Powerflex Arm - A Powered Upper Limb Orthotic

Final Report

Group # ECE 10 / ME 29

Team Members:

Ryan Whitney – rw10e@my.fsu.edu

Derek Pridemore – dbp12@my.fsu.edu

Robert Slapikas – res12@my.fsu.edu

Jared Andersen – jaa12b@my.fsu.edu

Donglin Cai – dc15v@my.fsu.edu

Advisors:

E.C.E. – Dr. Hooker

M.E. – Dr. Hollis

Florida Agricultural and Mechanical University 1887

Florida State University 1851

Florida A&M University 1982 Florida State University College of Engineering

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1. Group Members Information

The team is composed of four senior Electrical engineering students and one senior Mechanical engineering student. All students attend Florida State University.

Ryan Whitney is a senior majoring in Computer Engineering at FSU. He works as a developer in the Tallahassee area, and has three years of experience in building wearable hardware.

Derek Pridemore is a senior majoring in Electrical Engineering at FSU. His major of interest is robotics, and has made a robotic prosthetic. After he graduates he hopes to continue to work and develop high tech bionics. Derek wants to get his Master's Degree in Robotics after graduating.

Robert Slapikas, a senior majoring in Mechanical Engineering at the FAMU-FSU College of Engineering, is working towards a Certificate of Specialization in Mechanics and Materials. After graduation, Robert plans on attending graduate school to obtain a Master's Degree in Material Science and Engineering. After pursuing a Ph.D., Robert's desire is to perform research in the field of Materials Science.

Jared Andersen is a senior majoring in Electrical Engineering at the FAMU-FSU College of Engineering. He will graduate in spring 2016. After graduation, he hopes to work with a focus on control systems.

Donglin Cai is a senior majoring in Electrical Engineering at the FAMU-FSU College of Engineering. After graduation, he plans on attending grad school to obtain a masters in electrical engineering and working in the field of power systems.

2. Abstract

This project looks at enhancing human strength to increase productivity of healthy people and increase mobility and usability of unhealthy people. Current orthotics are bulky and weigh down the user, this orthotic will be designed to be ergonomic and enable the user to retain a natural level of mobility. This paper examines the status of project ECE 10/ME 29 and the progress it has made in detail. The dynamics of the arm motion is analyzed and the torque is calculated. Different methods of actuation to use for the powered orthotic are researched and examined. Material selection for the frame is broken down and examined. The designing of the frame and the control systems are also examined and shown. The electronics system is finalized and specifications are known. Finally, the overall system requirements that are still unresolved are looked at in detail.

3. Acknowledgments

There were several professors that have helped us with this project throughout this semester. This help has increased productivity and pushed our results faster than if we had done this on our own. Even though the professors have a busy schedule already, they took time out of their day to help out our project, and for that we are sincerely grateful. Dr. Patrick Hollis allowed the group to work on this unprecedented project and always made time to attend biweekly meetings and answer any questions we had. Dr. Hollis has always been extremely positive even when the team has been confused or stuck on a topic. Dr. Jonathan Clark has also been vital to the project, taking time to explain to us the process of selecting the correct motor to actuate our frame. Dr. Jerris Hooker and Dr. Nikhil Gupta have provided guidance on deliverables and helpful feedback to make sure the team stays on track.

4. Introduction

People need assistance with moving their arms under load if the load is too large. Current strength-assistance orthotics are bulky, expensive, or not user friendly. The primary objective of this project is to come up with a strength-assisting orthotic that is ergonomic and inexpensive. It should be light, strong, and long lasting. This project should ideally be user friendly: easy to modify, safe, and dependable under a wide range of use cases.

The power arm is a device that fits over the arms of the user and uses electromechanical actuators to add to their strength. It either contains a strong exoskeleton to help bear loads or it uses straps to attach to the user's body and increases the torque generated by the user's skeleton. The orthotic will start off being controlled by an onboard flex/relax switch and will later have an onboard system for determining with to do so in an autonomous fashion. The microcontroller being used will be the Arduino Nano, as it is well equipped to drive motors.

4.1 Background Research

The first thing that was researched was previous models of powered exoskeleton arms to come up with ideas to brainstorm and explore previous concepts that have already been built. The first is the *Titan Arm* [10] which was also a senior design project. The *Titan Arm* used a motor and a cable drive to actuate the exoskeleton arm. The second exoskeleton arm that was researched was the *TALOS Exosuit* [6] which was a whole suit and not just an arm. The *TALOS* suit used motors as well, but at the location of the joint that was being powered. The second thing that was researched was the average maximum and minimum length of the forearm and upper arm. That was found to be 52 cm and 38 cm respectively [1][5]. Physics of the bicep curl was then researched and developed to calculate maximum torque needed to lift the goal weight of 20 pounds [7][8]. Actuation methods were then analyzed and reduced to two possible actuators that would work for this project. Artificial muscles looked promising but after testing the rate of contraction wasn't great enough for the desired movement [4][9]. Motors were the other method of actuation researched, and they were found to be reliable and proven in the real world as opposed to the artificial muscles. After modeling the arm, materials research was done for the frame [2].

4.2 Needs Statement

People need assistance with moving their arms under load if the load is too large. Current strength-assistance orthotics are bulky, expensive, or not user friendly. The primary objective of this project is to come up with a strength-assisting orthotic that is ergonomic and inexpensive. It should be light, strong, and long lasting. This project should ideally be user friendly: easy to modify, safe, and dependable under a wide range of use cases.

4.3 Goal Statement

The goal of the project has multiple principal objectives that are required to be completed to be successful. The objectives are as follows:

1) The Orthotic must be able to lift its own weight and 20lbs.

2) The Orthotic must increasing endurance for holding said weights.

4.4 Constraints

The project cannot exceed $1,400 dollars, as that is the maximum budget. The exoskeletal arm must not harm the user in any way possible, whether that be from heat of the battery or the motor operating outside of the angles provided (that is the natural movement of the human arm). Safety is by far the largest constraint and consideration when designing this project. The device should be lightweight as well, if it is too heavy and bulky it is not useful and practical. The exoskeleton arm should have a operating life of 4 to 6 hours. The device should also have a large range of users, which is usable for people of different arm lengths.

4.5 Design and Performance Specifications

- The Arm must have a range in length for the forearm and the upper arm so a variety of people can use the orthotic.
- Stiffness of material for the orthotic has to be greater than that of a human forearm (the deflection needs to be almost nonexistent)
- Strength of the material can’t plastically deform.
- Range of Motion for the orthotic (180º-55º).
- The orthotic must be able to last 4-6 hours of continuous use.
- Have a lifespan of at least half a year to one year for the battery, at least one to two years for the bearings, and a lifespan a lifespan of 5-6 years for the frame.
- Range of motion about 145 degrees from a fully extended arm (~180 degrees) to a contracted arm (~35 degrees)

5. Design and Analysis

This power arm will be usable for several groups of consumers like rehabilitation use, military use, and civilian use such as increased lift for warehouse workers. The power arm will use actuation to increase the lift capacity and endurance. It will be lightweight and allow for a high natural flexibility, something other powered orthotics do not consider. For this project, the power arm is only looking at the bicep contraction movement. The power arm will increase overall biomechanical efficiency and make lifting easier for the user. Currently a worm gear with a high rpm motor is being looked at to save cost. Using a smaller motor and a worm gear a large enough torque can be generated and reduce rpm, the cost of the motor would be substantially less. The motor will either be mounted on the frame [**Fig 4**] directly at the elbow or on the back with a cable drive system. Below is the block diagram for the overall system, as well as the needs analysis charts and House of Quality --all of which were pertinent in designing the system.

