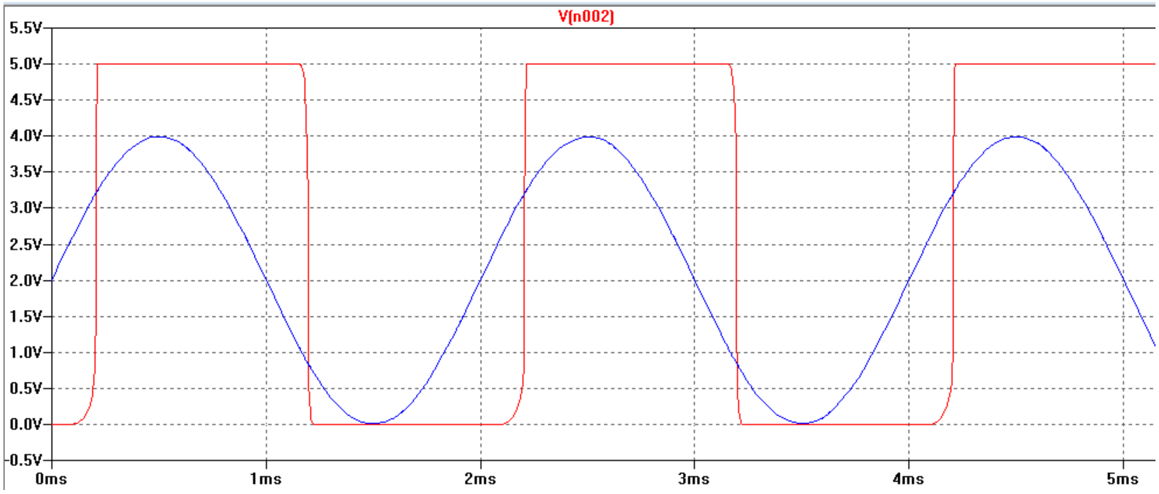


Figure 10. Schmitt Trigger Performance

The Schmitt trigger was simulated and the performance is shown in **Figure 10**. When connected to the input of the amplifier, we found the Schmitt trigger gave us the high value and low value we wanted. When using the sensors as the input to the amplifier, we were able to get a high value when the wrist muscle was flexed, and a low when the muscle was relaxed, with little error.

As shown from the performance of the Schmitt trigger shown in **Figure 10**, the Schmitt trigger triggered at around 3.3V from a low value of 0 V to a high value of 5V. Once the value output from the amplifier dropped below 0.7 V, the Schmitt trigger fell from it's high value to the low value. This design was close to the original design and was only slightly tweaked to fit our desired values better.

Driving Circuit

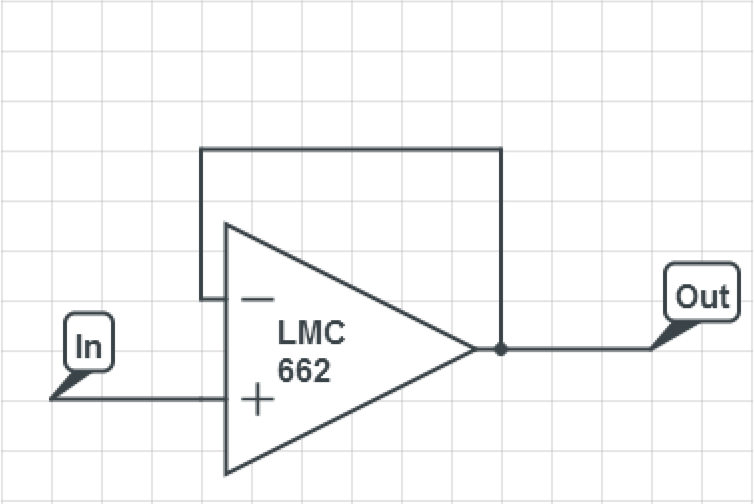


Figure 11. Buffer Driving Circuit for Servos

Since the Arduino was not capable of sourcing the current necessary to power the all the servos, an op amp buffer was used to buffer the signal to each servo. The Arduino can source 40 mA maximum while the servos use about 500 mA when making a large transition. A total of 9 buffers were used to cleanly send the signal to all 9 servos.

