Powerflex Arm - A Powered Upper Limb Orthotic

Final Report

Group # ECE 8 / ME 29

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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 the FAMU-FSU College of Engineering. His major of interest is robotics, and has made a robotic prosthetic with his 3D printer. 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 in rehabilitation of injured 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 8/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

The power arm is a device that fits over the arms of the user and uses electromechanical actuators to add to their strength. It contains a strong exoskeleton to help bear loads and uses straps to attach to the user’s body and increases the torque generated by the user's skeleton. The current control scheme just uses two push buttons as input, one for to lift and one to drive the frame downward. The microcontroller being used is the Arduino Nano, as it is well equipped to drive motors. The user base for this device should be large. It will be usable for several groups of consumers including rehabilitation use, military use, and civilian use, such as increased lift for warehouse workers.

4.1 Background Research

The first thing that was researched was previous models of powered exoskeleton arms. This was in order to come up with ideas to brainstorm and explore previous concepts that have already been designed and 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 is a full body exoskeleton suit. The *TALOS* suit used motors as well which were placed at the location of the joint that was being powered. The next 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 10 pounds [7][8]. Actuation methods were then analyzed and reduced to two possible actuators that would work for this project. Artificial muscles looked promising, however after testing they were found to not meet the requirements of the project. 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 lifting their arms under load if the load is too large. This includes workers that do heavy lifting, as they are prone to back injury and other such ailments. 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 desired to be completed to be successful. The objectives are as follows:

1) Provide a strength-assisting powered orthotic that will make lifting heavy objects easier.

2) Increase endurance for holding said objects, using a form of actuation to mimic muscles and frame to add structure.

3) Lift at least 10 pounds with just the power of the orthotic.

4) Give range of motion similar to a human arm.

5) Allow for a large user base.

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. Potential hazards could be from heat of the battery or the motor operating outside of the angles provided (the natural movement of the human arm). Safety was 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 will not be 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

- 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.
- 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 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

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. A worm gear with a high rpm motor is being used in the design. Using a small motor and a worm gear, a large enough torque can be generated and reduce rpm. However due to budget constraints the motor selected is larger. This motor still meets the requirements of the design, and is able to lift the amount of weight necessary for the project. The motor is mounted on the frame along the arm. Below is the block diagram for the overall system [**Fig. 1**], as well as the needs analysis charts and House of Quality [**Tables 1-2, Fig. 2**]. All of these were pertinent in designing the system.