Fig. 1 --System Block Diagram

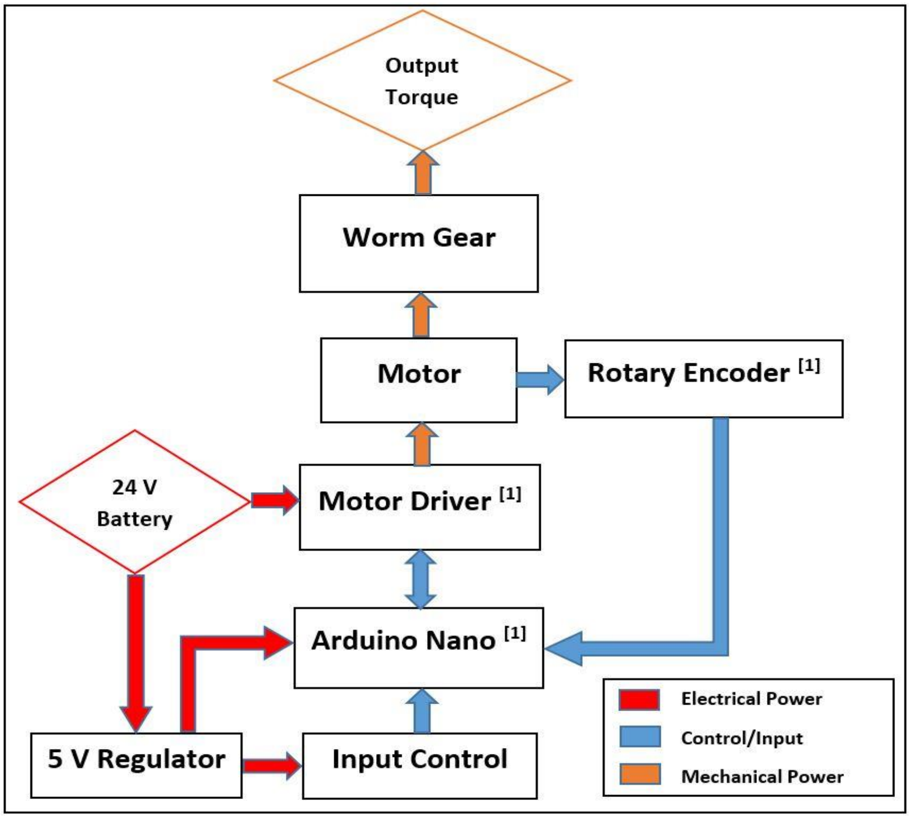


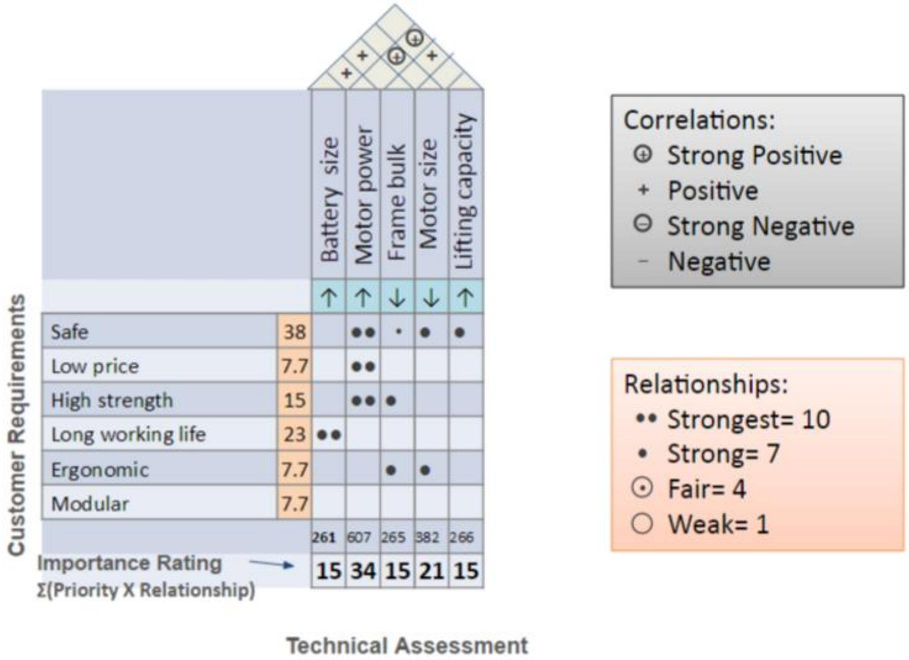
Table 1 –Needs Analysis Weight

	Price	Safety	Power	Lifespan	Geometric mean	Normalized weight
Price	1	0.2	0.5	0.333333	0.4273	0.0779
Safety	5	1	5	5	3.3437	0.6095
Power	2	0.2	1	0.5	0.6687	0.1219
Lifespan	3.000003	0.2	2	1	1.0466	0.1908

Table 2 –Needs Analysis Comparison

Need	Weight	Fits Inside Budget	Simplicity	Modularity	Safety	Dependability	Ergonomic	Lifts Minimum Weight	Lifespan
Price	0.0779	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
Safety	0.6095			**x**	**x**	**x**	**x**	**x**	**x**
Power	0.1219	**x**			**x**	**x**		**x**	**x**
Lifespan	0.1908	**x**			**x**	**x**			

Fig. 2 – House of Quality



		Battery size	Motor power	Frame bulk	Motor size	Lifting capacity
		↑	↑	↓	↓	↑
Safe	38		••	·	•	•
Low price	7.7		••			
High strength	15		••	•		
Long working life	23	••				
Ergonomic	7.7			•	•	
Modular	7.7					
		261	607	265	382	266
Importance Rating → Σ(Priority X Relationship)		15	34	15	21	15

Correlations:
⊕ Strong Positive
+ Positive
⊖ Strong Negative
- Negative

Relationships:
•• Strongest= 10
• Strong= 7
⊙ Fair= 4
○ Weak= 1

Time scale was found using a group of twenty people all doing a weighted bicep curl of 30lbs. 30 pounds was chosen to observe a weight that was heavier than our goal and as expected the average time for the movement was about one second for the up and the down movement. The time scale is necessary to calculate to with respect to the movement of the arm and change in angle.

Table 3 –Pertinent Data from Time Sampling

Direction	Time (s)
Up(Total)	22.8
Up(Avg)	1.14
Down(Total)	19.85
Down(Avg)	0.9925

5.2 Motor Simulation and Selection

In order to calculate the total torque we used equation 1. In order to calculate the load torque equation 2 was used, where theta is the angle between the arm beam and the axis normal to the ground. In order to calculate the moment torque we used equation 3 where θ’’ is the angular acceleration and the expression of I is shown in equation 4

$$\tau = \tau_{load} + \tau_{moment} \qquad \textbf{Eq. 1}$$

$$\tau_{load} = m * g * sin(\theta) \qquad \textbf{Eq. 2}$$

$$\tau_{moment} = I\theta'' \qquad \textbf{Eq. 3}$$

$$I = mr^2 \qquad \textbf{Eq. 4}$$

Where m is the mass of the load and r is the length of the arm.

