Electrical Engineering Senior Design: Affordable Prosthetic Hand

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I. Introduction

Low cost prosthetics are important because 80% of people with amputations are in developing nations, while less than 3% of them have access to affordable rehabilitative care. The prosthetic hand we are going to build can be used for evaluating sensor-motor control and can be built for around $500. This hand will be able to fit into standard prosthetic sockets, facilitating amputees the integration of a useful prosthetic into their daily lives.

II. Problem Statement and Proposed Solution

Currently the e-NABLED team is constructing mechanically operated prosthetic hands, but the problem with those type of hands is that they have a low usability. This means that patients are not able to use their hands for everyday purposes, these hands are designed to perform one task, which is gripping.

We are looking into building a prosthetic a hand that can help recent amputees accomplish tasks in their daily life. Using a powerful EMG we can acquire signals from the muscles in the arm of the patient. The hand is going to have 5 different gestures and grips that the patient will be able to freely utilize. The prosthetic is going to be designed for people with transradial amputation, which is partial removal of the arm below the elbow joint.

This EMG is going to capture the signal and, using a machine learning algorithm, the hand is going to know which hand gesture the person is doing. The training algorithm that we will be using trains the microcontroller to determine the different grip modes by taking the average strength of the signal coming from the EMG for 30 seconds and then we will confirm with the machine whether it was the grip that we wanted or not. This type of training will work best when the hand is used by a recent amputee since all of their muscle functionality is still intact.

III. System Requirements

Goal: A safe, lightweight, and affordable prosthetic that can be easily trained for recent transradial amputees.

Control Requirements:
The embedded intelligence must be capable of rotating the motors in order to acquire the correct hand gesture. It must also know what hand gesture is being requested from the signals acquired by the EMG. It should know the battery remaining and send a signal if it is running low. Finally, it should be able to know when the system is being trained and when training has stopped.

Power Requirements:
The Power Control System is the subsystem that powers the hand. It needs to provide enough voltage and current to drive 6 motors (one for each finger, plus two for the thumb), the microcontroller, and ADCs. The motors we are going to be using are rated at 6V, the max power

is 1.3 Watts. The microcontroller requires a voltage between 3.3 and 5V. Ideally, the battery should be able to power the hand for several hours so that multiple recharges per day are not necessary.

In addition to supplying the necessary power, this subsystem also has to fit other design requirements such as size, weight, durability, and safety. The system should also be transportable, so batteries are an obvious choice. The battery system should be compact, lightweight, and robust enough to withstand a patient's day to day activities.

Mechanical Requirements:

The prosthetic hand weight and size requirements are supposed to closely match the weight distribution of a biological arm. Weight should be roughly 2-3% of their total bodyweight to be accurate to average arm weighting, size should be equivalent to human hand measurements. We are working with a 7 year old girl. She weighs about 55 pounds, this means that the weight of the prosthetic should be around 1.1 - 1.5 pounds. The size should match the size of a 7 year old with some room to grow without it looking odd. The average width of a 7 year old's hand is 4.5 cm which means we should be around that same ballpark.

User Interface Requirements:

Not much interface is required, user only needs to attach the EMG electrodes in the proper positions and activate or deactivate training mode via a button press. There is no wireless interfaces as everything is self contained within the hand and microcontrollers, no data is needed to come out or go into the hand once it is trained and in use. EMG electrodes are attached to the bicep and forearm areas for signal reading. The 3D printed limb is attached to the arm through some harness.

