Prosthetic Arm

FINAL DESIGN DOCUMENT

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Executive Summary

Our team recognized a fundamental problem that amputees in today's society still do not have access to affordable, life normalizing, myoelectric prosthetic arms. Amputees are exposed to undue stress in all aspects of their lives. One solution to this problem is a robotic prosthetic, however, most solutions in today's market cost anywhere from $20,000 to $100,000 before insurance. This represents an additional financial burden that is unnecessarily forced upon them. Our goal is to design an affordable solution to disrupt the market. We have no plans of mass manufacturing, but if we are able to design and prove our concept in less than a year, we can hopefully provide a better option for some people and put pressure on manufacturers who are currently overcharging for their products. The largest benefit of this project is that development is student driven and university funded, so there are no overhead costs and no profit margin that will be passed on to users.

Development Standards & Practices Used

- Engineering Standards
  - IEEE: Institute of Electrical and Electronics Engineers
  - ASME: American Society of Mechanical Engineers
- Standard Practices
  - Define specifications
  - Build block diagrams
  - Effectively isolate signals
  - Reduce power consumption whenever possible
  - Use proper grounding to prevent EMI
  - Implement safety measures for ESD, reverse polarity, transients, and over-voltages
  - Carry out simulations and test all components, sub-systems, and systems
  - Verify component selection and schematics
  - Consider ergonomics
  - Consider methods of attachment
  - Maintain design modularity
  - Ensure accuracy and repeatability of design
  - Calculate centers of action and manage friction

Summary of Requirements

- Non-invasive
- Movement based on users surface electrical signals
- Touch sensitivity
- Haptic feedback
- All day battery life
- Manageable size and weight
- Cost-effective (less than $1000)
- Calibration suite to allow for adjustments to be made by user

Applicable Courses from Iowa State University Curriculum

EE Courses:

- EE 166 -- Professional Programs Orientation
- EE 185 -- Introduction to EE and Problem Solving I
- EE 201 -- Electric Circuits
- EE 224 -- Signals and Systems I
- EE 230 -- Electronic Circuits and Systems
- EE 232 -- Professional and Ethical Issues in EE and CPRE
- EE 285 -- Problem Solving Methods and Tools for EE
- EE 303 -- Energy Systems and Power Electronics
- EE 311 -- Electromagnetic Fields and Waves
- EE 322 -- Probabilistic Methods for EE
- EE 324 -- Signals and Systems II
- EE 330 -- Integrated Electronics
- EE 333 -- Electronic Systems Design
- EE 341 -- BioMEMS and Nanotechnology
- EE 450 -- Biosensors
- EE 491 & 492-- Senior Design Project and Professionalism
- EE 494 -- Portfolio Assessment

CPRE Courses:

- CPRE 166 -- Professional Programs Orientation
- CPRE 185 & 186 -- Intro to CPRE and Problem Solving I & II
- CPRE 232 -- Professional and Ethical Issues in Computer Engineering
- CPRE 281 -- Digital Logic

- CPRE 288 -- Embedded Systems Introduction
- CPRE 308 -- Operating Systems: Principles and Practice
- CPRE 310 -- Theoretical Foundations of COmputer Engineering
- CPRE 330 Integrated Electronics
- CPRE 381 -- Computer Organization and Assembly Level Programming

SE Courses:

- SE 101 -- Software Engineering Orientation
- SE 166 -- Careers in Software Engineering
- SE 185 & 186 -- Problem Solving in Software Engineering
- SE 309 -- Software Development Practices
- SE 317 -- Introduction to Software Testing
- SE 319 -- Construction of User Interfaces
- SE 339 -- Software Architecture and Design

COM S Courses:

- COM S 227 -- Object Oriented Programming
- COM S 228 -- Introduction to Data Structures
- COM S 230 -- Discrete Computational Structures
- COM S 309 -- Software Development Practices
- COM S 311 -- Design and Analysis of Algorithms
- COM S 321 -- Computer Architecture and Machine-Level Programming
- COM S 327 -- Advanced Programming Techniques
- COM S 352 -- Operating Systems
- COM S 363 -- Database Management

ME Courses:

- ME 160 -- Mechanical Engineering Problem Solving with Computer Applications
- ME 170 -- Engineering Graphics and Introductory Design
- ME 270 -- Introduction to Mechanical Engineering Design
- ME 324 -- Manufacturing Engineering
- ME 325 -- Mechanical Component Design
- ME 421 -- System Dynamics and Control
- ME 550 -- Advanced Biosensors

Non Major Specific Courses:

- Phys 231 -- Introduction to Classical Physics
- Phys 232 -- Introduction to Classical Physics II
- Engl 150 -- Critical Thinking and Communication
- Engl 250 -- Written, Oral, Visual, and Electronic Composition
- Engl 314 -- Technical Communication
- Math 165 -- Calculus I
- Math 166 -- Calculus II
- Math 207 -- Matrices and Linear Algebra
- Math 265 -- Calculus III
- Math 267 -- Elementary Differential Equations and Laplace Transforms
- IE 305 -- Engineering Economic Analysis
- MAT E 273 -- Principles of Materials Science and Engineering

New Skills/Knowledge acquired that was not taught in courses

- Consulting experts in industry/education for advice
- Creating a GANT chart
- Delegating tasks between team members
- Receiving funding/grants to help cover costs for project materials

Evolution of the project over the year

The project changed greatly since the end of the first semester. The original forearm and hand mechanical design of the prosthetic was redesigned and reprinted several times to get to our final design. We originally targeted a 30th percentile womens hand to keep our design as small as possible. After receiving feedback from our first semester presentation and through our own design process we decided our hand would need to be significantly larger to accommodate everything we wanted to implement. Our final prototype for this semester is a 65th percentile womens hand size which is still appropriate size and weight to accommodate for a variety of users. Unfortunately, we have yet to implement any movement of the wrist or the second knuckle of the thumb. Some of these design shortcomings were due to parts shipping delays and others lost priority due to importance of other project aspects.

There was very little information on our battery when we picked it and we assumed that we would have to design a full Battery Management System from scratch. However, once we found a datasheet on another distributor's website we determined that our battery was packaged with a small internal overcurrent and over temperature protection circuit. We then decided a full BMS was not necessary and we instead relied on the charging protocols of USB to provide the rest of our necessary safety measures. We then designed a charging circuit board with a built-in battery charge level indicator. This board is currently not visible from the outside of the fully constructed hand but in later prototypes we plan to have an easily accessible charging and data port as well as LED’s to show battery charge status for users.

The initial amplifier design was greatly modified from the first semester when we were doing initial testing. We changed the simple amplifier to an instrumentation amplifier, followed by a band pass filter and a basic op amp to boost the gain of the circuit. This is necessary to obtain proper surface EMG reading that we can process on our CPU and turn into movement.

The motherboard was the most difficult part of this project. It includes the three amplification circuits from our EMG system, 5 volt, 3.3 volt, and 1.8 volt regulation circuits, as well as the microcontroller itself and all of the necessary pins and connectors that deal with our motor outputs and encoder inputs. All of this needs to fit inside our 3D printed forearm with the charging circuit board and the battery.

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1 Team

1.1 Team Members

Leo Forney, Jack Vetsch, jacob Eisbrenner, Erik Raman, Scott Bolek, Sean Gray, Jeremy Wallace

Adviser: Professor Santosh Pandey

1.2 Required Skill Sets for Your Project

The ability to design and test advanced electrical circuits including a battery management system is required. Knowledge of developing software to be used in an embedded system is imperative. The ability to design mechanical components in a 3D CAD software is also needed for this project. To go along with this, a basic understanding of the anatomy of the human antebrachium(lower arm) is needed. Soldering is also an imperative requirement.

1.3 Skill Sets covered by the Team

Software Team: Leo Fornye and Erik Raman, Sean Gray

Mechanical Team: Jacob Eisbrenner and Jack Vetsch

Electrical Team: Sean Gray, Jeremy Wallace, Jack Vetsch, Scott Bolek, Sean Gray

1.4 Project Management Style Adopted by the team

The style we adopted is called "Agile." Our implementation of this involved meeting twice a week, one full team meeting and another meeting of sub groups, but we remained in constant contact with each other. This style was beneficial to us because there are many different aspects of the project that can be worked on separately from each other by smaller teams. This was also necessary because of our large group and conflicting schedules making it extremely difficult to all meet together.

1.5 Initial Project Management Roles

Jacob Eisbrenner is the leader of the team seeing as he is the one who proposed the project and has created and guided the vision of the project. Jacob's leadership role extends far beyond management and he is the hardest working member on the team because he truly cares about the vision we are constructing.

2 Introduction

2.1 Problem Statement

Amputees deal with a lot of hardship. There are infinitely many tasks in day to day life that able bodied people take for granted. A person cannot truly understand how much function a limb accounts for until they lose it. Especially when the appendage they lost is their arm. Anyone can lose an arm, whether it is due to disease, an accident, or combat; and there are amputees of all ages, sizes, and nationalities around the world. In fact, the largest number of amputees come from developing countries where giving birth is more dangerous and medicine or hospitals are less available. One thing that can alleviate some of the struggles for any form of amputation is a prosthetic. Prosthetics come in many forms and all do some part to improve the quality of life significantly for these constituents.

2.2 Intended Users and Uses

Transradial amputees are the projected user for our project however, some of the processes and technologies that we hope to work with could be applied to other amputees. While prosthetic devices are designed and intended for a single user there are many more people that are affected by a properly designed prosthetic. From the intended user, to family members of the user, all the way to a company or even a community. This is all due to the fact that the amputee can now experience a better quality of life both physically and mentally.

1. SPC John Doe
    a. Demographic: 26 Years old male, Highschool education, with single one bedroom apartment, No significant other or kids, has a dog
    b. Hobbies: Used to enjoy hunting, working on motorcycles
    c. Work Motivations: Has a part time job and is unable to work as at his dream job at a mechanic shop.
    d. Personality: Since accident very skittish around many people, loss of confidence, has a lot of want to get back to his old self
    e. Values: Religious man, wants to have a family one day, live happy and healthy away from any past experience.
2. Needs to be able to independently move each finger, have some form of touch feedback in order to get a higher quality of life, must be able to withstand daily use and wear from environment and operation, be able to be secured to the user with little to no unintended movement.

3. The prosthetic in question would be used to possibly aid in doing certain occupations. Along with jobs, the prosthetic can aid in certain hobbies as well. The actions in these activities include but are not limited to basic writing, grabbing and picking things up, pressing buttons, etc. The user can benefit directly from the prosthetic from being able to once again do some of the things that weren't available to them after losing their limb. This can make things easier for them doing everyday tasks and lift a figurative weight off of their shoulders. Another benefit is that this will lighten the work and load the other arm takes which in turn reduces stress, strain, and overuse.

Depression among amputees - PubMed (nih.gov)

Evaluation of treatment of psychiatric morbidity among limb amputees - PMC (nih.gov)

What Are Some of the Long-Term Physical Effects of Using or Not Using a Prosthesis? - Amputee Coalition (amputee-coalition.org)

3 Project Plan

3.1 Project Management/Tracking Procedures

We use a hybrid project management style. There is regular interaction between us and the client and there are regular meetings. At the minimum twice a week not including class time. Because our project has many working parts, we have to meet often. But we also have a concrete schedule with milestones.

Google Drive is currently being used to track all of our progress. Everything on the app is organized into separate folders with the relevant research, information, and documents. We will add new applications when necessary.