Operation of the arm was simulated in MATLAB as a function of time. The results were as follows:

Fig. 2—Movement vs. Time

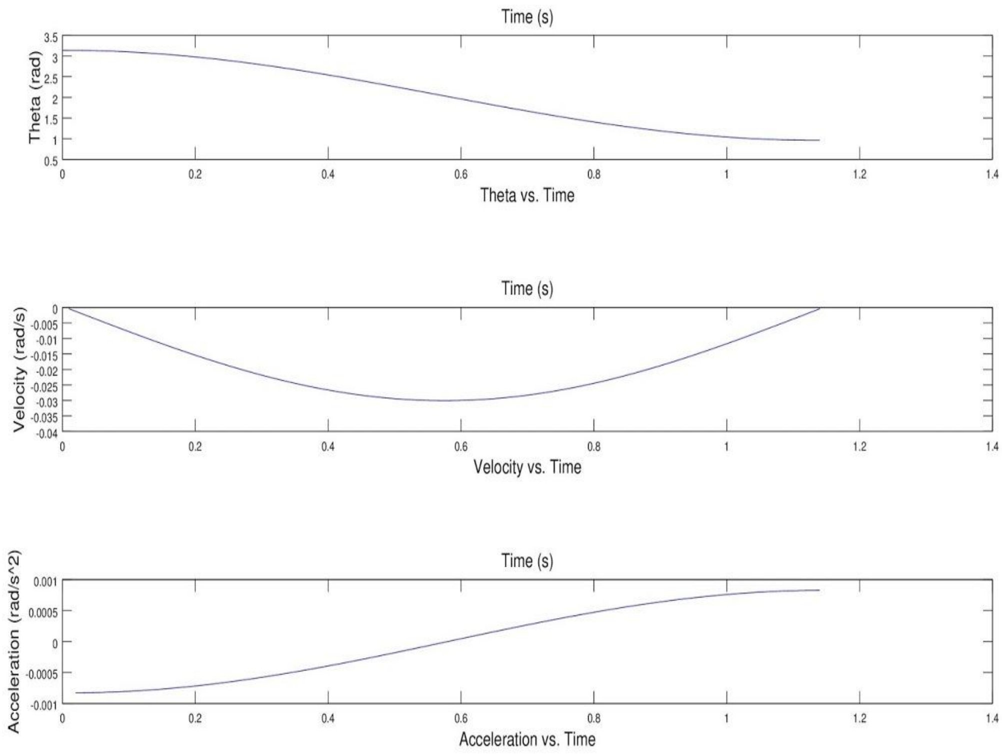
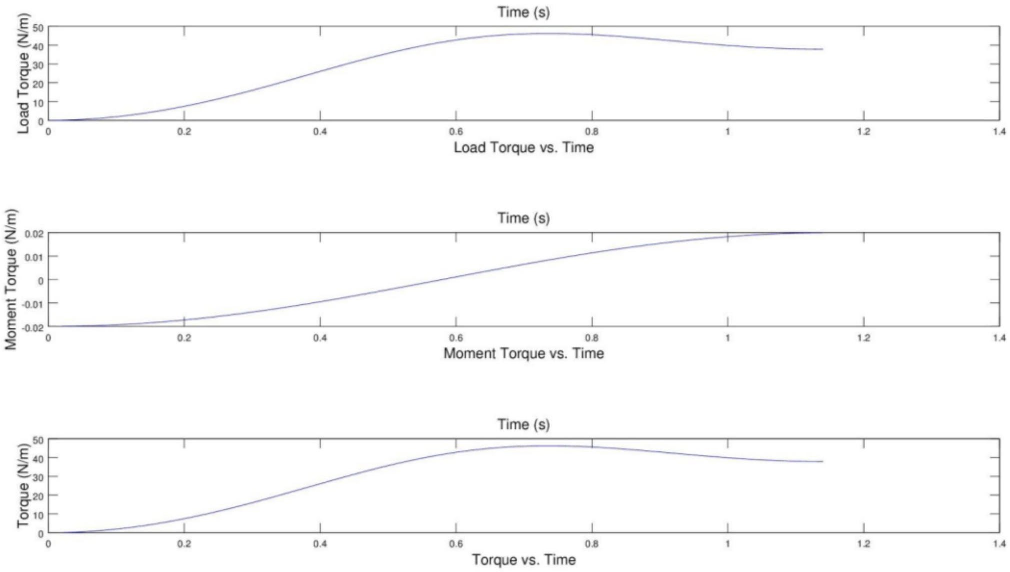


Fig. 3 –Position and Motion vs. Time



A second program was then created using Python and the MatplotLib library to calculate the operating points and relative fitness of the motors found when looking across distributors. The team decided to mostly look at DC brushed motors for their simplicity, high torque, and low cost. A table containing the stall torques, stall currents, and no load speeds were created and entered into the tables for the respective motors, and the program was written to calculate the operating points of the motors on the fly. Motors that would not be able to both supply enough torque at the maximum load and supply enough rpm at the maximum load were displayed as a fitness of zero, and removed from the simulation. At the end, three motors remained.

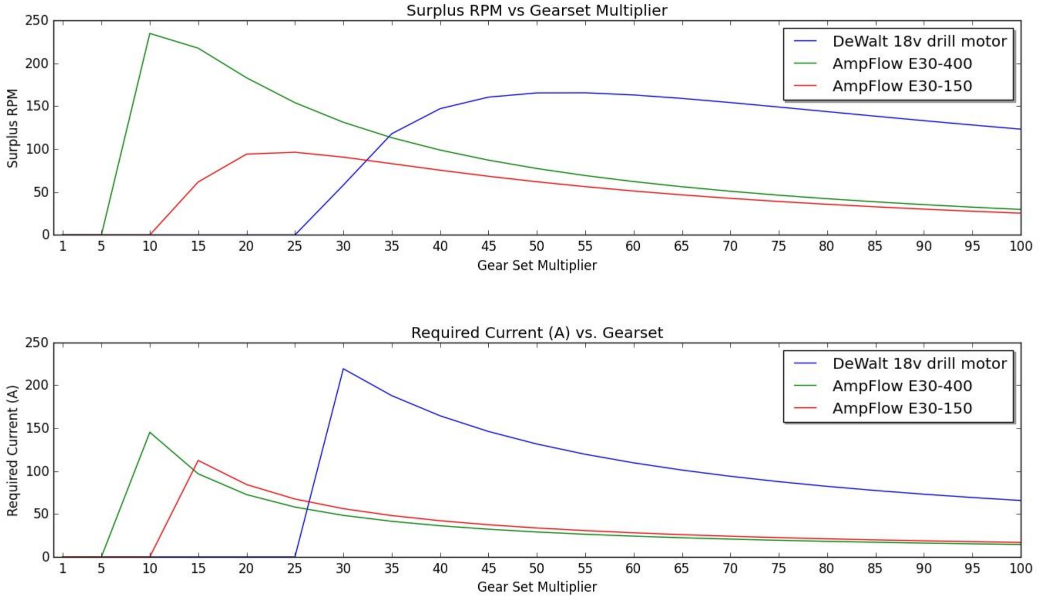
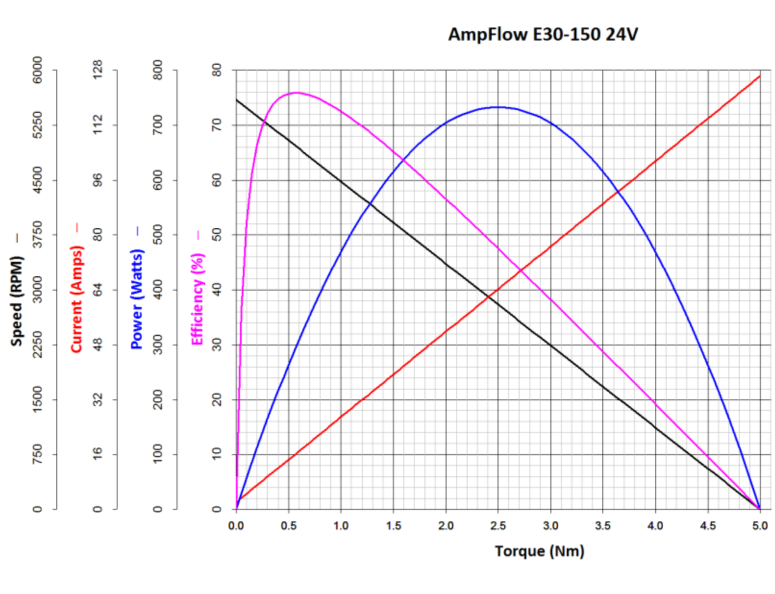