Figure 1 - System Block Diagram

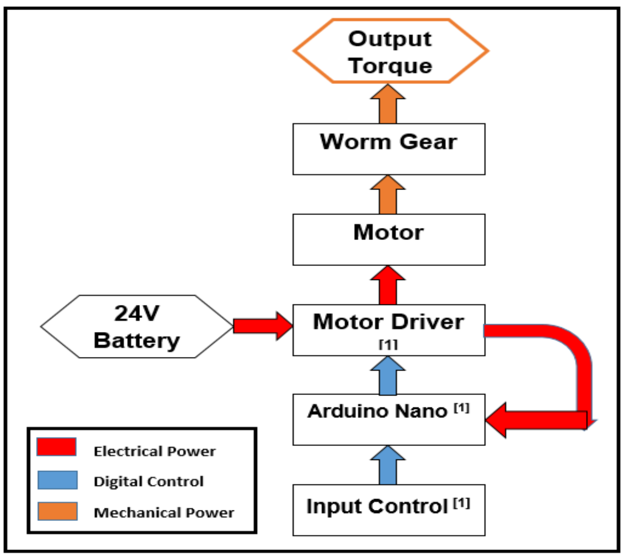


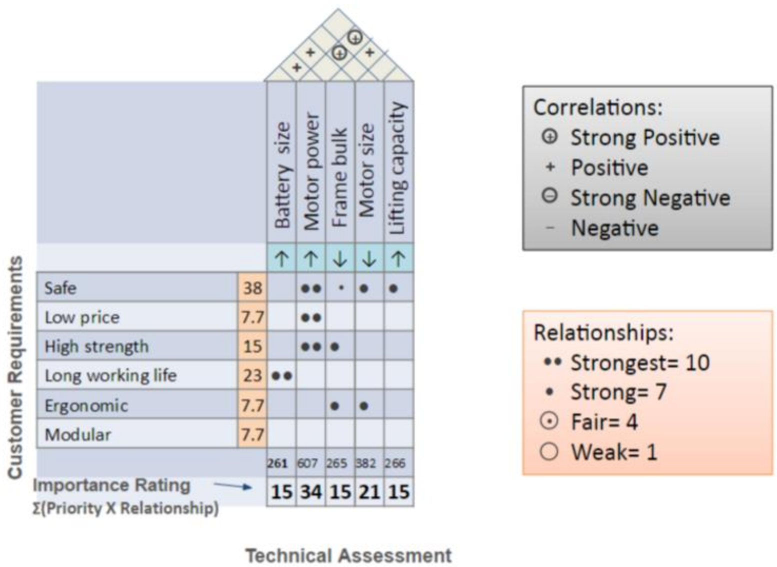
Table 1 - Needs Analysis Weight

	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			

Figure 2 - House of Quality



Time sampling was conducted using a group of twenty people performing a weighted bicep curl of 30 lbs [**Table 3**]. This weight was chosen to observe a weight that was heavier than our goal. As expected, the average time for the movement was about one second for the up and the down movements. This time scale is necessary to calculate 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

5.1 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.

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

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

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

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

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 [**Fig. 3-4**].