3.2 Task Decomposition

The main task is to create the prosthetic hand.To help make our task more clear we have separated the project into three main areas, mechanical, electrical, and software. Under each one there are multiple tasks:

Mechanical
Exterior Frame
Elbow joint
Socket/mounting
Finger movement
Skin/grip material
Hand joints
Electronic Housing
Electrical
Mother board design
Power delivery/ Charging
Flexable PCB(EMG sensors)
Touch Sensors
EMG Reader/Amplifier
Electro-mechanical movement
Software
Signal Processing
Touch feedback calculations
Calibration software

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Some of the milestones include finishing and printing the mechanical components of the prosthetic arm. We would like to accurately detect signals sent from the brain using EMG sensors to individually move fingers, but at the very least we need to get within the tolerance needed to determine a hand "on" or "off". Realistically we would like to have less than .1 seconds to respond and react to a signal. We would also want the feedback from the touch sensors on the prosthetic to be within 10 milliseconds or less. To measure progress of each task, some of them will be quantifiable but others won't be. For the ones we can measure, we can document the results on a spreadsheet for analysis. A lot of these values have not been set or cannot be fully realized at this time due to the nature of the project. A lot of this will come down to looking at waveforms on an oscilloscope or multimeter. Computer programs can be used for the analysis as well. As for the parts of the project that can't be measured, we can only observe the functionality of the working parts and decide whether it is acceptable enough for the project.

3.4 Project Timeline/Schedule

Link to our schedule:

https://docs.google.com/spreadsheets/d/1RxnH44qIunRC1xXpaTMkU9g_izk9jAdc/edit?usp=sharing&ouid=107243779695586660702&rtpof=true&sd=true

3.5 Risks and Risk Management/Mitigation

Possible Issues	EMG sensors being unable to pick up usable data	Battery Failing(Igniting/Exploding)	Sensor data is too noisy or low quality to use for software	Feedback from touch sensor is too strong	Mechanical system for moving fingers is ineffective
Probability of Occuring	0.1	0.3	0.7	0.4	0.5
Consequence Rating	High	High	Medium	Low	High
Analysis	EMG pads are standard and are made to pick up signals. Low probability of happening.	Lithium batteries can be dangerous if compromised. It can lead to serious injury and destroy the project progress. Worst case scenario is that we separate the battery from the rest of the project.	The worst case is we would have to create an averager for our data to use a binary approach(on or off). We can also invest in a better filter or other related parts as well if needed.	This is a relatively easy fix if it occurs. But for testing, don't test it on ourselves initially.	For this problem, it may require a redesign that would be very extensive and time consuming at the worst. There have been multiple designs that have been analyzed as of right now to prevent this from happening.

3.6 Personnel Effort Requirements

Task	Hours Expected
Mechanical	
Exterior Frame	12
Elbow joint	TBD
Socket/mounting	10
Finger movement	14
Skin/grip material	3
Hand joints	9
Electronic Housing	2
Electrical	
Mother board design	13
Power delivery/ Charging	3
Flexable PCB(EMG sensors)	5
Touch Sensors	13
EMG Reader/Amplifier	12
Electro-mechanical movement	14
Software	
Signal Processing	12
Touch feedback calculations	15
Calibration software	17

3.7 Other Resource Requirements

Current List of Components and Prices:

Part	Quanity	Price Per Unit	Price Total	Link/ETG	Purchased	Recived
Electrical						
Motors	7	$11.90	$83.30	https://www.digikey.com/en/products/detail/dfrobot/FIT0487/708716	☑	☑
Battery	1	$39.04	$39.04	https://www.digikey.com/en/products/detail/dantona-industries/L74A	☑	☑
MCU	1	$17.60	$17.60	https://www.digikey.com/en/products/detail/texas-instruments/TMS3	☑	☑
USB-C Adapter	1	$11.99	$11.99	https://www.amazon.com/Eiechip-Voltage-Regulator-Converter-Mod	☑	☑
Touch Sensor amps	4	$2.85	$11.40	https://www.digikey.com/en/products/detail/stmicroelectronics/TSZ1	☑	☑
EMG Amp	20	$1.28	$25.60	https://www.digikey.com/en/products/detail/rohm-semiconductor/LM	☑	☑
Touch Sensors	12	$6.25	$74.99	https://www.digikey.com/en/products/detail/uneo-inc/GHF-10/15657	☑	☑
3.3nF Caps(Motherboard)	20	$0.46	$9.20	https://www.digikey.com/en/products/detail/murata-electronics/GRM	☑	☑
Thermoster	2	$5.50	$11.00	https://www.digikey.com/en/products/detail/littelfuse-inc/KS103J2/26	☑	☑
5V regulator	10	$0.32	$3.21	https://www.digikey.com/en/products/detail/diodes-incorporated/AZ1	☑	☑
1.8V regulator	6	$0.39	$2.34	https://www.digikey.com/en/products/detail/diodes-incorporated/AP2	☑	☑
3.3V regulator	6	$1.41	$8.46	https://www.digikey.com/en/products/detail/texas-instruments/TPS7	☑	☑
1uF Caps(Motherboard)	20	$0.06	$1.24	https://www.digikey.com/en/products/detail/kyocera-avx/04026D105	☑	☑
2.2uF Caps(Motherboard)	50	$0.07	$3.50	https://www.digikey.com/en/products/detail/kyocera-avx/06036D225	☑	☑
22uF Caps(Motherboard)	50	$0.11	$5.35	https://www.digikey.com/en/products/detail/samsung-electro-mecha	☑	☑
33uF Caps (Motherboard)	20	$0.57	$11.32	https://www.digikey.com/en/products/detail/tdk-corporation/C2012X	☑	☑
1k resistors(motherboard)	100	$0.04	$4.03	https://www.digikey.com/en/products/detail/yageo/AC1206FR-7W1K	☑	☑
50K resistors(motherboard)	100	$0.09	$8.65	https://www.digikey.com/en/products/detail/vishay-dale/CRCW0805	☑	☑
500K resistors(motherboard)	20	$0.50	$9.94	https://www.digikey.com/en/products/detail/vishay-techno/CRMA120	☑	☑
Motor Driver (Driver Board)	8	$1.57	$12.56	https://www.digikey.com/en/products/detail/toshiba-semiconductor-a	☑	☑
10uF Caps (Driver Board)	20	$0.10	$1.98	https://www.digikey.com/en/products/detail/murata-electronics/GRM	☑	☑
100 ohm resistor	100	$0.05	$5.11	https://www.digikey.com/en/products/detail/rohm-semiconductor/ES	☑	☑
300 ohm resistor	100	$0.06	$5.79	https://www.digikey.com/en/products/detail/vishay-dale/CRCW0603	☑	☑
12 Pin JST Connectors	10	$0.41	$4.10	https://www.digikey.com/en/products/detail/jst-sales-america-inc/B1	☑	☑
6 Pin JST Conneectors	20	$0.25	$5.00	https://www.digikey.com/en/products/detail/jst-sales-america-inc/B6	☑	☑
22K Ohm Resistors(BMS)	10	$1.04	$10.42	https://www.digikey.com/en/products/detail/susumu/HRG3216P-220	☑	☑
3.57K Ohm Resistors(BMS)	10	$0.28	$2.83	https://www.digikey.com/en/products/detail/stackpole-electronics-inc	☑	☑
0.1uF Capacitors(BMS/Motherboard)	100	$0.01	$1.05	https://www.digikey.com/en/products/detail/samsung-electro-mecha	☑	☑
0.33uF Capacitors(BMS)	100	$0.05	$4.74	https://www.digikey.com/en/products/detail/murata-electronics/GRT	☑	☑
100 uH 2.1A inductors(BMS)	3	$1.27	$3.81	https://www.digikey.com/en/products/detail/bourns-inc/SRR1280-10	☑	☑
680uF Capacitors(BMS)	10	$0.32	$0.97	https://www.digikey.com/en/products/detail/rubycon/10ZLH680MEF	☑	☑
LM2577T-ADJ	2	$7.97	$15.94	https://www.digikey.com/en/products/detail/texas-instruments/LM25	☑	☑
2.2K ohm Resistors(BMS)	10	$1.00	$9.97	https://www.digikey.com/en/products/detail/stackpole-electronics-inc	☑	☑
1N5821 Shocky Diode	10	$0.54	$5.40	https://www.digikey.com/en/products/detail/nte-electronics-inc/1N58	☑	☑
800 Ohm 3W resistors	5	$1.57	$7.85	https://www.digikey.com/en/products/detail/ohmite/43F800E/823269	☑	☑
470K Ohm Resistors(Motherboard)	100	$0.02	$2.04	https://www.digikey.com/en/products/detail/yageo/RC1206FR-0747	☑	☑
100K Ohm Resistors(Motherboard)	100	$0.02	$1.60	https://www.digikey.com/en/products/detail/koa-speer-electronics-in	☑	☑
150K ohm resitstors(Motherboard)	100	$0.02	$2.04	https://www.digikey.com/en/products/detail/yageo/RC1206FR-0715	☑	☑
6.8uF Capacitors	20	$0.29	$5.76	https://www.digikey.com/en/products/detail/tdk-corporation/CGA4J3	☑	☑
68nF Capacitors	100	$0.01	$1.09	https://www.digikey.com/en/products/detail/walsin-technology-corpo	☑	☑
JST Connectors 1x12 1.5mm	10	$0.51	$5.07	https://www.digikey.com/en/products/detail/jst-sales-america-inc/B1	☑	☑
JST Connectors 1x6 1.5mm	20	$0.25	$5.08	https://www.digikey.com/en/products/detail/jst-sales-america-inc/B6	☑	☑
Linear Actuators	6	$7.99	$47.94	https://www.amazon.com/Acxico-2-Phase-Precision-Planetary-Gear	☑	☑
USB UART Connector	1	$7.39	$7.39	https://www.amazon.com/HiLetgo-CP2102-Converter-Adapter-Dow	☑	☑
JST wires 12 pin 12" long	4	4.12	$16.48	https://www.digikey.com/en/products/detail/jst-sales-america-inc/A1	☑	☑
JST wires 6 pin 6" long	3	1.84	$5.52	https://www.digikey.com/en/products/detail/jst-sales-america-inc/A0	☑	☑
JST wires 6 pin 2" long	10	1.179	$11.79	https://www.digikey.com/en/products/detail/jst-sales-america-inc/A0	☑	☑
Manufacting/Items						
EMG Pads	1	$14.00	$14.00	https://www.digikey.com/en/products/detail/mikroelektronik	☑	☑
3D Printing of Forearm	1	$104.98	$104.98	ME Additive Manufacturing	☑	☑
3D Printing Hand	1	$95.66	$95.66	ME Additive Manufacturing	☑	☑
3D Printing Hand Part 2 the electric boogalo	1	104.96	$104.96	ME Additive Manufacturing	☑	☑
Motherboard PCB	1	$17.58	$17.58	JLC PCB	☑	☑
Driver board PCB	1	$17.58	$17.58	JLC PCB	☑	☑
BMS board PCB	1	$17.58	$17.58	JLC PCB	☑	☑
Electro Gel	1	$3.90	$3.90	https://www.amazon.com/Spectra-PAR12-02-Parker-Laboratories-E	☑	☑
Mechanical/ Assembly						
Skin SIllicone	1	$50.89	$50.89	https://www.amazon.com/Dragon-Skin-Making-Silicone-Rubber/dp/	☑	☑
2mm Dowel 45mm Long	2	$2.85	$5.70	https://www.mcmaster.com/91595A171/	☑	☑
5mm Downel 32mm Long (Pack of 25)	1	$16.40	$16.40	https://www.mcmaster.com/91595A376	☑	☑
M3 Screws 16mm Long (Pack of 100)	1	$10.84	$10.84	https://www.mcmaster.com/91294A134	☑	☑
M3 Screws 8mm Long (Pack of 100)	1	$5.82	$5.82	https://www.mcmaster.com/91294A128	☑	☑
3mm Rod 100mm (Pack of 10)	1	$9.99	$9.99	https://www.amazon.com/Sutemribor-100mm-Straight-Helicopter-Ai	☑	☑
Screw Inserts	2	$7.55	$15.10	https://www.mcmaster.com/94459A421/	☑	☑

https://docs.google.com/spreadsheets/d/1kXUpEGYiqC2td_-lXtdBZp3m-Ov0Xz_0jgmVdpfonag/edit?usp=sharing