Figure 4 —Motor Fitness Graph

The AmpFlow E30-150 was selected for its low cost, low weight, and low current operating point. Its operating characteristics were then verified by hand to ensure the values supplied by the fitness graph were correct.

Fig 5 –The Motor Specifications Graph

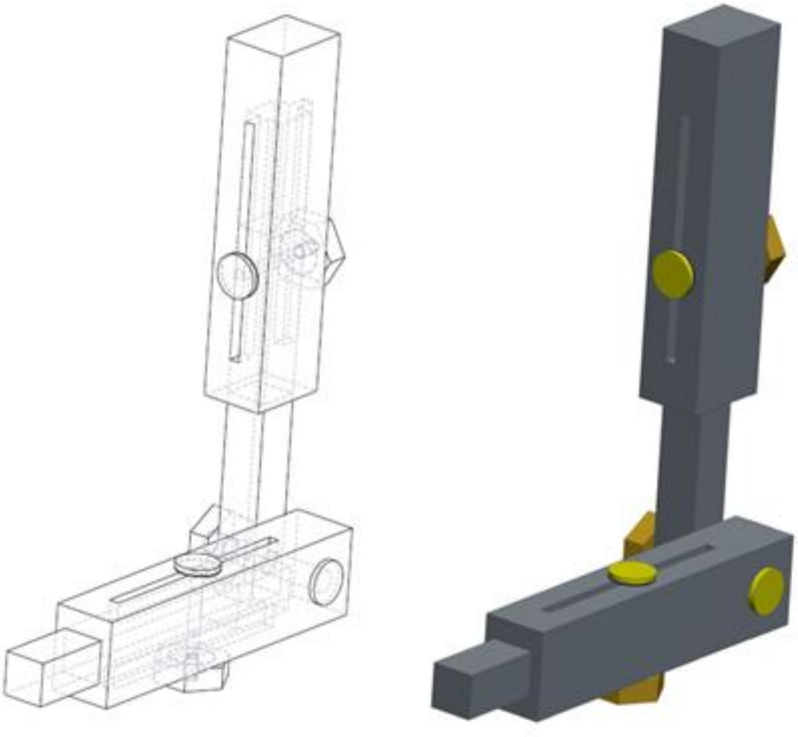


5.3 Frame Design

5.3.1 Initial Frame Design

The main component of the orthotic that our team has been working on is the frame of the arm. It will incorporate a sliding bar mechanism for the forearm and upper arm that will have a changing length of 38cm to 52cm for the forearm and a changing length of 40 cm to 58 cm for the upper arm which can be seen in the very basic design in figure 6. This will allow 95% of the world population to be able to use the orthotic, the frame will also have a range of motion from 180 degrees where the user's arm is fully extended to 35 degrees where the user has completed a full bicep curl. Under the design load of 20 lbs the frame of the orthotic cannot plastically deform at any time and must be made out of a material that has a greater stiffness than the human forearm.

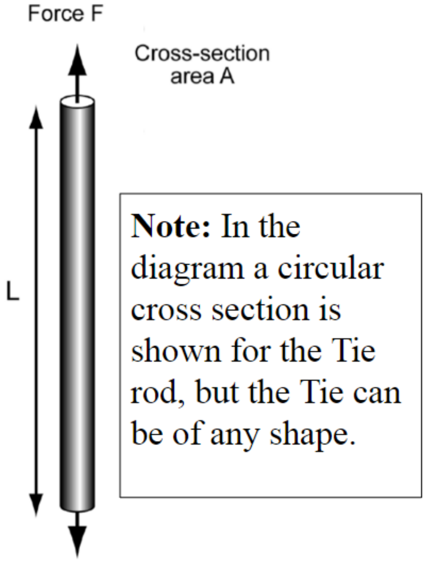
Fig 6 – Original Frame Designs with two slider bar cranks.



5.3.2 Material Selection

For the general design of our orthotic (shown in figure 6) we simulate the arm in two basic mechanical systems the first is a light, strong, stiff Tie rod (shown in figure 7) which is simulated when the orthotic arm is at 180 degrees. The second system is a light, strong, stiff cantilever beam which is end loaded and the thickness of the beam is known (shown in figure 8), this is simulated when the orthotic arm is performing a bicep curl. The end loaded force on the cantilevered beam is greatest when the orthotic is at 90 degrees. Such as in figure. From knowing these two designs we can perform an analysis for the material selection using the coupling equations (eq.5 and eq.6), which relate a materials specific modulus to its specific strength by a coupling constant, for a tie rod and a cantilevered beam obtained from [2].

Fig 7 – Light, Strong, Stiff Tie Rod



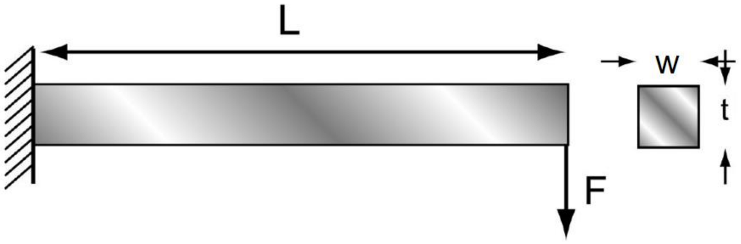
Note: In the diagram a circular cross section is shown for the Tie rod, but the Tie can be of any shape.

$$\frac{E}{\rho} = \left(\frac{L}{\delta}\right)\left(\frac{\sigma_y}{\rho}\right)$$

Eq. 5 [2]

Where E is the young's modulus, ρ is the density, δ is the deflection of the tie rod, σ is the yield strength for the material the tie rod, and L is the length of the rod.