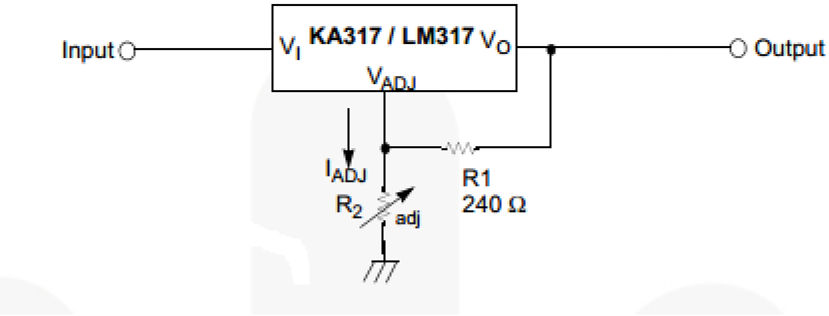


Figure 12. Voltage Regulator Schematic

Using 9V battery rails meant that a voltage regulator was required in order to drop the voltage to the 5V necessary to power the servos. The Voltage Regulator shown in **Figure 12** shows the circuit required to drive two servos. Each two servos required it's own battery to source the current necessary to transition properly, meaning 5 voltage regulators were used with 5 batteries to power the servos.

Servos

A servo less than two inches long was needed to function for the size of a hand, the weight had to be less than 20g to not make the hand heavy, yet strong enough to function properly. The chosen servo was a MG90S gear servo, typically used for hobby vehicles. A Voltage of 4.8 V was used to power the servo. The servo needed a Pulse Width Modulated wave (PWM) with a period of 20 ms and a pulse width between 400 us to 2400us. However, for the range of motion used, our servos pulse width varied between 600 us to 1200 us. These servos have a torque of 30.6 oz-in, strong enough to hold cans and bottles without crushing them.

Figure 13. Servo Used to Control Hand

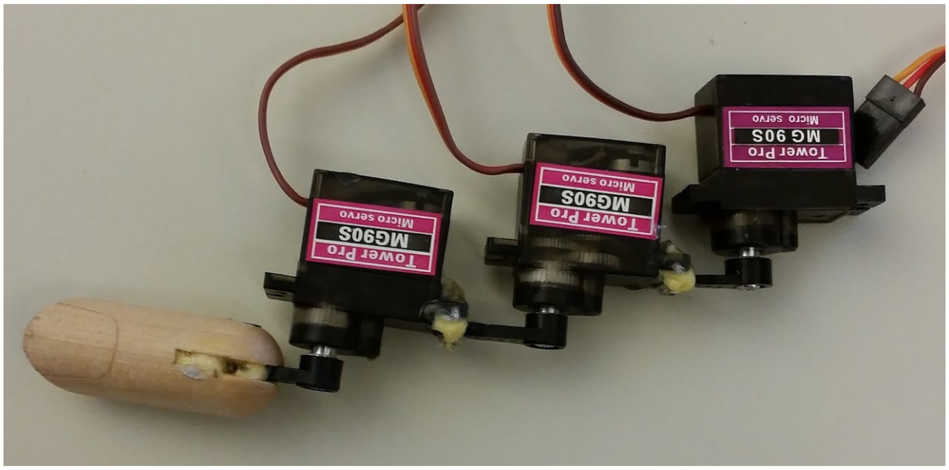


Figure 14. Servos Used in Hand

Testing concluded that for convenience sake the servos were capable of running on a 5V rail with a 5V peak PWM wave without issue.

Hand

The hand was the hardest part to construct. A base for the hand was found online as a mannequin hand shown below in **Figure 15**. From this base, we removed all of the fingers, replacing the wooden joints with eye screws to make the fingers more sturdy, and only used the slots for the index finger and the pinky finger. We then found the best place for the thumb and screwed that to around the middle of the palm. However, this proved difficult to attach the servos to, so we had to redesign.