4 Design

4.1 Design Context

4.1.1 Broader Context

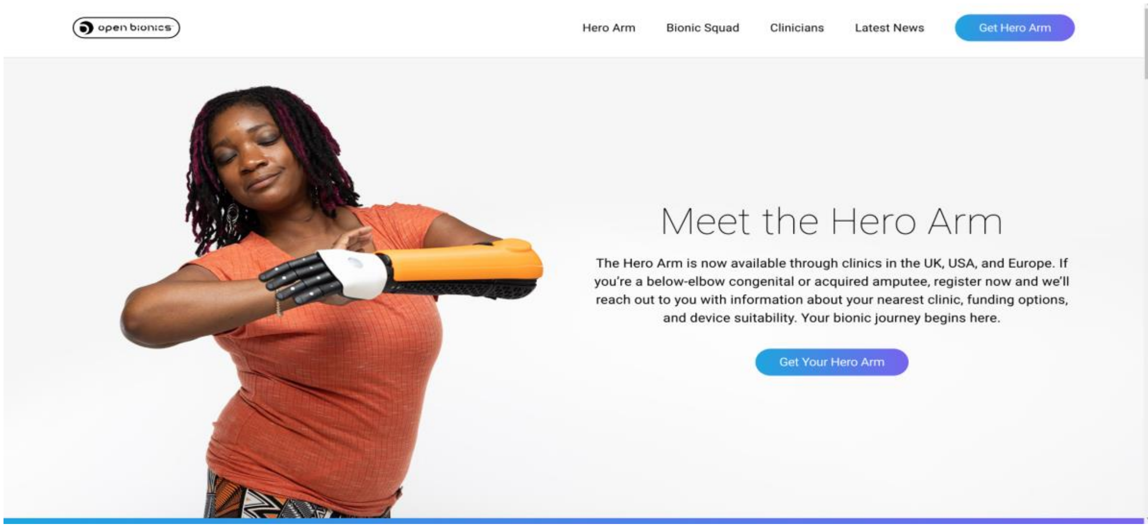
Our project differs from most of what is openly available in that it is a non-invasive prosthetic. This is relevant to a new market because by nature of its use not requiring surgery, it will be considerably more affordable. The accessibility of prosthetics to amputees not only improves the life of the amputee, but also reduces the burden on their friends and family. Allowing amputees to become more functional benefits their contribution to society, increases their feeling of normalcy, and can greatly improve mental health.

Hopefully, our research and final product can benefit the entire amputee community by furthering non-invasive prosthetic technology. Our findings could also pressure other companies to make their prosthetics more accessible and affordable through competition.

Area	**Description**	**Examples**
Public health, safety, and welfare	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities)	No major public health or safety impact. However, having an affordable but effective prosthetic arm will help others feel more integrated in society.
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.	From a social aspect, the arm users will feel more included in society. Friends/family of the user will feel satisfied that the user has regained
Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.	Increasing usage of non-recyclable plastics. Usage of lithium-ion batteries, energy used to manufacture silicon and electronics inside.
Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	The product will be affordable to users and will be easily obtainable. Within our company, the product's pricing must be competitive enough but enough to make profits.

4.1.2 Prior Work/Solutions

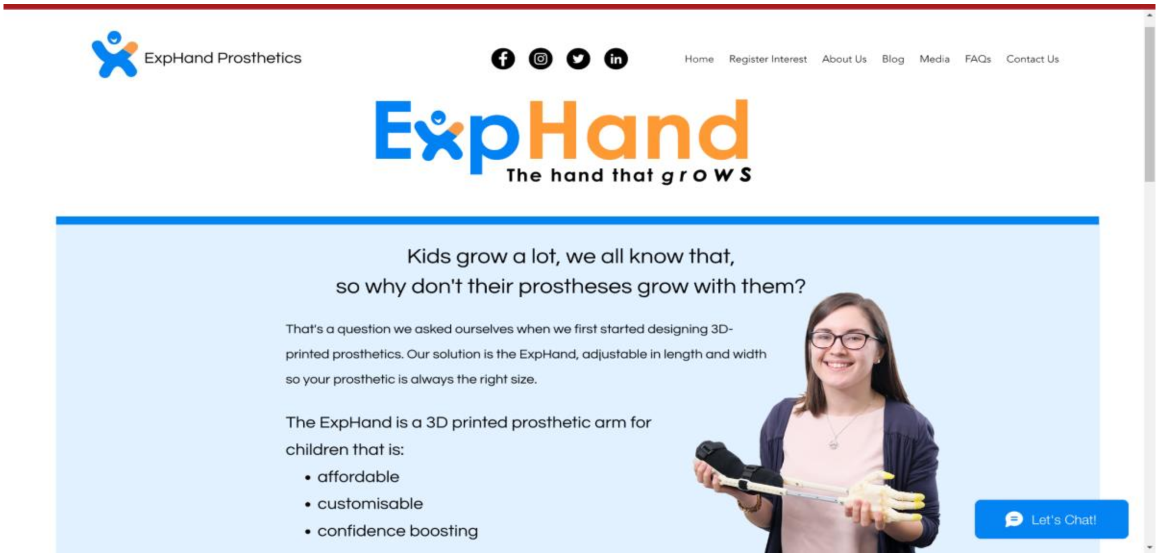
https://openbionics.com/



Openbionics main website

"Advanced, intuitive, robust and light. The Hero Arm is the world's most affordable advanced multi-grip prosthetic arm, with multi-grip functionality and empowering aesthetics… the Hero Arm is a custom lightweight and affordable myoelectric prosthesis…" This prosthetic is custom made from nylon 12 and uses "haptic vibrations, beepers, buttons and lights [to] provide you with intuitive notifications to help you control bionic arm movements."

https://www.exphandprosthetics.com/



Exphand front website

Exphand is an open source solution to provide a sense of normalcy to mostly child amputees. The goal of this hand is to be highly adjustable to conform to a rapidly growing child. It has no electronics and works through mechanical inputs to adjust the contraction of the hand. These controls are intuitive but very limited. Some design techniques from the Exphand that are very simple but could work well for us are velcro straps to help fasten the prosthetic to the amputee's arm; also the mechanism for contracting the hand seems to work really well.

4.1.3 Technical Complexity

Our project satisfies the requirements for complexity by requiring circuit design, component selection based on design constraints and technical requirements, pcb construction, signal obtainment, signal processing, software development, power delivery requirements, and power systems design. Our project aims to research, build, test, and adapt a fully functional robotic arm. These varying challenges relate to the scientific method of solving problems, relevant mathematical knowledge, and basic engineering design principles.

All of the previously mentioned aspects of the project are issues that are still faced within the industry of prosthetic limb design and manufacturing. Some of the methods that we are using to design and build this prosthetic meet and in some aspects exceed those found within the current industry.

4.2 Design Exploration

4.2.1 Design Decisions

One of the biggest design decisions made for our solution was the materials being used for the arm. We chose to use a mixture of ABS and a small amount of aluminum in order to have strength and durability. The next large design decision made was the inclusion of pressure sensors for touch feedback. The success of this project lies in the fact that the patient will be able to regain a great majority of what he/she lost after the amputation. One of those lost abilities in this specific case is the sensation of touch. By giving the user this critical sense back to them, it is more likely that the arm will be used to its fullest potential and give the user a satisfactory experience. A third design choice that was made was to create a more accurate and long lasting EMG reading circuit. In most instances of EMG signals, the electrode pads used are only good for a day and can lead to excessive noise if used any longer. By researching materials and layouts to improve this length of time, it not only gives the user a better experience but allows for easier and less frequent calibration by the doctors and technicians of the device.

4.2.2 Ideation

When identifying the best way to read muscle movements from the patient, a few possibilities came up. The first of which was EMG signal reading through surface electrodes also known as Surface EMGs. This was identified as it is the most rudimentary way to read EMG signals with the least amount of complicated equipment. The next option was in vivo EMG sensing which is a little more difficult and is intrusive to the patient. Ultrasonic signal reading was the third option discussed and this requires custom made sensors which allow for high accuracy at the cost of high difficulty and expense. Neural network signal reading was the fourth option discussed however this relies on two different surgeries and is quite costly and potentially harming to the patient. The final option discussed was the opposite method which is a fairly new technique that allows for all movements of the prosthetic to be based off of the opposite limb which causes difficulty with physical therapy as well as use of the arm.

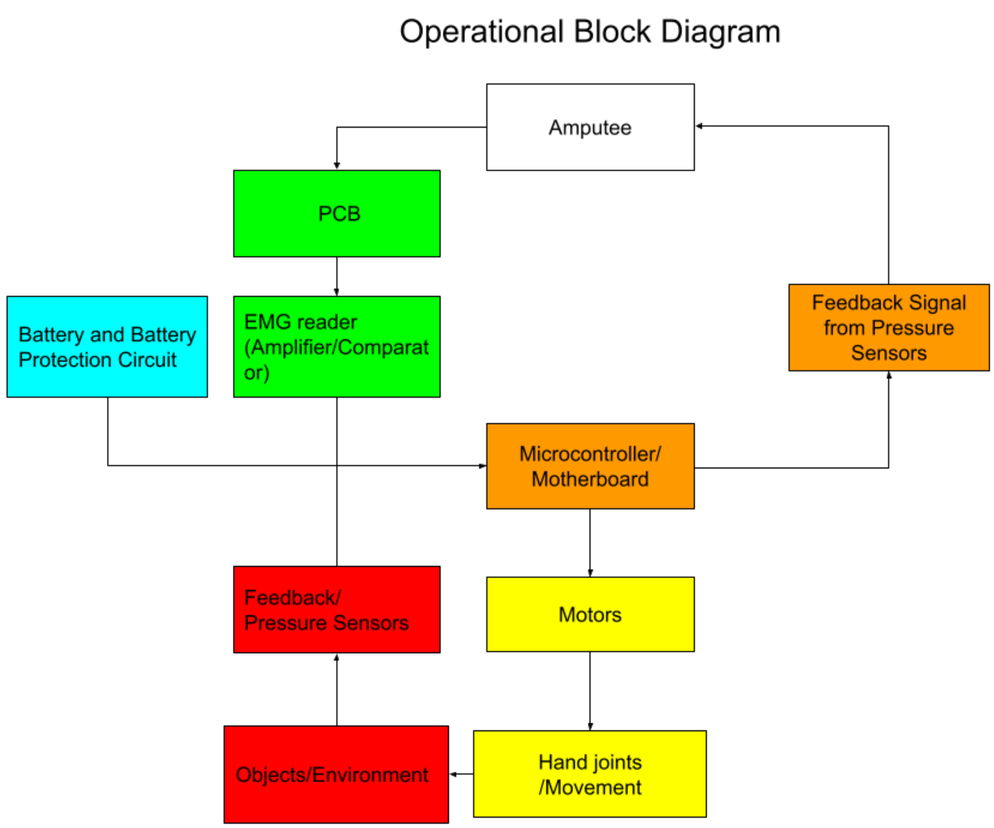
4.2.3 Decision-Making and Trade-Off

The pros and cons of each option were weighed using a few simple metrics, the first of which is ease of implementation. This metric completely ruins the idea of having any other form discussed during the design decision process due to the specialized implementation of all the other methods. The second metric was cost. The cost to generate readable EMG signals from any of the methods other than the opposite method and surface EMG is exponentially higher simply due to the equipment or surgery cost that is associated with it. The final metric used to choose the final solution in our design was the amount of background knowledge/ research. Most of the methods had a large amount of research that allowed for a greater understanding of how to use these techniques. However, only the surface EMG method had the least amount of background knowledge necessary in order to implement.

4.3 Proposed Design

4.3.1 Overview

Here is the project block diagram showing an overview of the integration of the areas of the project.



The microcontroller is where all of the signals are taken in and interpreted to dictate appendage movement. It also sends out signals generated by the pressure sensor to the amputee so the user can feel the feedback when they touch an object or any surface. This is one of the most important parts of the project.

