Powerflex Arm - A Powered Upper Limb Orthotic

Midterm Report

Group # ECE 10 / ME 33

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. – Hollis

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1. 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 33 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.

2. Problem Statement and Project Scope

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 Uno R3, as it is well equipped to drive motors.

2.1 Background Research

The first thing that was researched was previous models of powered exoarms 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 exoarm. The second exoarm 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 lbs[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].

2.2 Goal Statement & Objectives

Our minimum objective is to have a function prototype lift a paper cup, however our goal is to be able to lift and support 20 pounds.

Here are the desired specifications of the prototype:

- Range of motion about 130 degrees from a fully extended arm (~180 degrees) to a contracted arm (~55 degrees)
- Lift/carry 20 pounds
- Have a battery life of 6-8 hours for civilian and 13-15 for military
- Have a lifespan of at least 3-6 months

3. 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.

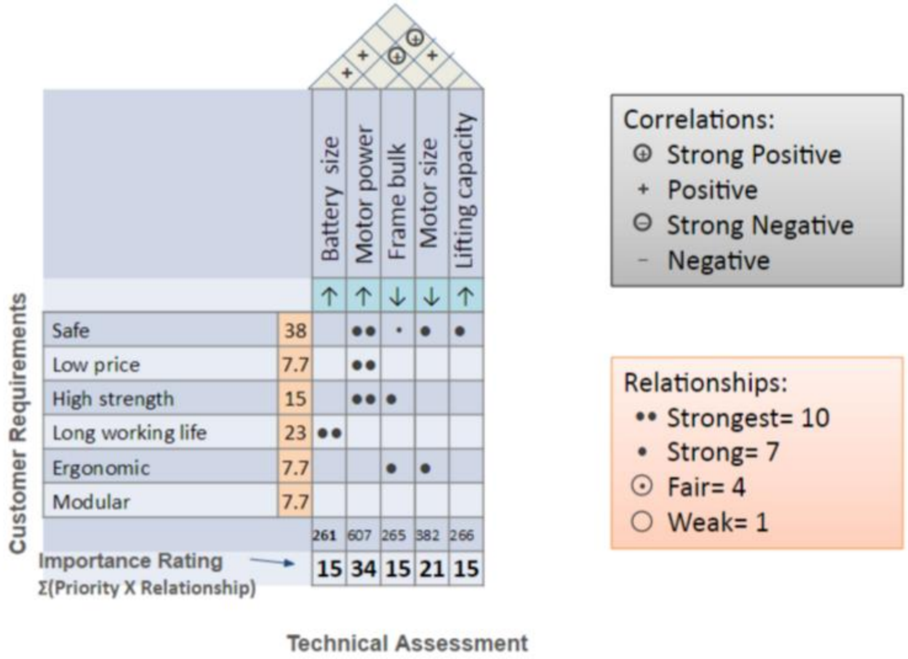
Table 1 - Needs Analysis Weight

	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	Ergonomics	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 1 - House of Quality



Customer Requirements		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

Technical Assessment

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- 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

Simulation

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

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

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

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

$$I = mr^2$$ **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:

Figure 2: Movement vs. Time

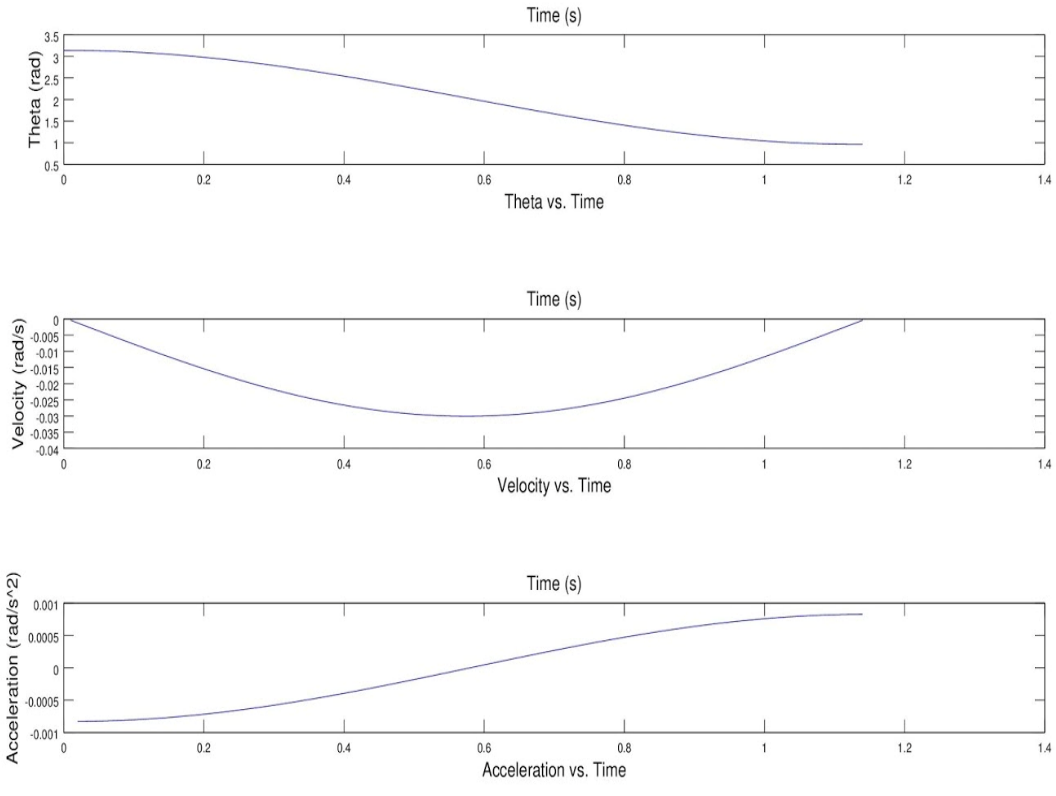
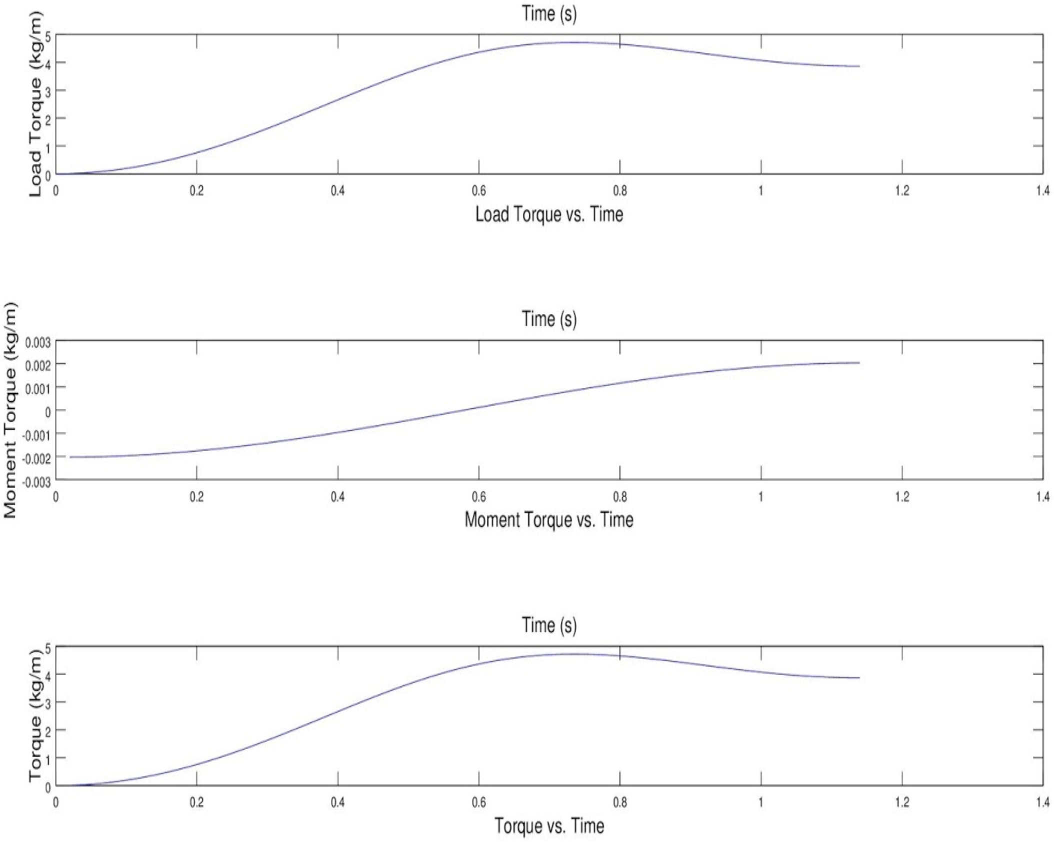