Figure 15. Base Mannequin Hand

The second idea was to use wooden spacers between the servos and the hand to better secure the servos to the hand. This meant the servo had a screw through the plastic parts, through a wooden spacer which was screwed to the hand, and then to the part of the hand we wanted it to be secured to. However, this as well was rather difficult and prohibited servo movement. Different size spacers were attempted however the result stayed the same. A third design was then considered.

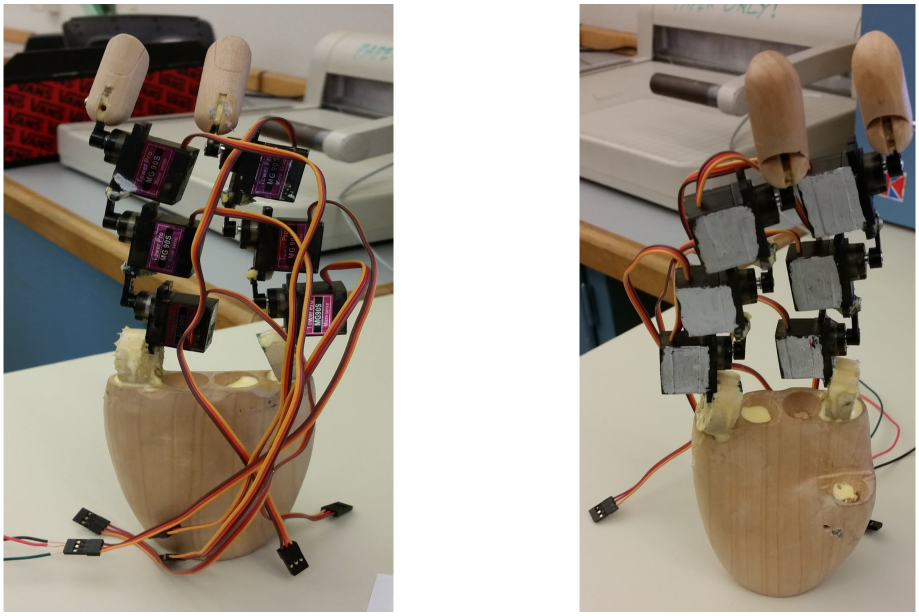


Figure 16. Servos Attached to Hand, Two Fingers

Instead of using the fingers that came with the mannequin hand, the servos were going to serve as the joints with the final joint being a fingertip. This can be seen in **Figure 16**, and the final hand in **Figure 17**. This configuration gave us the full range of a hand opening and closing, being about the same size as an adult male hand, and the amount of strength and grip desired.

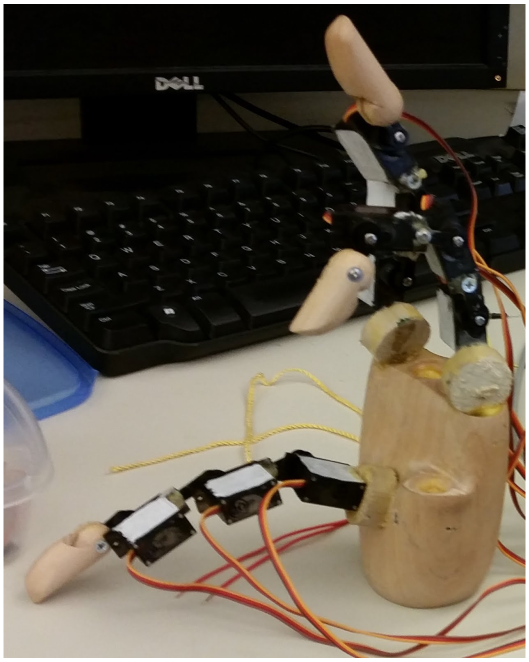


Figure 17. Completed Hand with Three Fingers

V Issues and Conclusion

Issues

Many of the issues throughout this project originated from the EMG sensor. The sensor was extremely fickle, working sometimes and not others. When first testing during the day, the sensor would work and we would progress with our project, but after an hour or so, the sensor would quit working and would need to be moved for a while until it worked again. The cause of this could not be determined.