The battery provides power to all of the components in the prosthetic arm. The battery protection circuit protects the battery from being compromised from overcharging, power surges, and indicates when the unit is done charging or low on battery.

The flexible PCB/EMG Pads pick up the signals from the muscles in the amputee. Specifically picking up neurons firing. The EMG amplifier amplifies the signal from the pads so the microcontroller can have an easier time analyzing.

The TENS unit is what we are using to send an electrical pulse back to the skin to act as feedback to the user.

4.3.2 Requirements & Constraints

Physical constraints:

- Prosthetic arm must weigh less than 8 lbs
- Cannot be longer than 20 inches

Physical Requirements:

- All fingers must be able to move independently
- Must be able to respond to touch/pressure
- Must be able to be held up by its own weight by socket

Power constraints:

- Must not exceed an operating temperature of more than 50 deg C
- Must have ease of charging
- Must have little to no exposed wires

Power Requirements:

- Must be able to operate for an 8 hour day
- Must be able to charge within 8 hours

Electrical constraints:

- Must be able to be shut down after signal loss
- Must be able to withstand light amounts of rain

Electrical Requirements:

- Must have all circuitry operate with low power and voltage levels

- Must be able to transmit power safely and effectively between the battery and motherboard

4.3.3 Engineering Standards

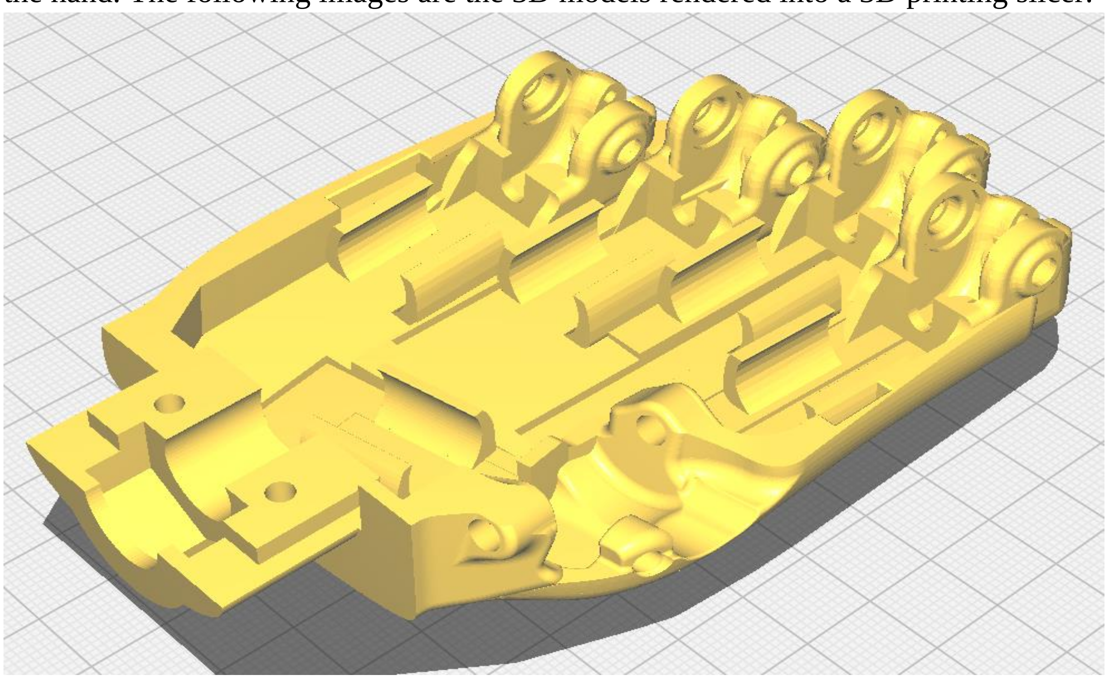
A lot of the devices and products used in the project were made according to IEEE standards and will not be modified.

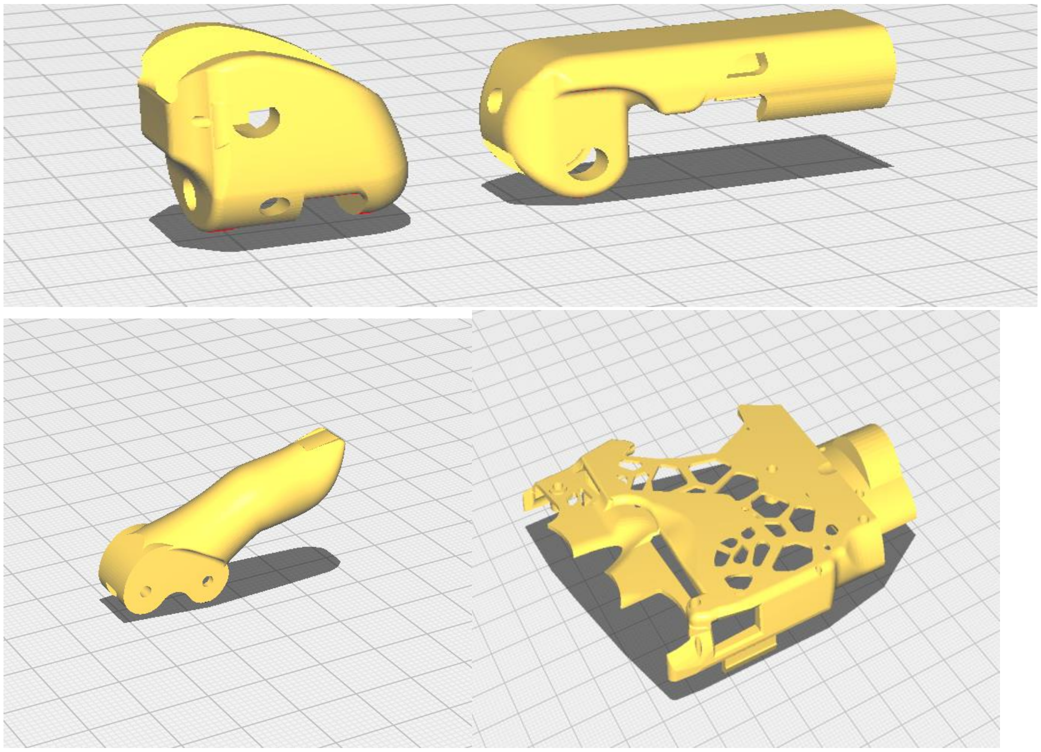
For the mechanical portion of the arm, some standards used were the ASME standards. This applies to creating tolerances for the different moving parts on the device. Such as tolerancing and dimensioning.

For the PCB, we adhered to the IPC-2221 Standards. These are a set of standards that help us build an efficient and successful PCB that will run into the least amount of issues when it comes to testing.

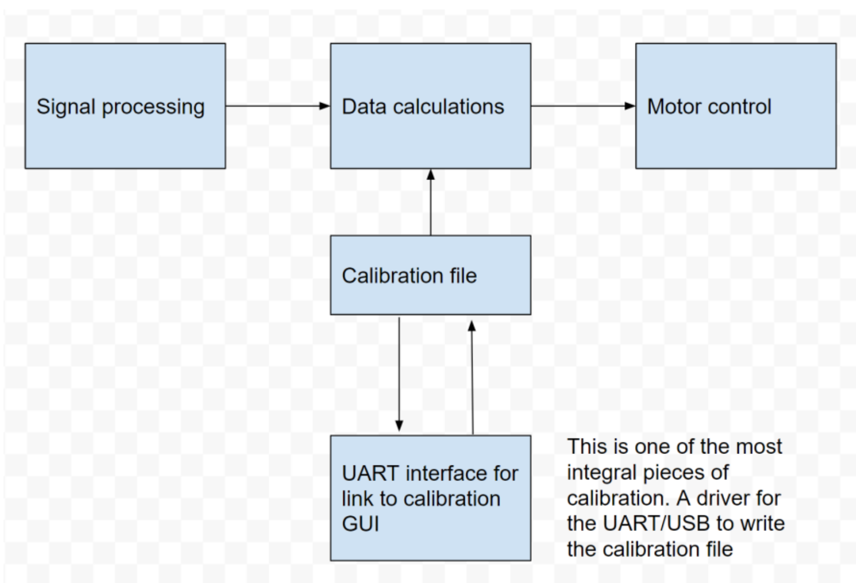
4.3.4 Detailed Design and Visual(s)

The mechanical portion of this project has been fairly set in stone from the beginning with small changes being made to accommodate for manufacturability and assembly of the hand. The following images are the 3D models rendered into a 3D printing slicer.





We also have an outline for the microcontroller unit which houses all of our software for the prosthetic arm. The UART interface is to communicate with the sensors and motors to send and receive data from. This is the embedded system diagram of the project.



4.3.5 Functionality

The user should be able to pick up objects, receive feedback from when they touch objects or surfaces, and as the ultimate goal, be able to write with a utensil.

The device is designed to get the user as close to normalcy as possible with the prosthetic arm. This would include the ability to do some of the daily activities they once were able to prior to the loss of their limb.

4.3.6 Areas of Concern and Development

With our product, there are certain goals we set that would achieve milestones for a user but in the end, how the user feels about how well the prosthetic works is subjective. The goal is to satisfy the user and not just hit certain qualitative milestones. This is why maintaining communication with the adviser and client as well as putting components of the prosthetic through rigorous testing was of the utmost importance.

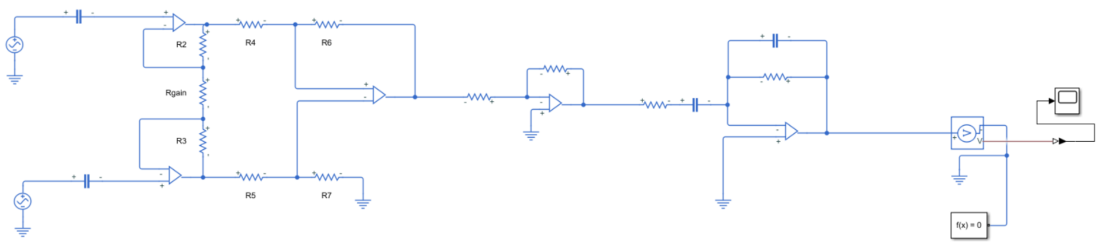
One of the primary concerns we had is how comfortable the device would be for everyday use. One of the top complaints for the prosthetic arms by amputees is the weight and how comfortable the device is. We also had concerns about how accurate we can get the movements based on signals from a user picked up by the emg pads. The main thing we did for this was to pay close attention to testing each component and creating a cohesive and comprehensive test plan to ensure each part we used was working properly. The software portion and signal processing played a huge role in interpreting the data we are given.