IV. System Block Diagram

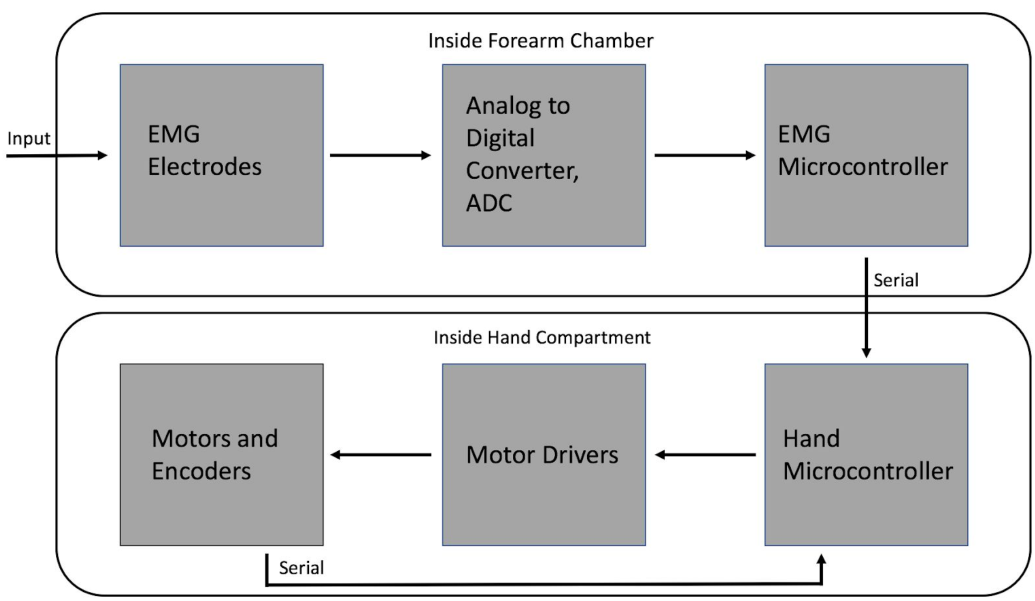

Figure 1.

Figure 1 above shows the block diagram of the entire hand system. The arrows show the path of data and how it is supposed to flow within the system. Figure 2 is the subsystem that is contained within the forearm portion of the prosthetic and is responsible for gathering data from the EMG leads and relaying that down the line to the hand microcontroller system. Figure 3 is the subsystem that cause the fingers to move. This system gets a signal from the hand compartment and depending on which signal is received the motors will move to one of their predetermined grips accordingly.

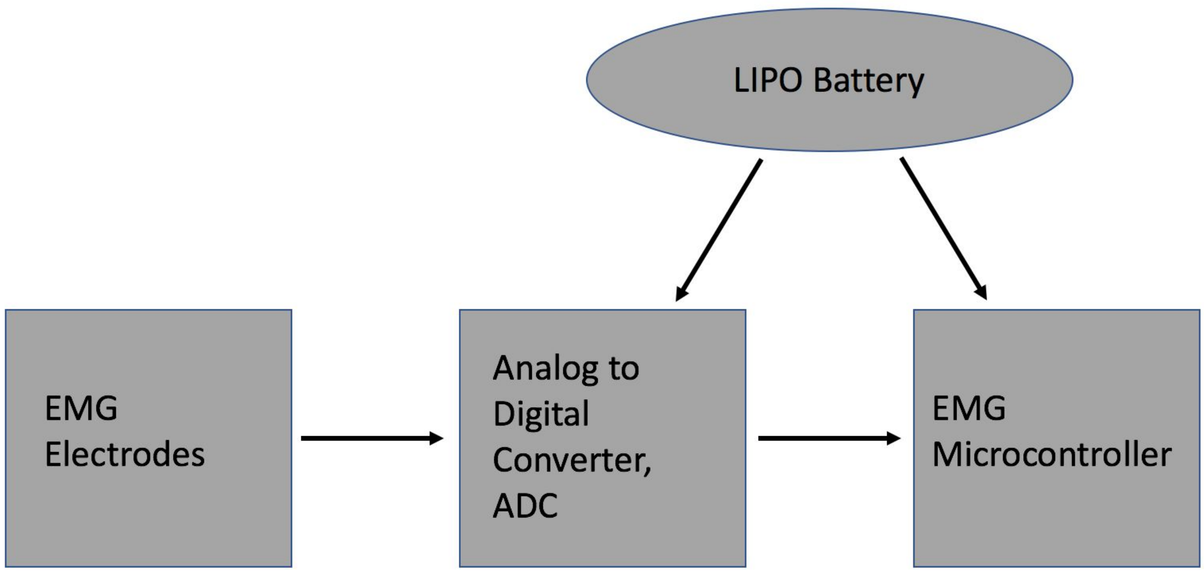

Figure 2.