At present, the entire system still needs a power supply due to this sensor not operating on a negative rail made from the batteries. When attempting to create a split supply source with positive and negative rails, while the design seemed to work, when connected to the sensor circuit, the rails were not at their proper values. Multiple attempts were made however a solution was not found. This error can be eliminated by adjusting the gain in the stage after the sensor and operating it using two batteries at +/- 9V.

This project has a lot of room for improvement in many different areas. The current hand, while working, could be made to be more aesthetically pleasing, have a wider range of motion, and could be made to be stronger without being too strong.

A different sort of sensor could be used. The reusable sleeve appeared to work well, however the actual emg's and the chip were a problem. Designing a working emg and reading circuit would vastly improve the functionality of this project, as well as removing the need for a split power supply.

The project currently runs on a power source and 6 batteries. This makes the hand a lot bulkier and heavier. Reducing the power draw on each battery from the servos could solve this problem, or replacing the servos with another type. Designing servos for this purpose could be a good approach to reducing power draw, need for multiple batteries, and increase the strength of the hand.

Using the servos as the actual finger joints seemed to give the hand more strength than those controlled by strings. This shift works well for the hands holding of objects.

Conclusion

There is a lot of room for improvement in this project, however as a prototype it does its job and is mostly portable with only one fix needed. This was a combination of multiple areas of engineering combining to create a finished project. The result of this project was to produce a low budget robotic hand. This project was completed for under the 400 dollars available through the electrical engineering department. This cost is less than one tenth the price of the leading myoelectric prosthetic, and one tenth the cost of those available online.

VI References:

[1] ATMEL, “8 Bit AVR Microcontroller,” ATmega328P datasheet, Oct. 2009

Will inform on use of microcontroller when learning how to interpret signals from arm.
The datasheet associated with the use of a microcontroller made by the people that made the microcontroller.

[2] Tan, Desney, Dan Morris, Scott Saponas, and Ravin Balakrishnan. Recognizing Gestures from Forearm EMG Signals. Microsoft Corporation, assignee. Patent 20090327171. Dec.Jan. 2009. Print.

Patent by known company. Information contained in this patent may lead to useful information on the design process.

[3] Adams, Amy. *The Muscular System*. Westport, CT: Greenwood, 2004. Print.

Book used to discuss biology useful in finding the nerves and weight of a human arm.
used in biology classes at cal poly

[4] Kim, Jonghwa, and Stephan Mastnik. "EMGbased Hand Gesture Recognition for Realtime Biosignal Interfacing." *IEEE* (2010): n. pag. Print.

IEEE article peer reviewed and useful in understanding picking up signals in the human arm.

[5] "How Products are Made." *How Artificial Limb is Made*. N.p., n.d. Web. 21 Oct. 2013.

Discuss how artificial limbs are made and has useful steps in the manufacturing process. Talks about a known process for the creation of prosthetics

[6] Williams, Adam. "Mindcontrolled Permanentlyattached Prosthetic Arm Could Revolutionize Prosthetics." *Mindcontrolled Permanentlyattached Prosthetic Arm Could Revolutionize Prosthetics*. Gizmag, 29 Nov. 2012. Web. 21 Oct. 2013.

Discussion on the uses of nerve signals in the control of circuits. Peers reviewed journal article

[7] Advancer Technologies, “Three Lead differential muscle/electromyography sensor for microcontroller applications,” Muscle sensor v3 datasheet, Feb, 2013

Datasheet for muscle signal sensors. Datasheet from company.

[8] Adee, Sarah. "Dean Kamen's "Luke Arm" Prosthesis Readies for Clinical Trials." *IEEE*

Spectrum. IEEE Spectrum, 1 Feb. 2008. Web. 21 Oct. 2013.