Fig 8 – Light, Strong, Stiff Cantilevered Beam

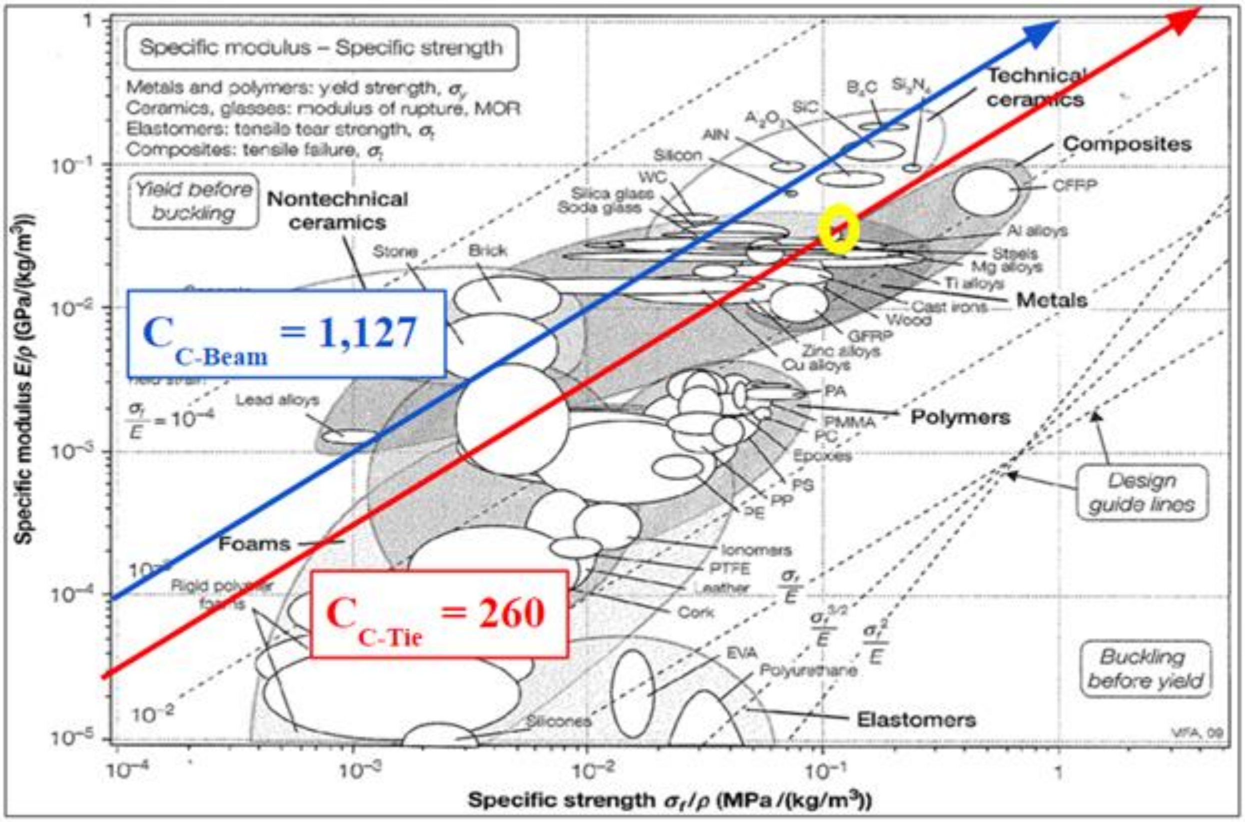


$$\frac{E}{\rho} = \left(\frac{4L^2}{6t\delta}\right)\left(\frac{\sigma_y}{\rho}\right)$$

Eq. 6 [2]

Where E is the young’s modulus, ρ is the density, δ is the deflection of the beam, σ is the yield strength for the material the beam, t is the thickness and L is the length of the beam.

Fig 9 –Material Selection Graph [2]



The graph shows the two coupling constant lines for the tie rod (red line) and the cantilevered beam (blue line). For both lines the arrow is pointing to lighter, stiffer and stronger materials. The coupling constant for the cantilevered beam is greater than the tie rod meaning that the materials along this line will be stronger and stiffer however the materials along this line are ceramics and a small flaw in the material can cause a brittle fracture do to the fact that they have such a low fracture toughness, these materials are also extremely hard to machine and for these reasons ceramics are ruled out as usable materials. Along the tie rod coupling constant line the materials are metals and they have very high fracture toughness and are extremely easy to machine. However, since we are using materials that will be below the cantilevered beam coupling line the weight of the orthotic frame that satisfies the constraints will be heavier than a frame made out of a material along the cantilevered beam coupling line. From this data we decided to go with aluminum for its cost is inexpensive and it is at the top of the tie rod coupling constant line.[2]

Table 4–Material Mass and Thicknesses

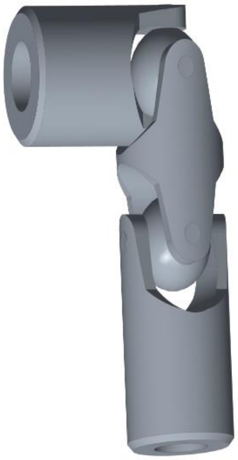
Calculation of material Mass and width for Al - alloy		
	m(kg)	**W(m)**
Beam		
Strength	0.218082	0.001808
Stiffness	1.083996	0.008985
Tie		
Strength	0.005592	0.005377
Stiffness	0.006414	0.006167

After calculating the Mass and width for the generic design of the orthotic frame using aluminum as the material which has a density (ρ) of 2.9 Mega grams per meter cubed, a young's modulus (*E*) of 68 (GPa), and a Yield strength (σ_y) of 30 (MPa) we found that the max thickness would need to be 9 mm and the total weight would be 1.08 kg. These values would allow us to design the frame of the arm to be anything we want since we calculated for a mass of the arm to be 1.08 kg, and the thickness of 9 mm is considered to be unrealistic. [2]

5.3.3 Final Frame Design

From the initial frame design and the material selection analysis we were able to produce two new designs that would satisfy the constraints for the design. For the shoulder joint we decided to use a double u joint as seen in figure 7, and two plate bearings to allow the user of the arm to have three degrees of freedom at any movement point which will give the user a complete full range of motion just as if the user wasn't wearing the arm. The u joint will be made out of A36 steel and bought from a manufacture so the design minimum design specs for the arm of strength and stiffness are satisfied.

Fig 10 – Double u joint that will be used for the shoulder joint.



Since safety is such a major part of this project the team decided when designing the elbow joint we would incorporate physical safety measures to stop the orthotic from going past the range of motion for a human elbow, a max of 180 degrees and a min of 35 degrees. We also shaped the design of the arm to be a hollow rectangular tube so that less material could be used since this shape would give the arm a shape factor of 4.16, which can be taken as a factor of safety. From this shape factor our new design would be 6 cm in width and 4 cm thick with a center piece of 4cm by 2 cm for the entire length of the arm would be removed. This would cause the weight of the design to be 1.5 kg's. The first design we made was a rectangular elbow joint as seen in figure (11) where we would have the physical properties of the arm to stop the arm at 180 degrees with bars that will extend off the back of the elbow joint and stop the arm from moving past this distance as seen in figure (12). At 35 degrees this design would stop the arm with an angled edge on the upper arm and can be seen in figure (13).

Fig 11 – Final design 1 of the orthotic with rectangular elbow joint where it is fully contracted at 35 degrees (left) and at the max torque 90 degrees (right).