4.4 Technology Considerations

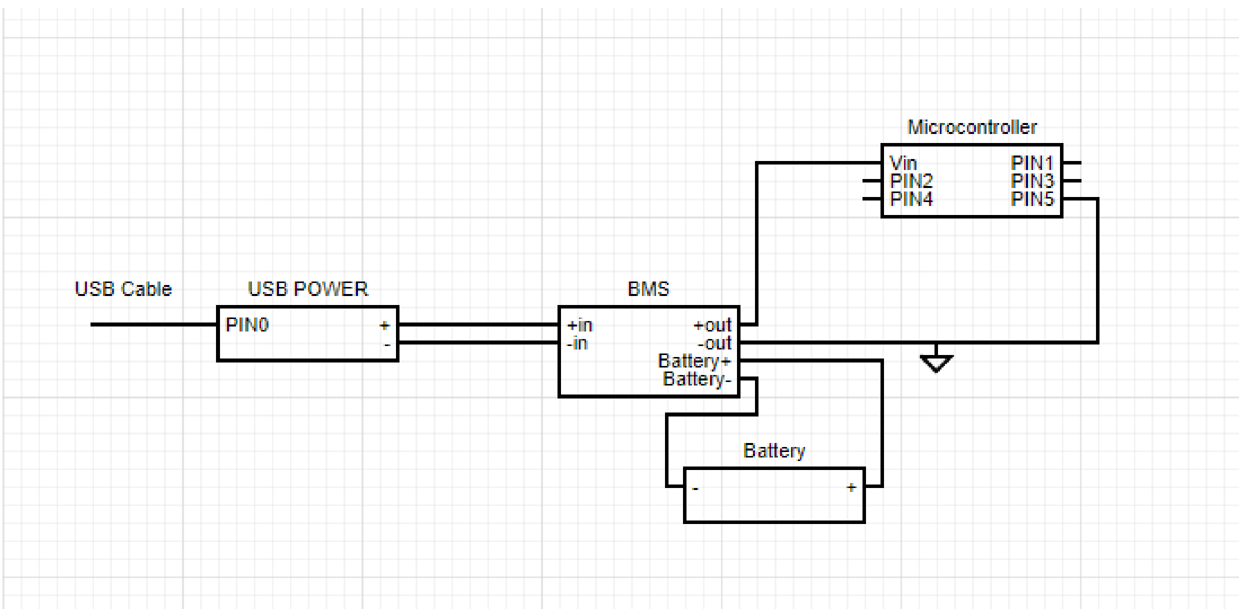
We have gone to great lengths to decide the best system of measuring as well as providing feedback to the user. We have settled on a custom EMG solution to record nerve signals and transmit signals to the microcontroller. We originally planned on modifying a TIMS unit to provide feedback to the user, but we switched to a linear actuator motor in the end. This allowed for more control of the feedback system.

4.5 Design Analysis

4.5.1 Amplifier Design



The above Amplifier is an instrumentation configuration that is able to detect voltage differences between two different points. The amplifier is designed to have a high input impedance to be able to pick up the voltage difference between the two ends of a muscle in the forearm. The output is in the range of a few millivolts to 30 millivolts.



4.5.2 Battery System

The above diagram shows a basic outline of the battery charging and management system. The system is too large to include in one diagram as it utilizes the charging circuit, BMS, motherboard and battery. This allows for maximum battery safety as it has double voltage/ current protection for charging the battery as well as a controller to limit power usage from the battery into the rest of the circuit. The Battery Management system also has built in short circuit protection so if the ground is relative to the Vin as opposed to the Vout it kills the whole circuit.

This system is able to power our system to the correct specs. Our battery ranges from 7.4v to 6v at minimum charge. Our circuit will continue to operate until it reaches 5v but the time from 7.4v to 5v is around 10 minutes. The motherboard has voltage regulators set up to manage this to allow for safe operation of the device.

5 Testing

5.1 Unit Testing

Motherboard:

The motherboard was tested by running a series of inputs into the MCU I/O pins and expecting certain outputs that have been determined by the software team. Tools that we needed were a DC power supply and oscilloscope.

EMG circuit:

The amplifier circuit was tested by inputting a multitude of different EMG signal magnitudes and checking to see if the desired output voltage range of 0-3.3V was achieved. Tools necessary for the testing methodology were the EMG electrodes, a DC power supply, and an oscilloscope.

Touch sensors/Feedback circuit:

The touch sensor and feedback circuit design is based on a provided schematic from the manufacturer of our sensor. It had to be modified to allow for the use of them in series as we switched to a design that averages pressure across the fingertips and provides this as feedback to a motor as opposed to the original idea of using electronic feedback through more surface EMG pads.

BMS/Charging Circuit:

The BMS/charging circuit was tested by using a DC power supply. The voltage input was changed from zero to 7.5 volts. On the BMS charging circuit the LEDs will light up in accordance to the Battery level.

Motor driver circuit:

The motor driver circuit was tested by attempting to move the motors being used in the design in both small and large increments based on specific ranges of inputs. Tools necessary for this testing included a tachometer, an oscilloscope, a DC power supply, and a multimeter.

MCU software:

The testing for the MCU consisted of two major portions. Both the output and input processing need to be processed. When it comes to both of those, Google Tests will be used to ensure that each module has its necessary processing covered. These tests will be done locally, however we may be able to look into running them from a UART connection to the MCU. Additionally, a simulator for the MCU might be used.

Mechanical Movement:

The mechanical movement will be tested based on the ability to have fluid movement without binding the motors or any loud noises when in motion. No tools are necessary for testing mechanical movement as the metrics of the testing methodology are purely based on opinion.

5.2 Interface Testing

When it comes to interface testing, we have to ensure that the data flow is correct in all aspects of the system. That's why in addition to our individual module testing, we will also test the flow between input processing to calibration data processing. Also we will need to test from the processed data to the motor output values.

5.3 Integration Testing

The critical integration paths for the design are the connections between the software side of the project to both the electrical and mechanical areas of the project. This includes how sensors are interpreted by the MCU, how the software analyzes that data, and how the software sends signals to the mechanical components for movement. This can be tested through the oscilloscope, using a compiler, and also using visual tests. After each area of the project is completed, we will then connect them together to test the integration and limit as many problems as possible(Unit Testing).

5.4 System Testing

Google Test used for testing the MCU code. This library test for C/C++ code for expected unit tests. This should be sufficient for testing the MCU base level code.

Additionally, the calibration software was provided by Texas Instruments with the purchase of the MCU.

5.5 Regression Testing

As the project advanced we implemented a system of testing where any change made we tested in depth that all functioning components remained operational. This was important as early on we were finding that what we thought were unrelated changes were causing problems in other systems. This method allowed us to verify product integrity while advancing in other sections of the device.

5.6 Acceptance Testing

Acceptance testing is done when we believe individual components were completed. An example is testing motor traversal speed as well as max rotation distances so as to not cause damage to the prosthetic shell/fingers.

5.7 Security Testing (if applicable)

One of the important aspects of security for our project is to ensure an actor can't manipulate the MCU and shock someone or cause other nefarious behavior. When it comes to security however, the MCU doesn't have any wireless capabilities. It could potentially get attacked when plugged into a computer, but the risk is extremely extremely low.

5.8 Results

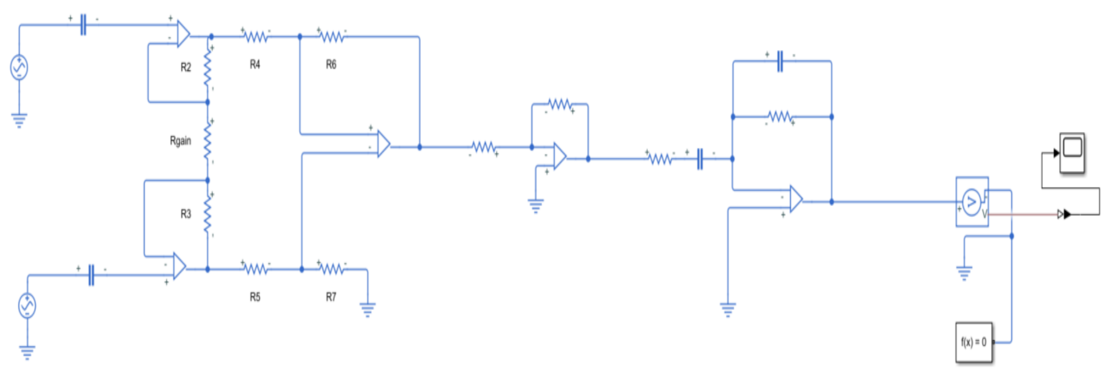
With the results of the test, we would expect to receive either the correct values or satisfactory values for a component or a system of components. With these results we can tell which parts are functioning properly or need to be adjusted. Some results will be somewhat subjective however because it will be based on the client and or opinion based conclusions. An example of the opinion based result would be whether the finger joints had a fluid movement when being moved by physical force. Some results will influence others however and some compromises will have to be made.

5.8.1 Testing: EMG circuit

The EMG circuit was first tested on a breadboard. The goal of this part of the project is to receive the electric signal from the muscles in the arm when they contract and relax. The EMG circuit is built of an instrumentation amplifier, a bandpass filter, and a simple amplifier to amplify the signal to be used by the MCU. Each part was to be tested separately. The final version of the EMG would be located on the PCB of the prosthetic arm which would also need to be tested.

5.8.1.1 Instrumentation Amplifier

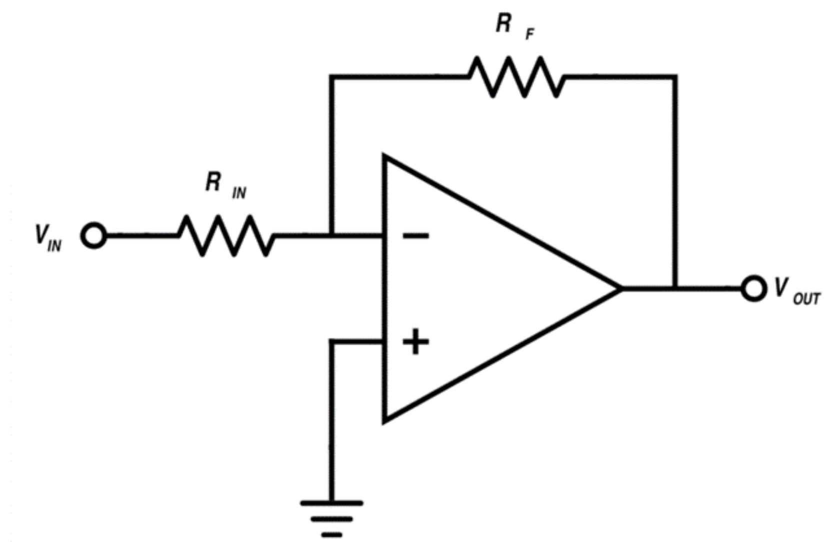
This consists of three operational amplifiers. The function of this piece of hardware is to pick up the difference in voltage from opposite ends of the customer's muscle in the forearm and output it into a signal to be used. The signal should be in millivolts. This needs to be done for each finger location on the prosthetic arm. Below is the Instrumentation Amplifier in question.



The Operational Amplifier(OpAmp) to be used in the circuit needs to be chosen. For this project, we chose the LM4565FJ-GE2. This is one that would be low noise, operate effectively with a source voltage of 5 volts, and be sensitive enough to be able to pick up the signal from the muscle through the EMG Pads. In total for our specific instrumentation amplifier, we need three amplifiers for each final circuit implementation. Once the OpAmp is chosen, it needs to be tested. On a breadboard, we set up the proper test for each component. This was done through the following:

1. On the breadboard, the OpAmp needs to be connected to a 3.3v DC source. The output needs to be connected to an oscilloscope to be able to read the output signal.

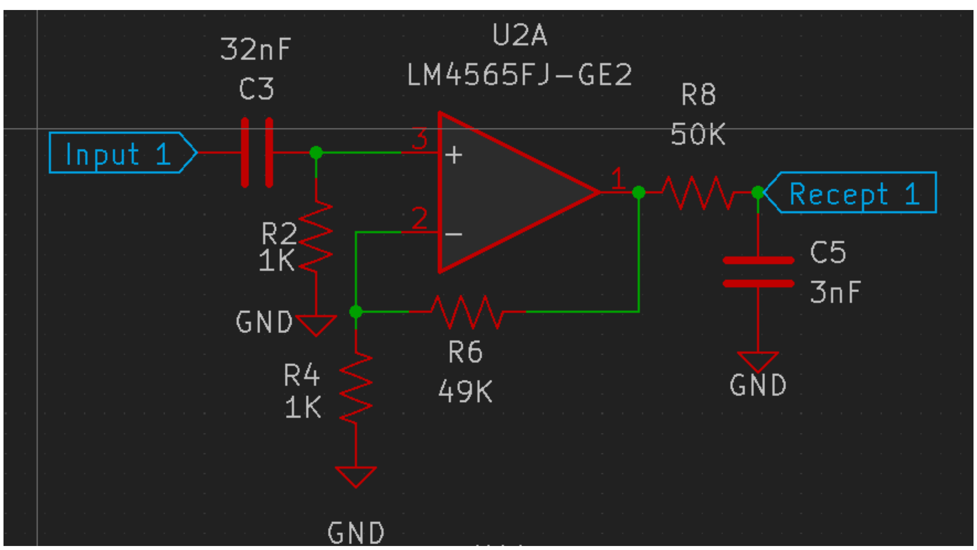
2. Using a simple inverted OpAmp configuration, you can test if the operational amplifier reaches the appropriate gain and DC voltage output. For the resistor connected to the output (Rf) it's best to use a potentiometer to adjust the gain freely. Below is a diagram of the inverting OpAmp.