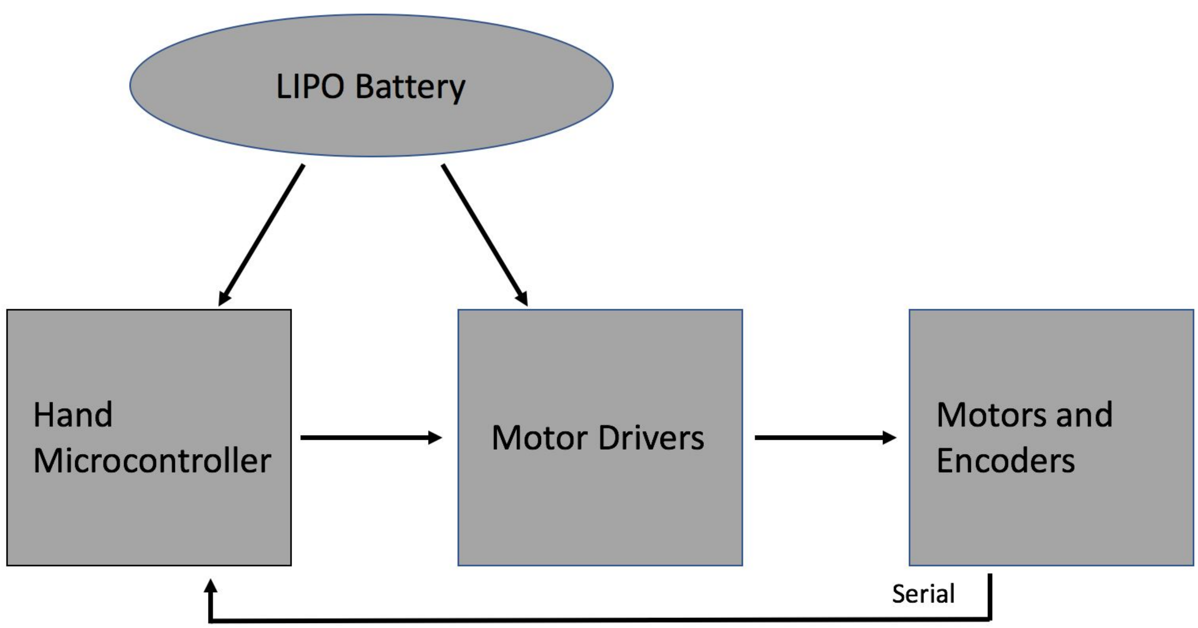

Figure 3.

Future Enhancement Requirements:

- Pressure sensor feedback to allow for gripping various objects such as an egg vs. a rock.
- Battery indicator during use.
- Increase battery capacity to extend time between charging.

V. High Level Design Decisions

Battery system:

The batteries tentatively selected are single cell LIPO batteries. They are rechargeable batteries that have lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte. The batteries come in many voltage and amp-hour options that seem to satisfy the power and voltage needs for the motors. They are also cheap, lightweight, and dependable. However, more testing needs to be done before the battery selection is finalized. Voltage regulators will be used to provide a steady voltage to the motors and the microcontroller. An overcurrent protection circuit will be included to protect the battery from excessive discharge load. Currently, we are looking at Turnigy 2200mAh single cell Lipoly batteries, which can provide 2.2 amps for one hour of constant usage. Our motors are rated to use about 0.33A at max efficiency, so that means that in total we would be drawing 1.98A at max efficiency. Considering that the hand is not in continuous use, usage time will be extended. Corroborating our initial selection of battery capacity, various literature suggests that 2000mAh is a satisfactory rating for more active users for a couple hours of usage.