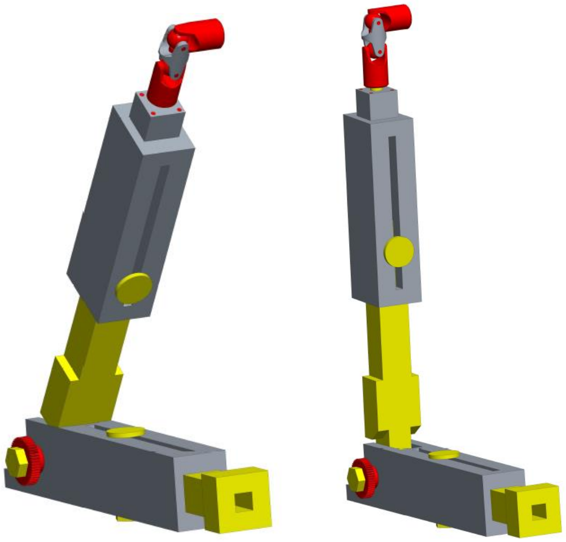


Fig 12 – Final design 1 side view of forearm elbow joint with bars to stop the arm at 180 degrees.

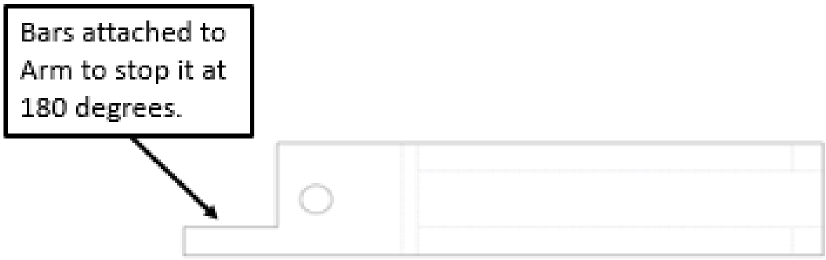
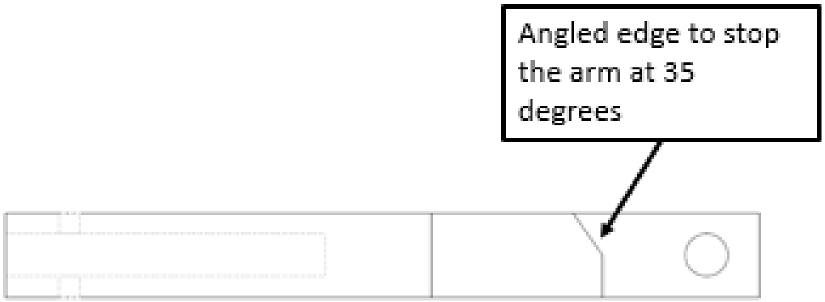


Fig 13 – Final design 1 side view of upper arm elbow joint with angled edge to stop the arm at 35 degrees.



The second design we made was a circular elbow joint as seen in figure (14) where the physical properties that would be used to stop the arm at 180 degrees and at 35 degrees were incorporated internally with a socket slider in the forearm as seen in figure (15) and with a socket sleeve in the upper arm as seen in figure 16. Also in both the forearm and the upper arm physical stop at 35 degrees is an angled edge.

Fig 14 – Final design 2 of the orthotic with circular elbow joint where it is fully contracted at 35 degrees (left) and at the max torque 90 degrees (right).

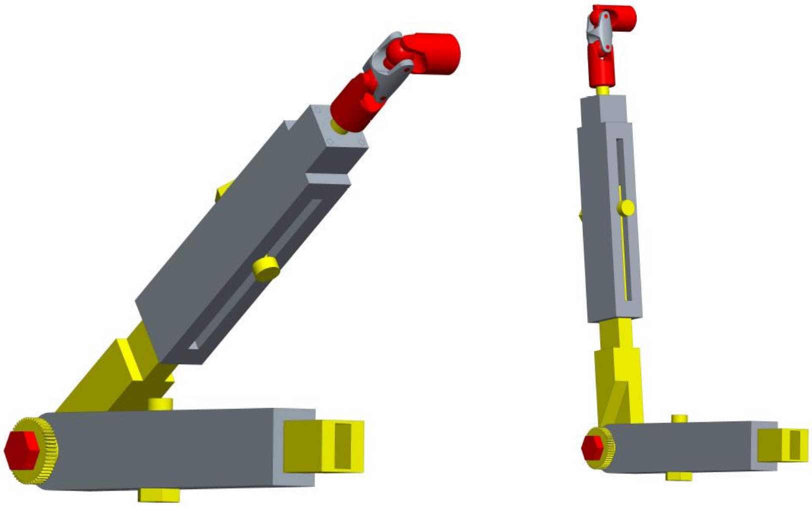


Fig 15 – Final design 2 side view of forearm elbow joint to stop the arm at 180 degrees and 35 degrees with internal socket slider and at 35 degrees with angled edge.

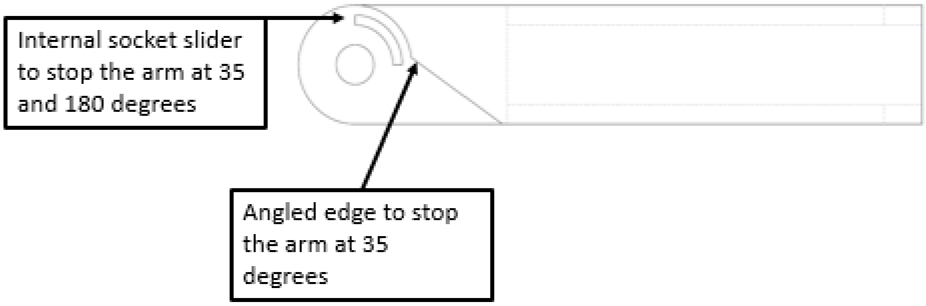
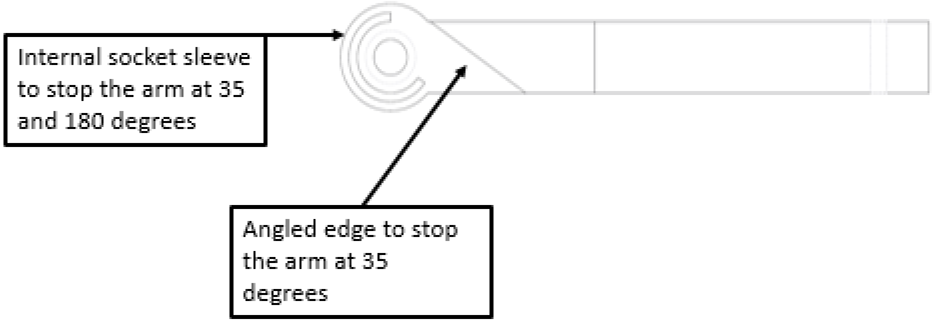


Fig 16 – Final design 2 side view of upper arm elbow joint to stop the arm at 180 degrees and 35 degrees with internal socket sleeve and at 35 degrees with angled edge.



From these two final frame designs we decided on the second one with the circular elbow joint since both designs would weight basically the same and the strength of both designs are equal and the team believed that by having two bars at the end of the elbow could simulate spikes and could have the potential to impale the user of the orthotic. Causing this design to not be safe for the user.