3. Once the DC test has been conducted, the AC test needs to be conducted. This has to be done between a frequency of 1Hz – 500Hz.

After each OpAmp has been tested, it's time to put them into configuration for the instrumentation amplifier. Each resistor and the capacitor should be brand new and tested before being used. When the circuit is finished, the same steps must be followed from before. The difference is that there are two inputs for the Instrumentation Amplifier.

5.8.1.2 Band Pass Filter



The band pass filter we used had a range from 20Hz to 500Hz. To set it up, we start out with a basic operational amplifier. On the breadboard we set up our circuit according to the diagram above. After hooking up our power supply and input signal, we can change the frequency of the signal and watch the output of the filter decrease as it reaches the upper and lower bounds of the frequency range.

5.8.1.2 Complete EMG Circuit

Once all individual amplifiers have gone through testing, they must all be connected together. The Instrumentation Amplifier output must go into the input of the bandpass filter, and then the output of the band pass filter must go into the input of the basic operation amplifier.

With all of the amplifiers set up, we can test the whole circuit. This is done by connecting the emg pads to the ends of the muscles in the forearm. Connecting the output to an oscilloscope, we can observe the change in voltage as the user contracts and relaxes the muscle being measured.

The results of this completed EMG circuit were inconclusive and one of the major roadblocks in the progression of this project. Excessive noise was seen throughout the entire experiment and no distinguishable pulse could be measured when clenching or in a relaxed state. Overall voltage seen on the oscilloscope was also moving in no particular pattern even when the arm or muscle group was in a relaxed state. Troubleshooting began and it was determined that the capacitance and resistance between the EMG pad and the electrical signal was too great causing excessive noise and in many cases loss of signal entirely. To remedy this issue a electrolyte gel was ordered to help reduce these values.

5.8.2 Testing: PCB/Motherboard

For the MCU, powering up the component failed. Multiple parts on the motherboard began to heat at a very rapid rate. After troubleshooting the primary power components it was determined that the primary power trace had been blown causing a massive short. This short caused a current draw of nearly 3 Amps. In order to test this theory further a second motherboard was populated with all of the power components one at a time in order to test for current draw and if the trace that the team believed to be blown would could be fully determined. The second motherboard did not pull near the current through the board as the first had but a significant amount of current (512 mA) was observed when the 3.3V linear voltage regulators had been added to the second motherboard. A little more indepth research led the team to believe that that the trace between the 5V and 3.3V regulator was not of correct width for the expected current draw of the motherboard. The images below show the required trace width requirements for both the inner and outer layer traces that make up the power distribution circuits in the board. These trace widths could also be mitigated by adding more of the 5V voltage regulators allowing for less current to be drawn from a single regulator and thus lowering the required width of the traces.

Inputs:

Current	1.5	Amps
Thickness	0.035	mm

Optional Inputs:

Temperature Rise	5	Deg C
Ambient Temperature	25	Deg C
Trace Length	133	mm

Results for Internal Layers:

Required Trace Width	2.08	mm
Resistance	0.0316	Ohms
Voltage Drop	0.0475	Volts
Power Loss	0.0712	Watts

Results for External Layers in Air:

Required Trace Width	0.800	mm
Resistance	0.0823	Ohms
Voltage Drop	0.123	Volts
Power Loss	0.185	Watts

Notes:

The trace width is calculated as follows:

First, the Area is calculated:

Area[mils^2] = (Current[Amps]/(k*(Temp_Rise[deg. C])^b))^(1/c)

Then, the Width is calculated:

Width[mils] = Area[mils^2]/(Thickness[oz]*1.378[mils/oz])

For IPC-2221 internal layers: k = 0.024, b = 0.44, c = 0.725

For IPC-2221 external layers: k = 0.048, b = 0.44, c = 0.725

where k, b, and c are constants resulting from curve fitting to the IPC-2221 curves

5.8.3 Mechanical Movement

The mechanical movement testing came from manually moving the fingers and testing the joints to check for fluid movement after assembly had occurred. Small adjustments to pin hole dimensions and widths of certain parts needed to be made in order to achieve this manual fluid movement but the final desired result was reached. When motors were added to the system to allow for autonomous movement less desired results were produced. Due to the size and load on the small micromotors a high pitched whining sounds can be heard during all areas of finger movements. This sound is only amplified when additional load such as attempting to press against something was tested. Further changes will need to be investigated to have more powerful motors which can handle the force at a lower operating speed to decrease overall noise.

5.8.4 Touch Sensors

The touch sensor circuits were tested individually in order to see if any additional background noise could be detected and thus cause inaccurate readings by the MCU. A sample circuit was set up on a breadboard and pressed on with different clamping forces through the use of a small wood clamp. Once a range of tests had been completed, the clamp was released and the voltage through the test circuit was monitored for 30 seconds in order to test whether or not the voltages settled. In most instances the voltage stabilized after three seconds of pressure change or pressure release.

5.8.5 BMS Circuit

The BMS circuit was tested on a breadboard by setting all of the components and subjecting the circuit to an input voltage of 5V. This simulated the standard voltage that comes out of a phone charger. The voltage that would be sent back to the battery through the battery terminals was measured to be 7.583V which is slightly higher than the nominally charged voltage of 7.4V experienced by the battery. Further implementation was tested by applying 7.4V at the battery terminals and testing to see if the BMS circuit relayed the correct charge level of the simulated battery. This test had some form of success but only 3 of the 5 charge indicator lights lit at this voltage level. The following lights would turn on when a voltage of 7.8 and 8.3 V were hit respectively.

5.8.6 Motor Driver Circuit

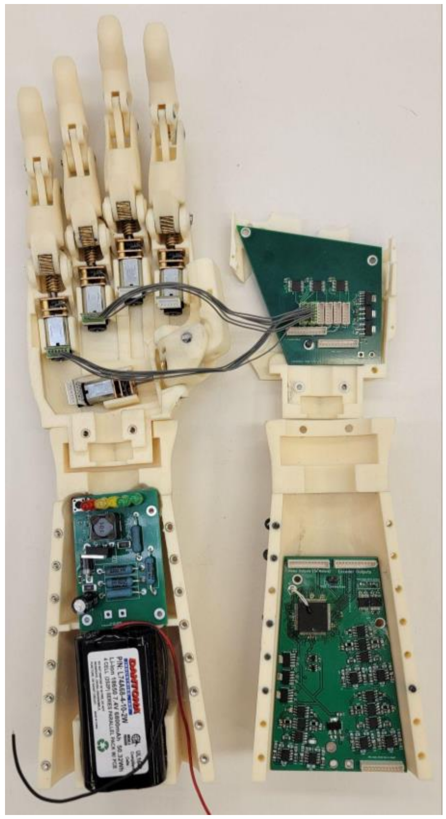
The motor driver circuit was tested through the PCB as the motor drivers were only found in surface mount components making it difficult for the team to test the circuit in a breadboard environment. Once the PCB was populated with the correct components a voltage of 7.4V was applied to the power input terminals. This then turned on lights found on the motors and ensured that the encoders of every motor were powered. Since the motherboard at this point had already failed, a separate breadboard was connected to a raspberry pi in order to test encoder outputs. Proper measurement of the encoder outputs were seen by the raspberry pi and the motor drivers could be controlled through all of the ports adding to a successful implementation of the driver board circuit.

5.8.7 MCU Software Testing

Our main goal was to load initialization code from Texas Instruments that was specially made for our specific microcontroller unit. Unfortunately, we ran into the issue of size, as it turned out that this specific MCU that we had purchased was intended to run in parallel with external storage. We had estimated that the onboard memory would be sufficient, but failed to take into account the sheer size of extra code it would take to run the MCU under the hood. We came up with a second plan; create our own initialization code to set up all the MCU pins without much overhead memory cost. We wrote initialization code to match the pin mapping that we initially created, and continued to update the code throughout the course of this semester. We began to write the initialization code by hand before switching to the Texas Instruments System Configuration software that helped automate and simplify the process. We maintained these files until we were able to get our hands on the MCU, but unfortunately ran into the same problem with the lack of memory. Even loading the basic library's that Texas Instruments used with compiled C code on their was impossible due to size constraints. This issue, coupled with the motherboard failure led us to begin working on Arduino/Raspberry Pi code to run the motors. We tested the motor control on single motors using an Arduino and were successfully able to maneuver it in the ways we wanted to.

6 Implementation

The most important aspect of our project is that the different components and areas of the project are able to interact with each other. Whether that be directly or indirectly. The EMG circuit must be able to communicate with the MCU of the project. And the MCU must be able to send out the necessary signals to the motors and the feedback sensors.



We have three PCBs. The motherboard houses the Microcontroller, EMG Amplification circuits,and voltage regulators. The battery connects to the battery charging circuit to effectively control and monitor the voltage in the battery. The final PCB is the driver board that drives the micro motors located in the prosthetic arm and provides a supplementary power distribution. In finality, the battery connects to the charging circuit, the charging circuit connects to the motherboard to power the circuit, and then the motherboard connects to the driver board that powers the micro motors.

7 Professional Responsibility

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

From the IEEE

Work Competence: to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

Financial Responsibility: to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;

Communication Honesty: to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems

Health, Safety and Well-Being: to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment;

Property Ownership: to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses;

Sustainability: (Repeated) to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment;

Social Responsibility: (Repeated) to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment;

They don't differ too much. But certain codes of ethics are grouped together into one in the IEEE, while in the NSPE version there are separate and specific categories for each code.

7.2 Project Specific Professional Responsibility Areas

Health, Safety and Well-Being: (High) Because our project interacts directly with the user and aims to improve the quality of life, this was the highest priority for our project.

Property Ownership: (High) There are already certain technologies that exist that are similar to our product and/or are doing similar tasks. We made a large effort to differentiate ourselves from the rest.

Financial Responsibility: (Medium) This isn't really something that affected our project. None of us were in other businesses that would want the project to fail. The cost of the project is supposed to be as low as possible while also providing a high quality product.

Communication Honesty: (Low) The project goal was straightforward and there weren't many things we could hide from the trained eye.

Sustainability: (Low) The materials we used in this project could have had an effect on the environment if they were disposed of improperly. Especially the lithium-ion battery.

Work Competence: (High) It was essential to us to provide as high quality of a product as possible because of the nature of the project and its goal. We had separate groups according to expertise but we also had discussions so we know what is going on in each area of the project.

Social Responsibility: (High) If this project worked as planned, then it would greatly benefit society. With an aim of helping amputees and coming at a cheap price while also being noninvasive, all of these things would objectively be a positive for a certain demographic in society.

7.3 Most Applicable Professional Responsibility Area

Health, Safety, Wellbeing:

Our project is the prosthetic arm. Because of this, the user's safety, health, and wellbeing are the highest priority. Many of the ways we design something is specifically to protect the individual or improve their wellbeing. Such as creating new parts that weigh less, or making certain components placed away from the user's skin to reduce the amount of heat getting to the individual.

8 Closing Material

8.1 Discussion

The final product of this project was to be a fully functional robotic prosthetic arm. This arm would be equal to or less than 8 pounds and would have touch feedback sensing allowing for as close to full functionality as possible. This prosthetic would also be made of a material that can handle day to day operations of the user without much damage to the components. There were many different challenges faced throughout the project which delayed initial progress and even caused complete stoppages in other areas.