Motor units and drivers:

We have chosen to use the DRV8833 motor driver because they have a range of 2.7V to 10.8V and are able to control two brushed DC motors. Thus, we would only need three total motor drivers, reducing total weight and effort sunk into assembly. The DRV8833 has H-bridges which will be used to switch the direction of the motor to perform extension and flexion of the fingers. As well, the driver can regulate output current, up to a max of 2A. As well, there are several available functions such as overtemperature protection, overcurrent and short-circuit protection. A low power sleep mode is also available, which will help to conserve battery life.

For the motor units, we are looking to use 100:1 Micro Metal Gearmotor HP with Extended Motor Shaft units. These are currently in use by the e-NABLED team and as a result they are readily available. They run at a low 6V and draw a modest 0.33A at max efficiency. Additionally, they only way 9.5g each, thus keeping the weight of the hand down. The 100:1 gear ratio provides high speeds of rotation. The size of the package as well is a major benefit, as it is only 10 x 12 x 26 mm.

EMG system:
For the microcontroller, we need a component that can process around eight or less leads and be able to send the correct grip to the microcontroller for the motors. It should have onboard memory in order to handle filtering. As well, it would be a benefit if we could use a simple programming interface so we could focus more on the physical configuration of the leads and construction of the hand. Thus, we have tentatively chosen to use a Teensy 3.1 microcontroller as it has onboard memory, is able to communicate using Serial, SPI, and I2C, and can interface with the Arduino environment.

ADS1298 (ADC for EMG) was chosen as Texas Instruments designed the part with an ECG in mind and thus they equipped it with the functionality you would need for those applications. The ADS1298 allows for the development of medical systems at reduced size, cost, and power consumption. It also communicates via SPI and can perform simultaneous sampling.

For the leads, we are looking to use a maximum of eight leads at one time. We have not selected a specific lead system yet as there are many to choose from and the functionality of a lead is fairly simple, in that you need a node and the wire to go the microcontroller circuit. We do not assume we need any specific lead set and a simple lead system such as the CAB-12970 and disposable pads will be sufficient for initial demos at least.

Training System:
The training system that we are using is an averaging machine learning algorithm that uses the closest neighbor to train the system. The way this training works is the user chooses what motion that they would want associated with a certain grip, and then hold that muscle motion for 30 seconds. During this 30 seconds the EMG will gather data points on this grip. Once enough data points are gathered the algorithm will be sufficiently trained and uses the closest neighbor method to determine which grip is being activated. The closest neighbor method takes an incoming signal from the user once the prosthetic limb is trained and then chooses which signal it most closely resembles from training.

VI. Open Questions

These are questions that have/will arise during the construction and completion of the prosthetic limb as we progress further in its design:

a. How will we determine the cutoffs or the different modes with the EMG?
b. How will it be best to incorporate a more robust training algorithm in the future for people who have had an amputation in the distant past?
c. Where on the arm will placing the leads give us the best signals?