5.4 Electronic Design

The electronics side of the project is nearly completed, the only remaining item is the code to operate the Arduino. That being said the microcontroller that was selected to run the motor through the motor driver and read the encoder as a safety feature is the Arduino Nano.

The Arduino Nano has plenty of computational power for what will be needed to run the motor safely, more than enough memory, and more than enough input/output ports. The first method of control that will be utilized will be a pushbutton for the curling direction and a pushbutton for the relaxing direction of the arm, if the prototype is finished swiftly the control scheme will be upgraded to a biofeedback sensor.

Table 5 –Logic of Control System

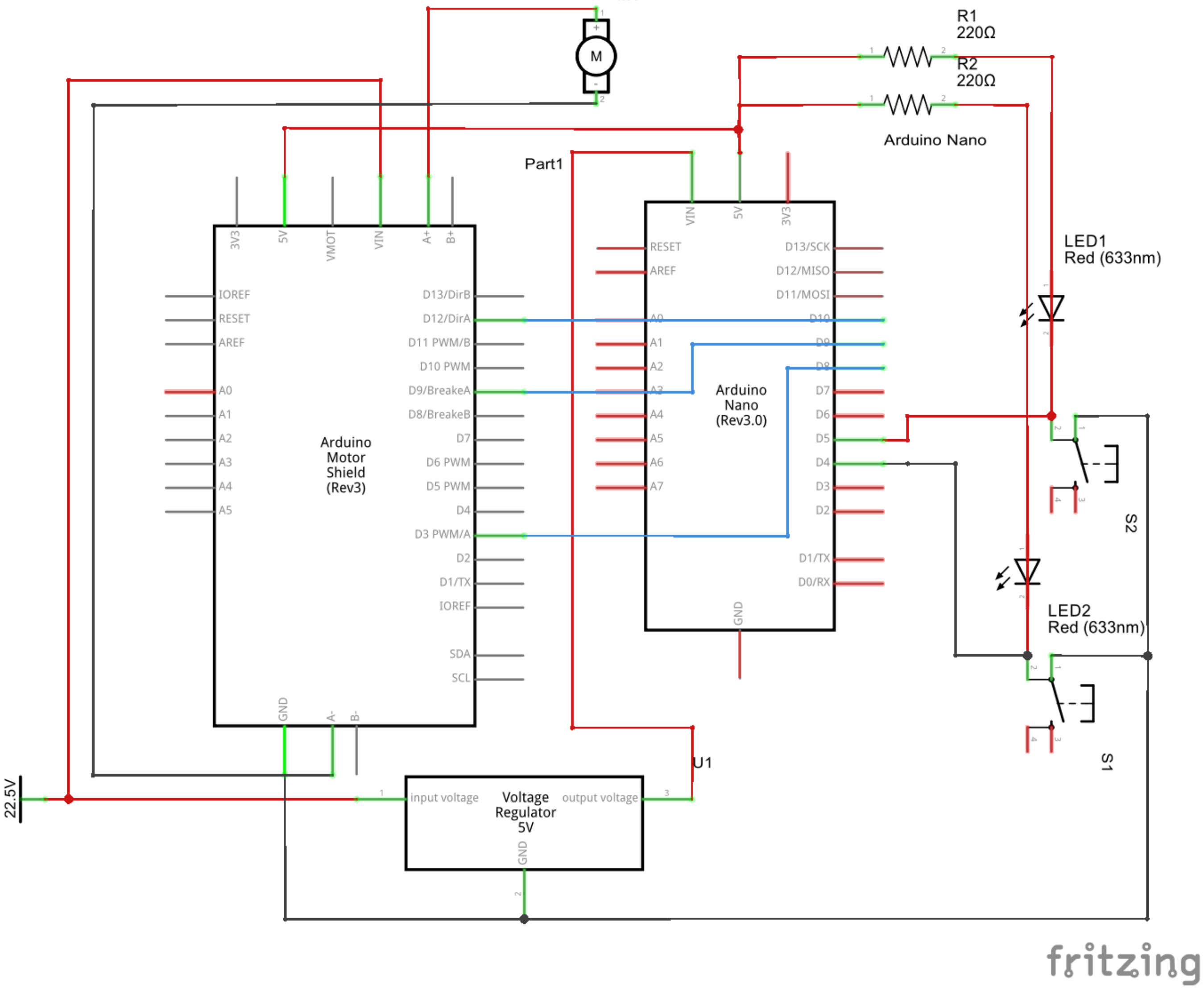
Input A	**Input B**	**Motor State**
High	Low	Turns Clockwise
High	High	Turns anti - Clockwise
High	High	Braking Occurs
Low	Low	Braking Occurs

The motor driver was selected based off of the current needed to drive the motor, voltage specifications, safety features, and compatibility with the Arduino. Even though the driver is made for up to 50A continuous current usage, it can safely peek up to 100 Amps, including a passive safety feature in case the battery overloads. The motor driver selected also has numerous safety features such as regenerative braking capability, which will freeze the motor if it tries to pass safe angles (180 or 35 degrees), integrated thermal protection from overheating using two large heatsinks, and other control protocols of the like. Although the motor driver in figure (17) is different from the motor driver selected, it will use the same pin setup as shown below.

Both the stepdown voltage regulator and pushbuttons are general electronic pieces that did not need intense work to select. The regulator needed to handle up to 24V and drop it down to 5V and resistor will take care of the current rating for both the Arduino Nano and voltage regulator.

The 24V battery will supply both the motor and the Arduino Nano, saving money from having to buy a separate smaller battery for the Arduino Nano. The battery selected will be able to operate for 4-6 hours of continuous use, however the actual motor is not being used continuously so it should last significantly longer than 6 hours.

Fig 17. –Circuit Diagram



6. Risk and Reliability Assessment

There are a number of risks associated with this project, not just in the operation of the orthotic, but in the construction and storage of it. In order to safely build the device, all electrical and mechanical components will be constructed in a supervised shop setting. Safety glasses, long pants, and close toed shoes will be worn at all times during the construction process. Proper ventilation will be used during all soldering sessions. A buddy system will be used during the construction process.

During the testing and operation of the device, a number of safety precautions will be used. In order to combat the risk of fires, all tests will be performed in a fire-resistant environment, with fire extinguishers present. In order to combat dangerous glitches in the operation, meticulous testing of the setup under different operating conditions will be done in order to simulate different usage cases. A number of hardware and software failsafe's will likewise be built into the device itself in order to prevent undesired operation. For mechanical tests, three testers will be present at all times. For electrical tests, two testers will be present at all times.

Since the device will be using a high-energy lithium battery in order to operate, when the device is no longer being used the cell will be removed from the setup and stored in a fireproof container to prevent damage from its possible failure.

7. Scheduling and Human Resource Allocation

The team used online vendors for research of parts and materials to fabricate the prototype and the college of engineering machine shop for analysis of actuation methods. Below lists the team members with their respective responsibilities and jobs.

Ryan Whitney –Ryan performed research and calculations vital to the project moving forward and helped give values to the ideas. He worked on the Code of Conduct and the Needs Analysis papers. He designed the artificial muscle version of the prototype and will continue to do research and updates to it. Ryan developed the simulation of the movement of the arm in MATLAB and will continue to update it with the motor simulated as well. Ryan handled most of the entrepreneurial aspects of the design project.