IEEE article discussing the current existing technologies and their uses. Peer reviewed IEEE article

[9] Fildes, Jonathan. "Bionic Hand Wins Top Tech Prize." *BBC News*. BBC, 06 Sept. 2008. Web. 21 Oct. 2013.

News story discussing bionic hand picking up signals. Reported by credible news agency.

[10] "World Premiere of Muscle and Nerve Controlled Arm Prosthesis." *ScienceDaily*. ScienceDaily, 22 Feb. 2013. Web. 21 Oct. 2013.

Article discussing nerve signal detection and use. Peer reviewed article of known website.

[11] “TowerPro MG90 - Micro Servo”*ServoDatabase.* ServoDatabase, Web. 5, Feb. 2014

Datasheet of the Servo’s used. Gives the basic information and specifications of the servo needed in order to operate the servo.

[12] “Arduino Uno”, *Arduino.* Arduino. Web. 11, April. 2014

The datasheet and specifications of the microcontroller used for the project. This is the information from the makers of the microcontroller.

[13] Leis, A. Arturo. Trapani, Vicente C. “Radial Nerve” *Atlas of Electromyography*, New York, Oxford University Press, 15, Feb. 2000, pp *46-58.*

Book on the nerve locations in the arm for possible use of emg locations. Very detailed pictures and published by a reputable source.

Appendix A - ABET Senior Project Analysis

Project Title: Robotic Hand
Student's Name: Daniel O'Bryan **Student's Signature:**
Kyle Staskus

Advisor's Name: Tina Smilkstein **Advisor's Initials:** **Date:**

Summary of functional requirements:
The robotic hand operates from signals picked up in the arm. These signals travel to a microcontroller and control the movement of the hand. This hand works similar to a human hand and has strength capable of grabbing and moving objects.

Primary constraints:
Numerous challenges to this project exist and each requires its own attention. First the sensors must pick up a small deviation in electrical signal from the arm and influence the reaction of a circuit. The device itself must lift and grab objects. This requires a more sturdy hand than one produced by simpler technologies. Each finger of the hand must withstand a certain weight. The hand itself limited to the maximum weight a human arm can support for extended periods of time ideally no more than the weight of a human hand. Finally the circuit cannot achieve temperatures far greater than those considered comfortable for a human to withstand.

Economic:
Human capital required for the project is limited to the hours worked by delivery personnel to deliver parts and hours spent designing and testing hand circuits by us and our advisor. Financially this project requires enough capital to pay for parts and the shipping costs of those parts. The project requires IC chips and circuits made by other companies increasing cost. Minimal Earthly resources construct this project. Wood made up the larger parts. Silicon and common elements make up all IC chips and premade circuit. Costs will most likely appear during build and test cycles when redesigning and tweaking occur, and additional parts necessary for the operation of the hand are ordered. This project will require initial startup costs paid by the California Polytechnic University of San Luis Obispo in no less than 400 Dollars. Below are initial estimates on how this 400 Dollars will be divided and used.

Manufacturing on a commercial basis:
This device will have limited customers and as such will not sell many devices per year after its initial burst of purchases. Additionally the winding down of US foreign wars limits the number of soldiers returning home with amputated hands. These factors contribute to the device selling no more than 1000 units per year after the initial burst of purchases from current amputees with no working alternative. Each device has a manufacturing cost of the components plus the cost for designing the project and man-hours of manufacturing. 500 dollars per device purchase price covers all costs. This 500 dollar cost leads to a profit per device of 50 dollars after subtracting parts cost and labor costs. This leads to a profit per year of 50000 dollars and every year after the initial burst of an estimated 200000 dollars. The device ideally uses 9V batteries, rechargeable can be used, and has a limited upkeep cost for the user. No warranty will be offered on the device.

Environmental:
Environmentally this project has very low impact. Aside from the rare earth metals needed for the battery and the silicon needed for the ICs there are only common substances used such as wood. This project impacts domesticated animals as with this product amputees gain the ability to play fetch with their dog and toss mice for their cat. This improves the mental health of these pet owners and causes them to exert more physical effort in their day to day lives making them more healthy in general. This project does not negatively impact the environment unless put into large scale manufacturing where it utilizes too many natural resources.