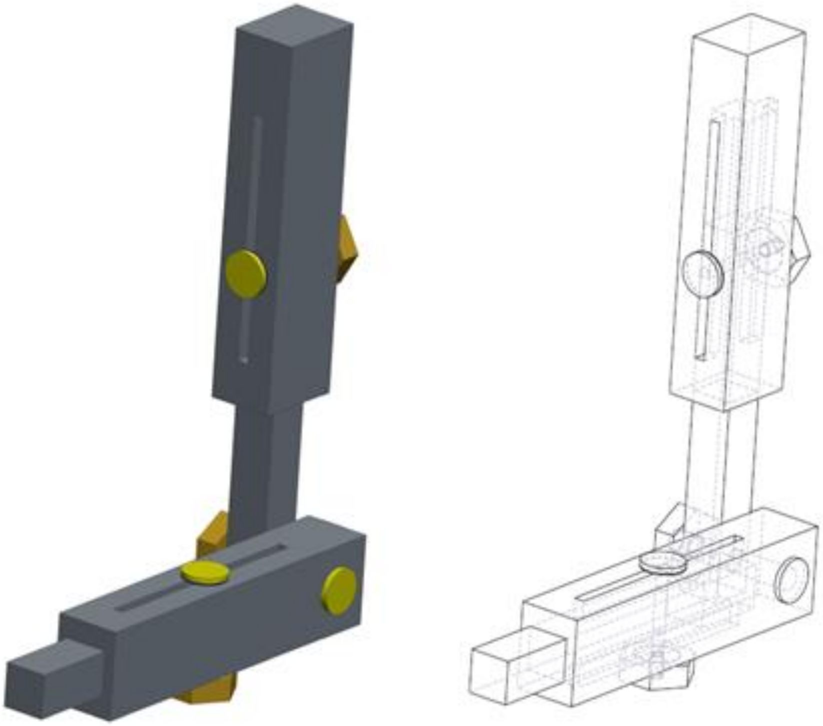
Figure 3 –Torque vs. Time



Material Selection

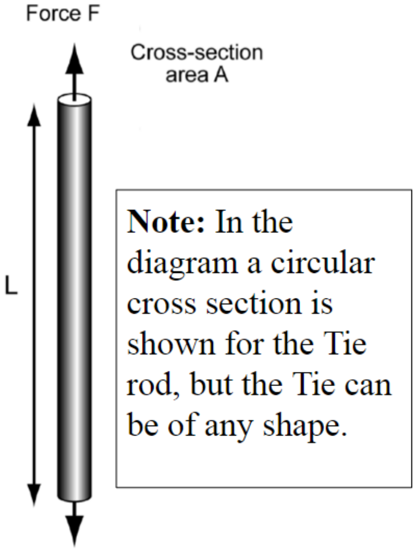
The main component of the orthotic that our team has been working on is the frame of the arm. It will incorporate a sliding bar mechanism for the forearm and upper arm that will have a changing length of 38cm to 52cm for the forearm. Which will allow 95% of the world population to be able to use the orthotic, The frame will also have a range of motion from 180 degrees where the user's arm is fully extended to 55 degrees where the user has completed a full bicep curl. Under the design load of 20 lbs the frame of the orthotic can not plastically deform at any time and must be made out of a material that has a greater stiffness than the human forearm.

Fig 4 – Intitial Frame Design



For the general design of our orthotic (shown in figure 4) we simulate the arm in two basic mechanical systems the first is a light, strong, stiff Tie rod (shown in figure 5) 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 6), 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 5 – Light, Strong, Stiff Tie Rod



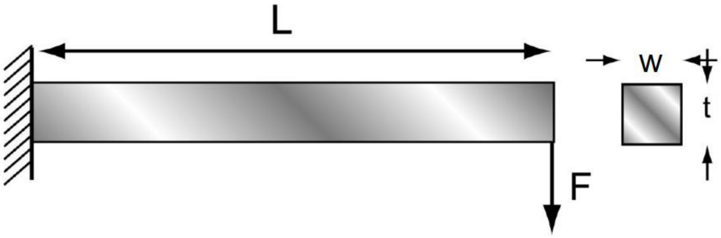
Note: In the diagram a circular cross section is shown for the Tie rod, but the Tie can be of any shape.