8.1.1 Milestones

Over the course of the design process many things went right. Our group started with very inefficient time management that improved a great deal as the project advanced. As a learning experience this project was invaluable as many members of the team had not worked on a system that has so many areas of expertise required. This resulted in everyone gaining exposure to disciplines they have not worked in such as electrical engineers working on the assembly as well as working around constraints of a mainly mechanical system. This project also trained respect for the time required to complete portions of the project, this was observed in a large part due to the fact that our software team very often had nothing they were able to work on until other systems were completed by the electrical team.

As far as individual systems of the device are concerned most designed components functioned exactly as intended. The charging system, while missing a usb connector that was ordered but never came in, functioned perfectly in testing. It featured a built-in battery level monitor that shows approximate charge levels of the battery. The Driver board for the motors functioned as intended in testing with encoders checking out properly, successful movement of motors and correct voltage supplied.

As far as software testing was concerned, software control motor control was successfully done on a raspberry pi and breadboard setup. This was conducted after the motherboard stopped working.

8.1.2 Setbacks

Concerning the few shortcomings of our device, there was a failure of the printed circuit board for our motherboard. We believe there is an issue with the trace between the 5V regulator and 3.3V regulator. This caused improper voltages to the mcu and was unable to be corrected as we would have needed to order a replacement microcontroller and pcb, this fell outside of our time constraints for the project. All devices that were able to be tested without microcontroller use were within expected parameters.

8.2 Conclusion

As the project for the prosthetic arm comes to a close, we can look over the goals we set and the amount of progress we have made to attain them.

With the mechanical design, we were able to design a hand and forearm prosthesis frame. The hand includes movable fingers and a thumb with the ability to grip. The motors were found to be inadequate for what we strived for and the design on use of different motors will need to be revisited later. This part of the project was a success overall, but there is still room for improvement.

For the electrical design of the project, we ran into many issues. One of those being the power delivery for the motherboard was faulty and burnt out the board. But for the individual designs, the circuits were able to be tested individually and were able to be assessed. In finality, the motherboard was the core of the electrical design. But our electrical designs were satisfactory. With that in mind, we also found issues with the functionality of our circuits. Including how the EMG amplifiers need to be as close to the skin as possible. This is another area for future improvement that will greatly improve the overall design and usability of the arm.

For the software design, we were able to initialize and construct rough embedded systems code. Unfortunately due to the issues found on the electrical side of this project the actual code was unable to be tested and used. Other issues were persistent through this project primarily with memory size of the overall code and implementation of external memory will more than likely be required to operate the arm to its full capability.

Overall, this project had a wide variety of engineering elements and challenges allowing the group to gain experience and knowledge in a wide array of engineering disciplines. While the final product could not be made to work for the final presentation time, the amount of progress made and professionalism taken to ensure that the product was as sound as could be in the time we had showed substantial capabilities of all participating members.

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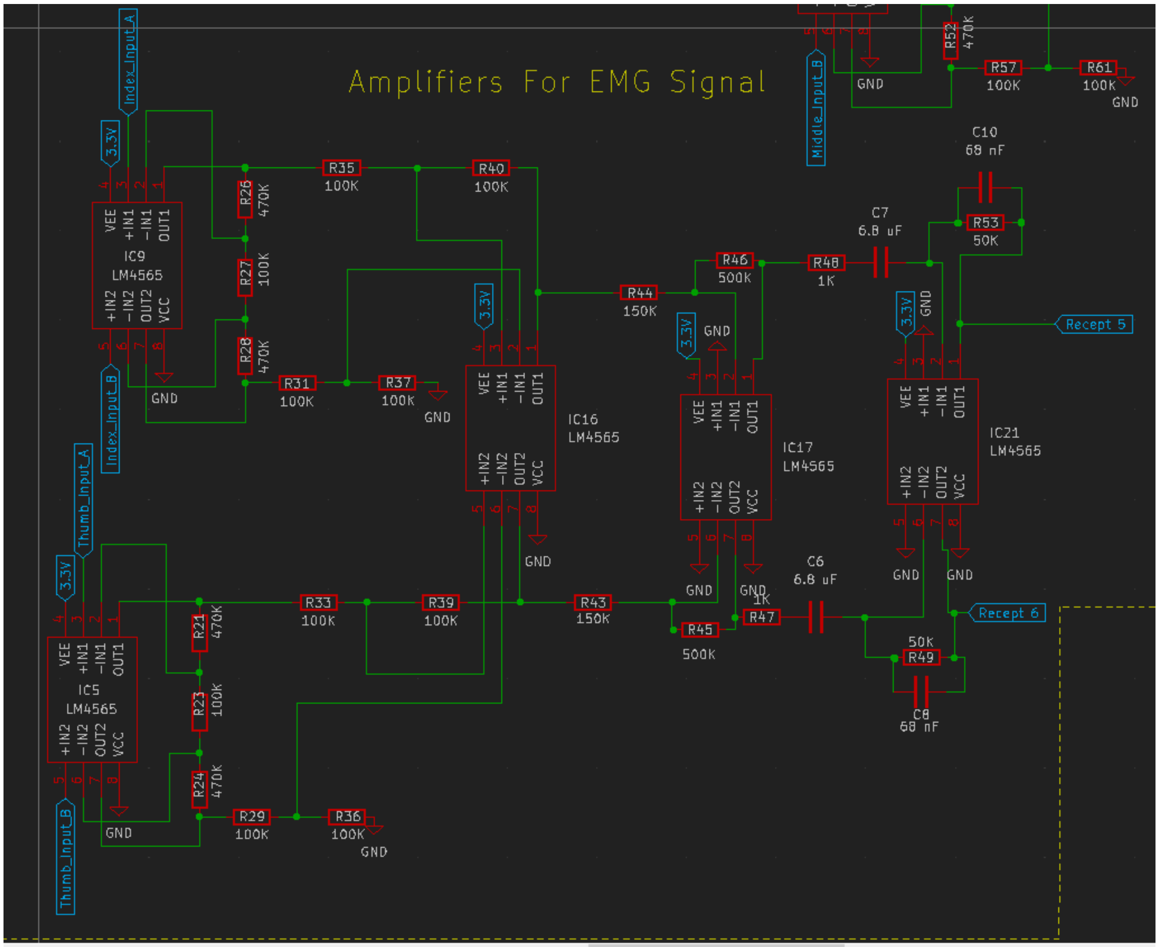
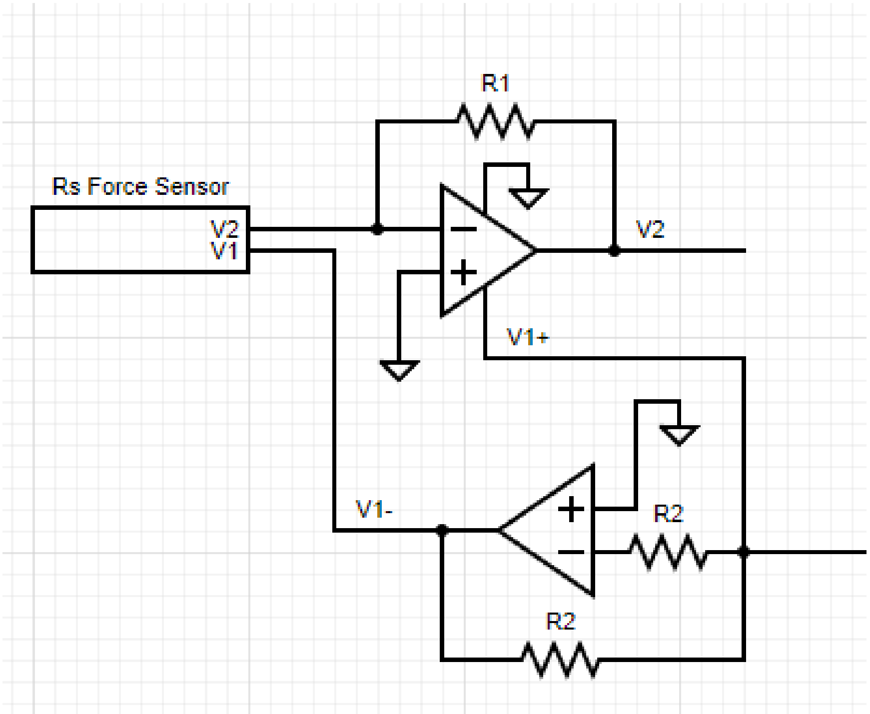
8.4 Appendices

Instrumentation Amp and Band Pass Filter using the **LM4565FJ-GE2** Op-Amp

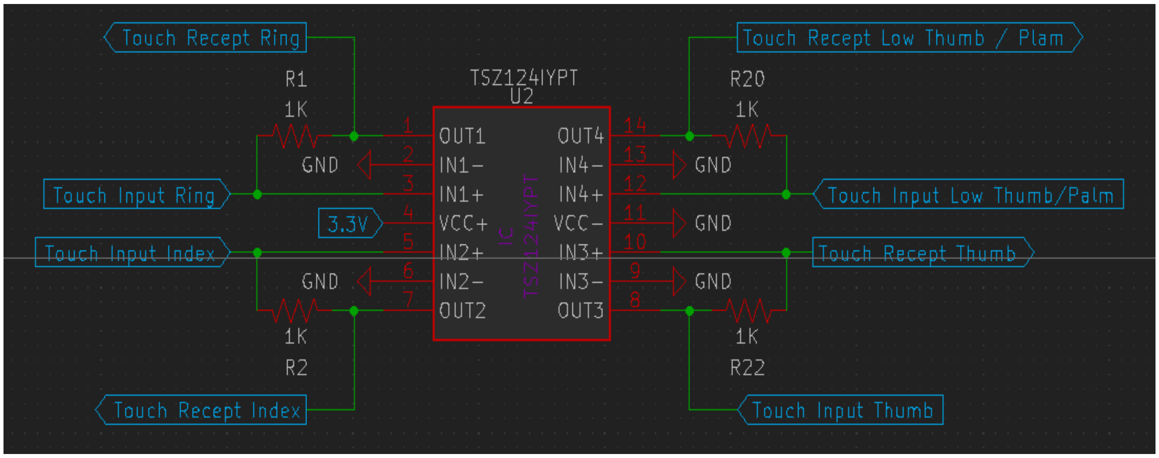


- Surface EMG signals range from 20 to 500 Hz
- High Corner frequency at 500Hz
- Low Corner frequency at 20Hz
- Filter is being used to amplify signals from MIKROE- 2456 EMG Pads for accurate measurements from MCU
- Final Gain of Av = 500 V/V

Touch Sensor GHF-10 Feedback Circuit



- $V2= -V1*(R1/Rs)$
- Rs force sensor values known through datasheet and verified through experimentation
- Allows for scaling to MCU parameters for V2
- Fine control of V1 from motherboard
- V2 scales linearly with force applied
- Can be modified to scale on a curve with minor changes
- This design is set up for one sensor per finger
- Final configuration and circuit schematic shown below



8.4.1 Team Contract

GROUP: sdmay23-13 (Prosthetic Arm)

PROFESSOR: Dr. Nicholas Fila

FACULTY CONTACT: Dr. Santosh Pandey

TEAM MEMBERS: Jack Vetsch, Scott Bolek, Sean Gray, Erik Raman, Jacob Eisbrenner, Leo Forney, Jeremy Wallace

DATE: September 23, 2022

Project Summary:

The goal of this project is to make a non-invasive yet fairly responsive prosthetic arm that has touch-sensing capabilities within the fingertips and portions of the palm.