Manufacturing:
This product cannot be easily tested as it requires modeling on a specific user’s arm and differs for every user. This makes spot testing for errors very difficult. To address this issue a trained technician must attach the unit and a manual for how to modify the device must accompany every unit. The device has a possible test procedure involving a synthetic arm composed of a flesh like material implanted with electrodes. This test however cannot be conducted until further funding and a proof of concept for the overall design has been established.

Sustainability:

The device itself requires maintenance to continue functioning properly. The device will have a battery which will gradually lose maximum charge and must be replaced. The many moving parts of this device require maintenance similar to any mechanical part. The buyer or a third party company pays to maintain and repair the device. This project suffers from ecological issues. The devices used in this project will not be made from entirely recycled materials, or made in a manner with no waste. After initial developments the profits of the company will be used to produce advances in the technology of the hand. The hand will ideally become more sensitive to the attempted motions sent through the nerves in the arm. Ideally the hand itself will become capable of finer motions, instead of being able to pick up a child’s building block it could pick up a pencil. This project has lots of room to advance with a larger budget and less time constraint.

Ethical:

Ethical issues with the project include the Utilitarian goal of providing the best hand for the cheapest cost to the users. This robotic hand must not endanger its user and those around him, therefore it should not be able to squeeze down too strong. This hand must not completely replace a human hand and should not be marketed as such. The design for this will be available to the public making it fully capable of critique by several peers. Finally this hand must not do anything above or beyond that of a normal human hand to prevent those seeking to abuse it in some way.

Health and Safety:

The main goal of this product is to keep the user safe and to keep those they interact with safe as well. Health wise this product must replace the functionality of a human hand without harming the user in any way. There must not be adverse side effects to using the robotic hand; any side effect negatively impacting the life of the user defeats the purpose of the product. The product itself will undergo extensive testing before being put on the market for customer use to prevent any unforeseen health issues.

Social and Political:

This project improves the lives of all amputees capable of purchasing and maintaining it. It offers them greater function than any similar product on the market for a smaller cost. Stakeholders in this project only gain the knowledge that they aided in the humanitarian improvement of life for amputees. Those without access to this device due to monetary reasons will be aided with current medical aid tools in place.

Development:

I have learned of a simpler driving circuit due to EE 409. Also through clever placement of the sensors on the arm more accurate signal detection is possible. I must also review work with microcontrollers and sensors in order to produce the proper response when a signal is sensed. Finally I will need to research into the human arm, in order to replace one I should first understand what it is I intend to replace.