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

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 6 – Light, Strong, Stiff Cantilevered Beam

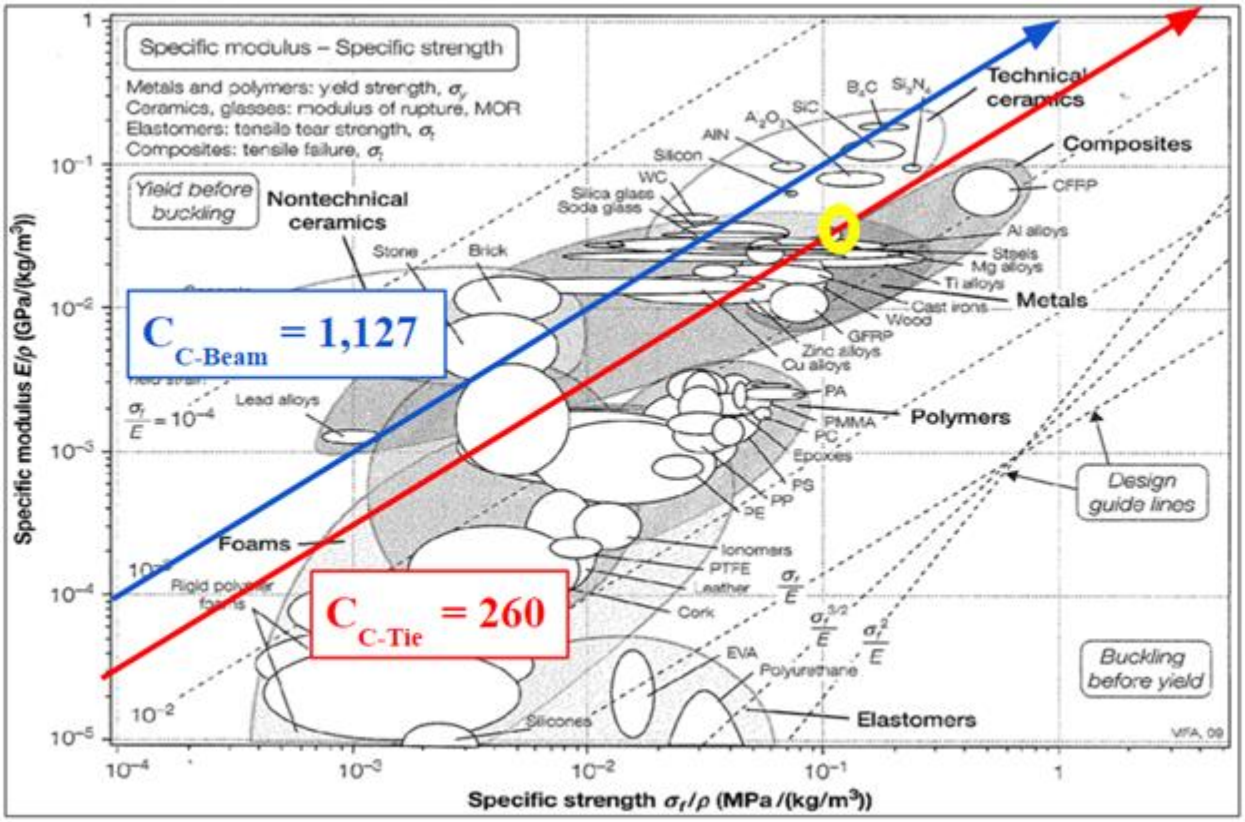


$$\frac{E}{\rho} = \left(\frac{4L^2}{6t\delta}\right)\left(\frac{\sigma_y}{\rho}\right)$$

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 7 –Material Selection Graph [2]