Robert Slapikas –Robert also performed research and calculations vital to forward progress and gave vital insight into the mechanical process of the design. He makes sure that all of the calculations are correct and also worked on each technical paper. He worked on material selection that best fit the needs of the project. He also designed initial frame for the project in ProE. He will continue to provide oversight on the mechanical design and financial aspect of the project.

Derek Pridemore –Derek has performed research for both methods of actuation and helped find the right equations for Ryan to use. Derek also worked on both previous papers. He has made rough designs for the motor version of the project and built the webpage for the team and project. He performed initial motor calculations and helped on the arm simulation in MATLAB. He also keeps note of meeting minutes and will continue to update the webpage. Derek also designed the circuit schematic in Fritzing and initial electrical setup for the overall system.

Jared Andersen –Jared has performed research for both methods of actuation and worked all technical papers as well. He also helped design the motor version of the prototype and added to the design of the artificial muscle version. He did substantial work on both midterm presentations, and researched different types of batteries to power the design.

Donglin Cai –Donglin has helped develop the artificial muscle design and added to the background research for this method. He also worked on the previous two papers. He worked on the midterm presentation and is now working on controlling the motor with Arduino code.

8. Communication

The main form of communication will be over Facebook, email, and google drive among the group, preferably phone as well as through regular meetings of the whole team. Email will be a secondary form of communication for issues not being time- sensitive. For the passing of information, i.e. files and presentations, email will be the main form of file transfer and proliferation. Each group member must have a working email for the purposes of communication and file transference. Members must check their emails at least twice a day to check for important information and updates from the group. Although members will be initially informed via a phone call, meeting dates and pertinent information from the sponsor will additionally be sent over email so it is very important that each group member checks their email frequently. If a meeting must be canceled, an email must be sent to the group at least 24 hours in advance. Any team member that cannot attend a meeting must give advance notice of 24 hours informing the group of his absence. Reason for absence will be appreciated but not required if personal. Repeated absences in violation with this agreement will not be tolerated. Communication will be polite and respectful at all time and all messages sent to advisors will be cc'd to all team members.

9. Budget Allocation

The team was given $1400 for the purposes of this project by the college of engineering. The team's projections place the budget at about eight hundred dollars, which means that the project will have a decent amount of safety in case something goes wrong in the process of development (see appendix).

10. Conclusion

Over the span of this semester, the team has designed and analyzed various arm frames. Actuation methods and were then researched and analyzed. The team has decided on a motor based actuation system that will be using a worm gear and will be attached at the elbow of the arm. The arm frame will be built from two sets of rectangular aluminum telescoping tubes that will be 3D printed. The design will also use a double u joint made of steel to allow full range of motion.

11. Environmental Safety and Ethics

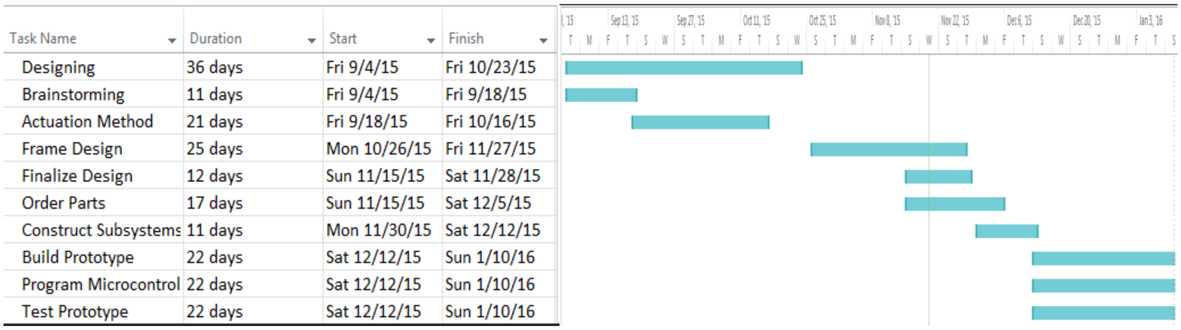
Although the device itself is not intended to be disposed of, in the usage lifetime of the device, the battery that powers it will likely fail and have to be disposed of. As lithium ion batteries are considered “hazardous waste” by the EPA, instructions for the proper disposal and/or recycling of the batteries will be included with the device.

When the device itself begins to fail, the majority of the materials can be recycled, as it will contain little to no dangerous chemicals and will be made mostly of metal.

12. Future Plans

The code will be finished after the circuit is assembled. The team is selecting and pricing the final materials that will be utilized for construction of the prototype in spring. During the next semester, the team plans to receive safety clearance from FSU and to start testing the design that was decided upon. After safety clearance the actual prototype will be built and the design will be improved upon will the time leftover.

12.1 Gantt Chart



Task Name	Duration	Start	Finish
Designing	36 days	Fri 9/4/15	Fri 10/23/15
Brainstorming	11 days	Fri 9/4/15	Fri 9/18/15
Actuation Method	21 days	Fri 9/18/15	Fri 10/16/15
Frame Design	25 days	Mon 10/26/15	Fri 11/27/15
Finalize Design	12 days	Sun 11/15/15	Sat 11/28/15
Order Parts	17 days	Sun 11/15/15	Sat 12/5/15
Construct Subsystems	11 days	Mon 11/30/15	Sat 12/12/15
Build Prototype	22 days	Sat 12/12/15	Sun 1/10/16
Program Microcontrol	22 days	Sat 12/12/15	Sun 1/10/16
Test Prototype	22 days	Sat 12/12/15	Sun 1/10/16

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A1 Appendix

Table 6 –Bicep Curl Time Sample

Test Subject	Up (seconds)	Down (seconds)
1 (Robert)	1.8	1.71
2 (Derek)	1.6	0.78
3 (Jared)	2.7	1.55
4 (Ryan)	1.9	1.93
5	1.1	1.1
6	1.1	0.75
7	1	0.95
8	1	1
9	1.3	1.15
10	0.9	0.9
11	0.8	0.78
12	0.8	0.9
13	1	0.9
14	0.9	0.8
15	0.7	1
16	0.6	0.7
17	0.6	0.6
18	1.3	0.8
19	0.8	0.95
20	0.9	0.6
Direction	Time (s)	
Up(Total)	22.8	
Up(Avg)	1.14	
Down (Total)	19.85	
Down (Avg)	0.9925	

Table 7 –Budget

Part	Price	Time
Arduino Uno Nano	$8.88	Here
DC Voltage Stepdown Regulator	$8.36	Here
Two Wire DC Voltmeter	$10.99	Here
AmpFlow E30-150 24V	$79.00	Not Ordered. - 7 to 10 days
Driver Board	$110	Not Ordered. - 7 to 10 days
Aluminum	$200	Not Ordered
Steel Double U joint	$120	Not Ordered
24V Battery	$87	Not Ordered - 8 to 12 weeks
Push Buttons	$4	Not Ordered
High Current Wire	$10	Not Ordered
Wire	$0	Not Ordered
Solder, Glue, Aluminum Tape	$0	Not Ordered
Worm Gearset	$80	Not Ordered
Bushings	$30	Not Ordered
Axle Bearing	$60	Not Ordered
Heat Sink	$20	Not Ordered
Total Cost:	$828.13	
Money Leftover	$571.87	