Appendix B - Arduino Code

```
  /*
  Hand Control Code
 Creates a Pulse Width modulation at 50 Hz with the pulse width changing based on
whether or not the sensor is reading high.
 Due to the need to delay both microseconds and milliseconds, both the normal delay and
delaymicroseconds was used since there is
 an error when only using delaymicroseconds. So the code delays for the necessary width
in microseconds, then the rest of the 50 Hz
 cycle is calculated with k and z and delayed.
  */
int x = 600; //counter joints
int z = 0; //delay variable
int k = 0; //Microsecond delay variable
int on = LOW; //whether the wrist is sending a signal or not
int part = 0; //whether the hand should open or close (open when part = 0, close when part =
1)

void setup()
{
  pinMode(5, INPUT); //Setting input pin
  pinMode(13, OUTPUT); // Setting Output pin
}

void loop()
{
  on = digitalRead(5); //Beginning of the loop finds if the sensor is reading high or low

  k = 0; // resetting k

    // First Part where the hand closes.
if (part == 0 && on == HIGH)
  { part = 1;
    while(x >= 560 && x <= 1200 && on == HIGH) // while the sensor reads high, close the
hand at a medium speed
    {
      if(x < 1000){
        digitalWrite(13, HIGH);
        delayMicroseconds(x); // Changes Joint 1 Duty Cycle to move servo
```

```
        digitalWrite(13, LOW);
        k = 1000 -x;
        delayMicroseconds(k);
        z = 20000-x;
        z = z/1000;
        delay(z);
       }

      else if(x >= 1000){
        k = x-1000;
        digitalWrite(13, HIGH);
        delay(1);
        delayMicroseconds(k); // Changes Joint 1 Duty Cycle to move servo
        digitalWrite(13, LOW);
        z = 1000-k;
        delayMicroseconds(z);
        z = 19000-k;
        z = z/1000;
        delay(z);
       }
      on = digitalRead(5);
      x = x + 1;
    }
  }

   // Second part when the hand opens
else if (part == 1 && on == HIGH)
  {
      part = 0;
    while(x >= 600 && x <= 1300 && on == HIGH)//While the sensor is on again, open the
hand at a medium speed
    {
      if(x < 1000){
        digitalWrite(13, HIGH);
        delayMicroseconds(x); // Changes Joint 1 Duty Cycle to move servo
        digitalWrite(13, LOW);
        k = 1000 -x;
        delayMicroseconds(k);
        z = 20000-x;
```

```
     z = z/1000;
     delay(z);
    }

   if(x > 1000){
     k = x-1000;
     digitalWrite(13, HIGH);
     delay(1);
     delayMicroseconds(k); // Changes Joint 1 Duty Cycle to move servo
     digitalWrite(13, LOW);
     z = 2000-k;
     delayMicroseconds(z);
     z = 19000-k;
     z = z/1000;
     delay(z);
    }
   }
   on = digitalRead(5);
   x = x - 1;
  }
 }

else{ // keep the hand at the current level, not opening or closing
 if(x < 1000){
  digitalWrite(13, HIGH);
  delayMicroseconds(x); // Changes Joint 1 Duty Cycle to move servo
  digitalWrite(13, LOW);
  k = 1000 - x;
  delayMicroseconds(k);
  z = 20000-x;
  z = z/1000;
  delay(z);
  }

  else if(x > 1000){
   k = x-1000;
   digitalWrite(13, HIGH);
   delay(1);
   delayMicroseconds(k); // Changes Joint 1 Duty Cycle to move servo
```

```
    digitalWrite(13, LOW);
    z = 1000-k;
    delayMicroseconds(z);
    z = 19000-k;
    z = z/1000;
    delay(z);
   }

}
}
```

Appendix C - Specs And Requirements

TABLE I

ROBOTIC ARM REQUIREMENTS AND SPECIFICATION

Marketing Requirements	Engineering Specifications	Justification
1	Less Than 15-20 Lbs	Must weigh less than or equal to arm it replaces
2	Rigid attachments less than 1 mm from where signals are picked up	Must find signals without customer knowing how it works
3	Less than 10 % error in signal detection	Must not have errors in distinguishing signal in arm from ambient noise
4	Operates without being wired to a nonmoving power source	Must be able to move with person for practicality
5	Must not get hotter than 85 Degrees F	Must not get too hot for user to continue wearing
6	Must be able to hold onto 10 lbs without error	Has to be able to replace a human hand in holding of objects
7	Device digits must follow human digits to within 1 cm	Has to work as a replacement for a hand and have full range of motion similar to actual hand
8	Device must respond within 25ms of users arm signal generation	Cannot lag to severely behind users input
9	Must not be capable of exerting more than 20 lbs of force	Must not crush or damage delicate objects accidentally
10	Able to withstand minimal water and temperature changes	Must function in a variety of different weathers

Marketing Requirements

1. Light Enough to carry with one arm
2. Easy to attach and use
3. Picks up signals from your arm muscle
4. Portable and non restrictive
5. Comfortable to wear
6. Strong enough to hold light objects
7. Works similar to a human hand
8. User had fast reaction time not slowed down by device
9. Cannot be a danger to user or those around user
10. Must work in a variety of temperatures for dependability

Appendix D - Gantt Chart