VII. Major Components Costs

Component Name	Cost	Description	Web location	Comments	#	Total
Teensy 3.1	$19.80	Microcontroller	https://www.pjrc.com/store/teensy31.html	Provided by e-NABLED Team	1	$19.80
ADS1298	$36.81	ADC for EMG	http://www.digikey.com/product-detail/en/ADS1298IPAG/296-27734-ND/2360825	Have 1 in stock, hopefully doesn't break	1	$36.81
MPL115A-2	$5.46	Pressure Sensors	http://www.digikey.com/product-detail/en/MPL115A2/MPL115A2-ND/2508976	OPTIONAL	6	$32.76
DRV8833	$2.13	Motor driver	https://www.ti.com/store/ti/en/p/product/?p=DRV8833PWPR	We have 3 in stock	3	$6.39
0.4Ω 1206 resistor	$0.46	Resistor	http://www.digikey.com/product-detail/en/yageo/RL1206FR-070R4L/311-.4LWCT-ND/3886080		6	$2.76
1kΩ 0603 resistor	$0.10	Resistor	http://www.digikey.com/product-detail/en/yageo/RC0603JR-071KL/311-1.0KGRCT-ND/729624		2	$0.20
2.2uF 0603 capacitor	$0.12	Resistor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R61C225KE15D/490-3296-1-ND/702837		3	$0.36
10uf 0603 capacitor	$0.18	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R61A106ME69D/490-10475-1-ND/5026393		4	$0.72
0.01uF 0603 capacitor	$0.10	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R71H103KA01D/490-1512-1-ND/587862		3	$0.30
220Ω 1208 4 resistor array	$0.10	Resistor Array	http://www.digikey.com/product-detail/en/yageo/YC164-JR-07220RL/YC164J-220CT-ND/1005664		3	$0.30
1uF 0603 capacitor	$0.04	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R71E105KA12D/490-5307-2-ND/2039034		13	$0.52
1nF 0603 capacitor	$0.10	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R71H102KA01D/490-1494-1-ND/587851		1	$0.10
0.1uF 0603 capacitor	$0.10	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R71C104KA01D/490-1532-1-ND/587771		6	$0.60
22uF 0603 capacitor	$0.25	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188C80G226MEA0D/490-7196-1-ND/3900451		1	$0.25
1.5nF 0603 capacitor	$0.10	Capacitor	http://www.digikey.com/product-detail/en/murata-electronics-north-america/GRM188R71H152KA01D/490-1498-1-ND/587878		1	$0.10
1MΩ 0603 resistor	$0.10	Resistor	http://www.digikey.com/product-detail/en/yageo/RC0603FR-071ML/311-1.00MHRCT-ND/729791		1	$0.10
10kΩ 0605 resistor	$0.10	Resistor	http://www.digikey.com/product-detail/en/yageo/RC0603JR-0710KL/311-10KGRCT-ND/729647		5	$0.50
TPS73225DBVT	$1.58	2.5 V regulator	http://www.digikey.com/product-detail/en/texas-instruments/TPS73225DBVT/296-15810-1-ND/604364		1	$1.58
TPS60403DBVRG4	$1.32	Voltage Inverter	http://www.digikey.com/product-detail/en/texas-instruments/TPS60403DBVR/296-27005-1-ND/2255295		1	$1.32

L7805CV	$0.44	5V Regulator	http://www.digikey.com/product-detail/en/stmicroelectronics/L7805CV/497-1443-5-ND/585964		1	$0.44
100:1 Micro Metal Gearmotor HP with Extended Motor Shaft	$16.95	Motor	https://www.pololu.com/product/2214		6	$101.7
Tunigy 2200mAh 1S 20C	$4.37	Battery	https://hobbyking.com/en_us/turnigy-2200mah-1s-20c-lipoly-single-cell-1.html		2	$8.74
CAB-12970	$5.00	Lead Cable	https://www.digikey.com/product-detail/en/sparkfun-electronics/CAB-12970/1568-1803-ND/6833933		3	$15.00
MIKROE-2456	$14.28	Electrode pads pack (30 pads)	https://www.digikey.com/product-detail/en/mikroelektronika/MIKROE-2456/1471-1682-ND/6490565		1	$14.28

VIII. Conclusion

The prosthetic limb problem given to us by the e-NABLED team is both challenging and rewarding. This problem requires the knowledge of many different fields and areas. We plan on delivering a functional product that raises the quality of life for its users and makes their everyday life better, at an affordable price. Currently, we are very close to having a whole finger unit working consistently with no major electrical or mechanical issues with the given setup as laid out above and are looking to refine the structural design. As well, we will be looking to improve on our selection of the components to maximize cost efficiency and performance and optimize the layout of each system.

IX. References:

http://www.limbless-association.org/images/Types_of_Amputation.pdf
https://exrx.net/Kinesiology/Segments
http://fiberdreams.com/hand-sizes/
https://batteryuniversity.com/learn/article/what_is_the_c_rate
https://en.wikipedia.org/wiki/Electromyography
http://liberatingtech.com/products/batteries/Built-in_-_Removable_Prosthetic_Batteries.asp
https://www.pjrc.com/teensy/teensy31.html