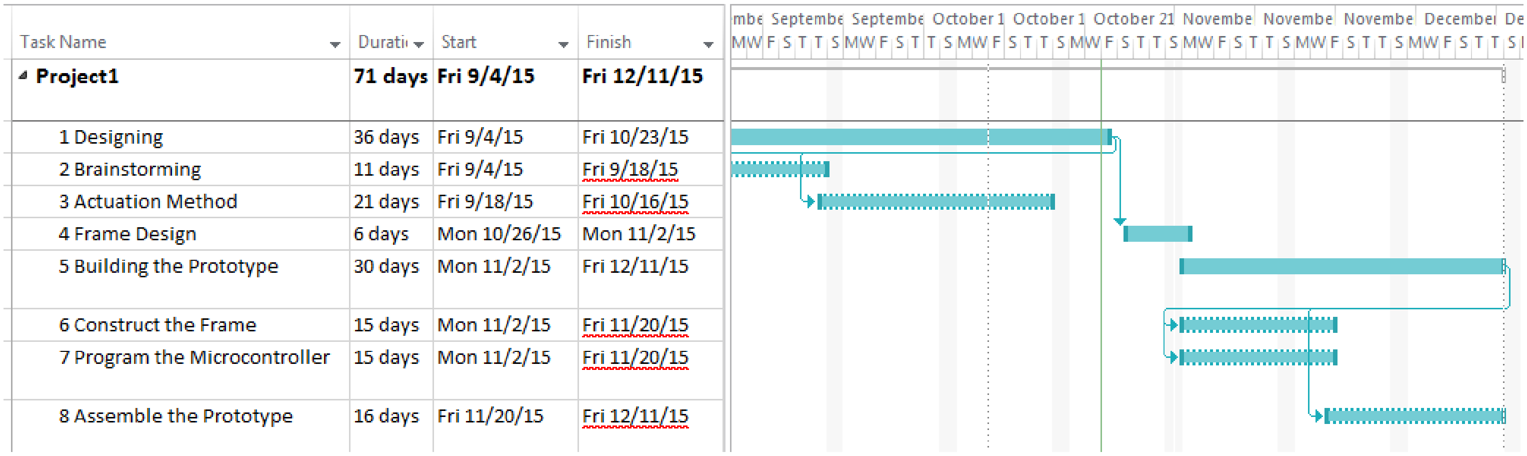
The graph shows the two coupling constant lines for the tie rod (red line) and the cantilevered beam (blue line). For both lines the arrow is pointing to lighter, stiffer and stronger materials. The coupling constant for the cantilevered beam is greater than the tie rod meaning that the materials along 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 2.27 kg, and the thickness of 9 mm is considered to be nonrealistic. [2]

4. Scheduling and Resource Allocation



Task Name	Durati	Start	Finish
Project1	**71 days**	**Fri 9/4/15**	**Fri 12/11/15**
1 Designing	36 days	Fri 9/4/15	Fri 10/23/15
2 Brainstorming	11 days	Fri 9/4/15	Fri 9/18/15
3 Actuation Method	21 days	Fri 9/18/15	Fri 10/16/15
4 Frame Design	6 days	Mon 10/26/15	Mon 11/2/15
5 Building the Prototype	30 days	Mon 11/2/15	Fri 12/11/15
6 Construct the Frame	15 days	Mon 11/2/15	Fri 11/20/15
7 Program the Microcontroller	15 days	Mon 11/2/15	Fri 11/20/15
8 Assemble the Prototype	16 days	Fri 11/20/15	Fri 12/11/15

<ins>Ryan Whitney</ins> –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.

<ins>Robert Slapikas</ins> –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 AutoCad. He will continue to provide oversight on the mechanical design and financial aspect of the project.

<ins>Derek Pridemore</ins> –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.

<ins>Jared Andersen</ins> –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 the midterm presentation, and is currently researching different types of batteries to power the design.

<ins>Donglin Cai</ins> –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.

5. Results

Although the simulation was able to provide some insight into how much power will be required of the mechanical drive system, there are always uncertain aspects to every project. Ultimately, the true required power will not be known until it is experimentally verified.

After running the simulation, the team realized that there were likely a great number of motors that could potentially be selected that would fulfill the goals of the project, especially if they ended up using a worm gear drive. After some calculations, they realized that the torque multiplication would be fairly large, so safety might become a larger consideration as the project moves forward. The material calculations resulted in the use of aluminum as the choice of material for the frame. It has the needed strength and rigidness while being lightweight and budget friendly.

6. Conclusion

Our team is making solid progress towards the design of an initial prototype. We have decided to use motors instead of pneumatic muscles as our method of actuation for this project. It has also been decided to use an Arduino microcontroller. Aluminum has been chosen as the material of the orthotic frame. We are currently working on a complete design of the prototype which will include but not be limited to: type of motor, type of driver board, power source, locking mechanism, and a feedback system. When completed, this prototype will meet all desired specifications.

7. References

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