Deliverables Due Dates:

December 2022: Mechanical parts designed and manufactured, Breadboard circuits, Necessary signal processing software

Spring Break: Completed PCBs ready for assembly with the rest of the prosthetic

End of Semester: Testing, fine-tuning, and any extra necessary mechanical design

Team Goals:

We hope to communicate changes in schedules, individual responsibilities, and conflicts clearly, kindly, and in a time-efficient manner. We plan to have as many team members as possible meet with Dr. Pandey, our faculty advisor, on Wednesdays at 1:30 pm in Coover Lab 1050. Those with class conflicts will be filled in either in class the following day or through the GroupMe or team email. Our final goal is to have a functional prosthetic arm that will improve the quality of life for the patient as well as have the ability to provide feedback to the user giving them the sensation of full mobility and touch capabilities.

Individual Goals:

Jack: I have a very busy schedule, but I am passionate about this project, and therefore I will work diligently to communicate with my group and make myself available whenever possible to foster a great team environment and lead to a successful project. I have significant leadership experience and feel I can be a successful coordinator of responsibilities for the team. I am a strong creative and decision maker, but I also recognize when I will have to defer and delegate responsibilities to whoever in the group is best qualified.

Sean: This exact project is the main reason I chose engineering as my major and I am extremely excited to try to bring it to fruition. I am very comfortable with coding, mostly in C, and although I am not as good with electrical hardware I'm sure I could learn how to do what is necessary in a short time.

Scott: This project is something that has interested me for a long time, it relates to my future career as experience in control systems. I am dedicated to putting in the work to make an exceptional product. I have a lot of experience with technical writing for projects like these so if we need any extra documentation done that can be arranged pretty easily. During this project I hope to develop skills I can add to my resume as well as a project to cap my portfolio.

Jeremy: For me, this project is bringing most of my interests into one project. Robotics, mechanical, electrical engineering, and biomedical engineering all play a part here and I'm excited to see how this all pans out. My goal is to be as helpful as possible to my team and help the project go along smoothly. I also want to help realize a quality end product that will help cap off my time here at the university. I also hope to gain more knowledge about the other disciplines involved in this project as well.

Jacob: This project has been in the back of my mind for close to a year and a half now. When given the opportunity to actually turn it into a working device I had to jump on the opportunity. I have many goals within this project from increasing my mechanical and electrical engineering skills, to effective team communication, and project management. I am determined, detail-oriented, and time efficient in my work, I hope to bring all of these qualities to the team and put them in place during the development of this project.

Leo: Coming from a family with a very strong medical background, I was the oddball that chose to go into engineering. This project stood out to me because I'd really like to apply my knowledge on something that can really help someone. When it comes to my technical skills, I have a great amount of experience in embedded systems, lightweight code (like C/Rust) and signal processing. Additionally, I have a very limited knowledge on electrical circuits but I'd really like to expand on that. Overall, I have a great amount of experience in communication and team leadership that I can help our team thrive.

Erik: Neural prosthetics and BMIs has been a fringe interest of mine for a year or two now. Since electrical engineering wasn't my strong suit, I switched to software and had to put BMIs on the backburner while I tried to catch up in a new major. This project presents my first opportunity to work on a project in university that aligns with my personal interests. I have a basic understanding of neural prosthetics, as well as a year of electrical engineering under my belt and some signal processing coding experience. I've worked with Arduinos and microcontrollers before, but the main skills I bring to the table are my practice with traditional coding languages (C++, C#, Java, etc.) and my experience working with teams, both in university and in the engineering industry. My goal is not only to get an A and create something with my team we can all be proud of but also to learn a focused set of skills relating to BMIs in hopes that my interest can develop into a long-term career.

Deadlines and Conflict Resolution:

In the case of poor quality contributions, the team member who feels as though work has been neglected or not given full effort will kindly ask the offending team member in the group chat if they need help finishing the work or if they will accept changes from the team member initiating the contact. Multiple offenses of low-quality work will be met with a team intervention and notification of Dr. Fila. Failure to change behavior could result in removal from the group.

Missed deadlines for team-assigned tasks related to project research and idea theorizing will not be considered detrimental, though the team will work diligently to avoid them. However, repeatedly missing deadlines will be treated the same as poor quality work. Failure to do one’s part in class-graded assignments will result in a message to Dr. Fila and a lower grade for the nonparticipating member. Again, repeated offenses will be treated increasingly harshly.

Keeping contact within the group chat will prevent speculation situations as the whole team will be witnesses to the interactions. In the case that the offending team member becomes uncooperative, the initiating team member will email Professor Fila, CCing the whole group (using the group email), to explain the situation. The process, to put it simply, will be one-on-one within the group chat first, then the rest of the group can get involved if needed. Finally, if there is still contention, the professor will be notified and asked for assistance.

Availability:

Sean: Available weekends and Tuesdays and Fridays as well as most early afternoons.

Jacob: Available weekends, Mondays and Wednesdays after 1pm, Tuesdays and Thursdays after 8pm, and Fridays after 5pm.

Leo: The best times for me would be after 6PM on Tuesdays and Thursdays and middays on saturdays. Also, late in the afternoon on Sundays would work great too.

Erik: After 3pm on Mondays, Wednesdays, and Fridays work best for me, but weekend afternoons are also available. Tuesdays and Thursdays can have time in the afternoon, but I have practices in the early evening.

Jack: Available after 4:30 on Mondays and Thursdays; and before 11am on Thursdays. Available on weekends pending work schedule.

Scott: Available Monday, Tuesday, Thursday, Friday after 5 and any time on weekends.

Jeremy: Available most weekends. Monday, Wednesday, and Friday after 12pm until 3:45. And then after 5:30. Tuesday from morning until 12:30pm.

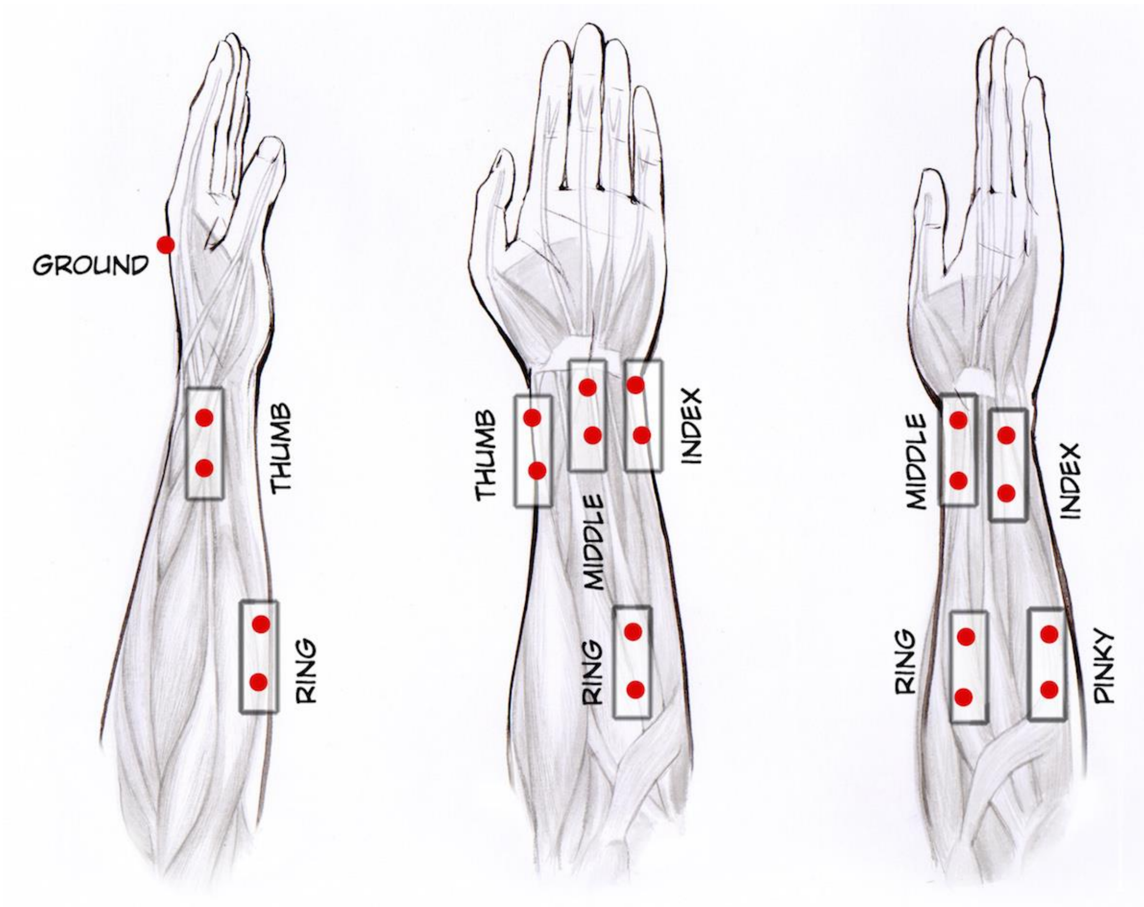
Team Member Signatures:

Digitally Signing (type full name and date) below ensures that I have…
a) taken part in formulating our team contract,
b) read and understand the terms and conditions of being a functioning member of this team,
c) read and understand the possible repercussions of failing to meet team expectations.

1. Jack Vetsch 9/23/22
2. Sean Gray 9/23/22
3. Jacob Eisbrenner 9/23/22
4. Leo Forney 9/23/22
5. Erik Raman 9/23/22
6. Scott Bolek 9/23/22
7. Jeremy Wallace 9/23/22

8.4.2 Operations manual

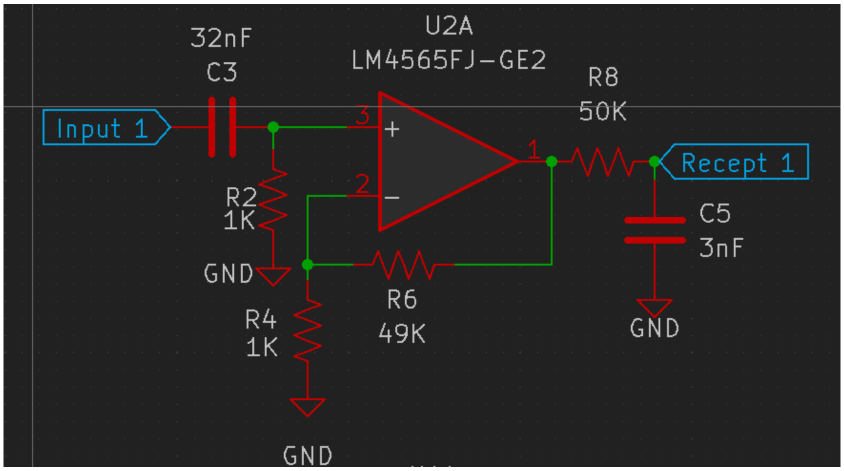
In order for the user to operate the device extreme care must be taken to thoroughly clean the remaining portion of the amputation. This will ensure that proper connection and signal can be read through the EMG pads and appropriately used by the microcontroller. It is also important that the area is as dry as possible prior to application of the EMG pads. Consistent spacing and placement of the EMG pads should be followed as outlined by the patient's prosthetist.



EMG Pad Arrangment Image Courtesy:
https://backyardbrains.com/experiments/RobotHand

8.4.3 Initial Designs

EMG Circuit



Initially, this was the only amplifier we were going to use for our EMG circuit. It turned out that we required more signal attenuation than we anticipated after we started testing the design. The changes we made were adding an instrumentation amplifier, and also adding another op amp circuit to boost the signal received from the forearm of the customer.

Touch Sensor

The initial plan for our touch sensor was to send an electric pulse back to the individual once they touched an object. This changed to using a linear actuator to squeeze the individual gently. We decided that this would be a safer and more user-friendly way to imitate feedback.

Battery Management System

After discovering that our chosen battery had included load balancing as well as overcurrent and overtemperature protection we decided there was no need for a separate integrated circuit to handle a battery management system. Insead we designed a simple charging system with built in battery charge level monitoring. This will use a USB-C input for charging which will allow us to charge from a variety of different devices for ease of use. In future prototypes this port could also be used for data transmission.