Figure 3 - Movement vs. Time

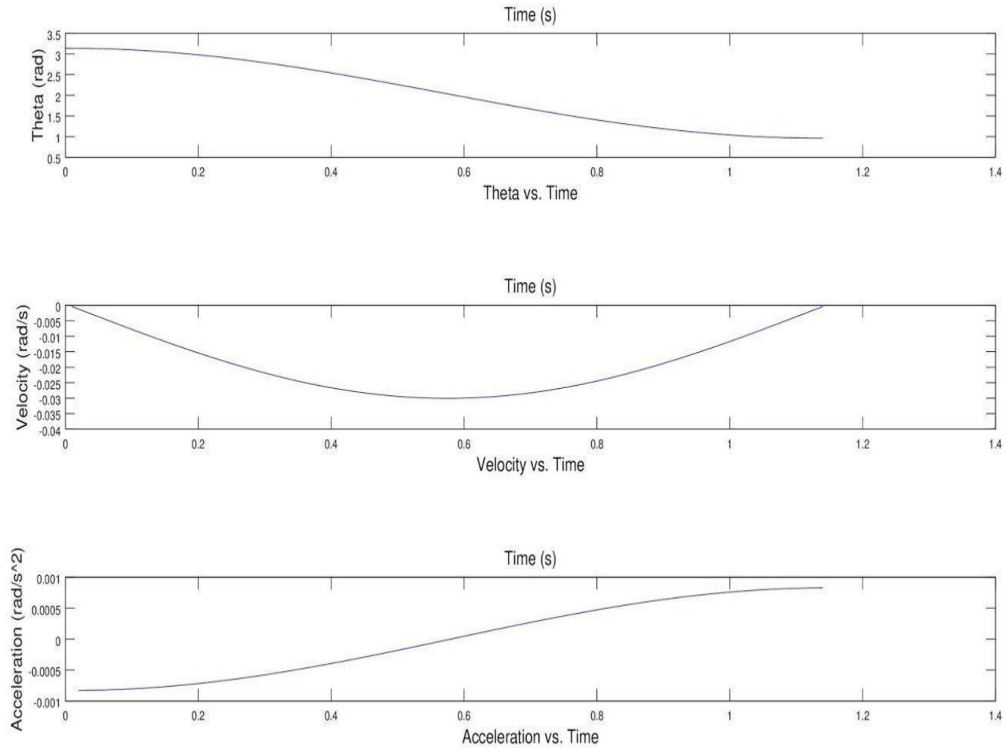
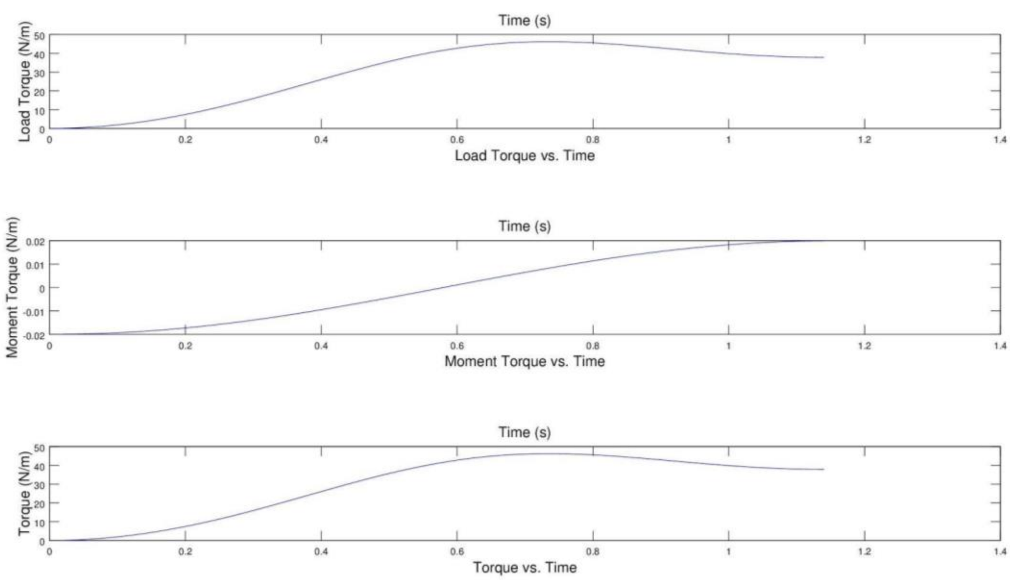
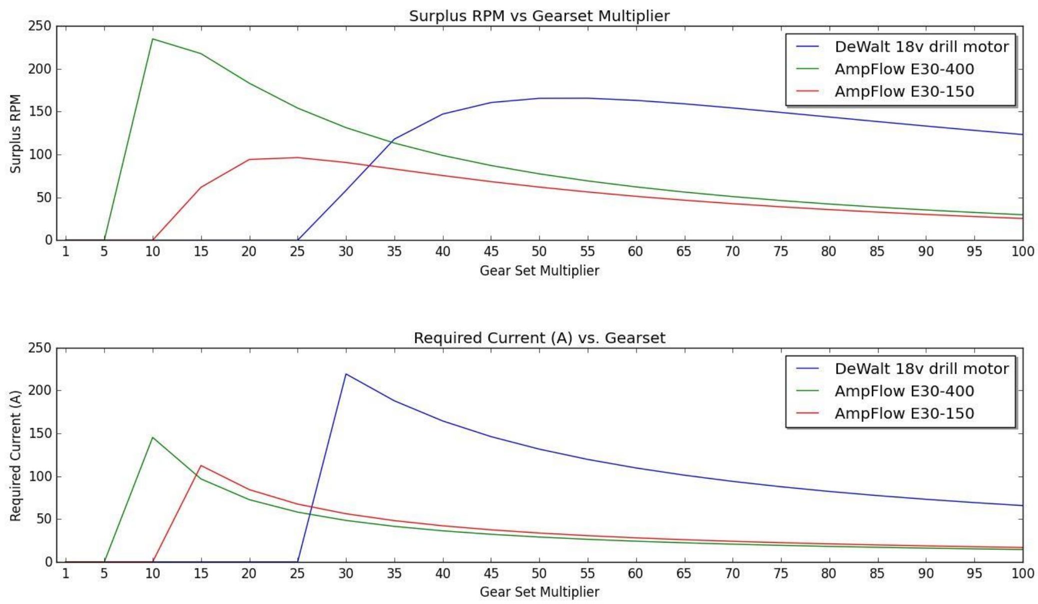


Figure 4 - Position and Motion vs. Time



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 [**Fig. 5**]. Although other motor types were considered, the team decided to primarily focus on 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.

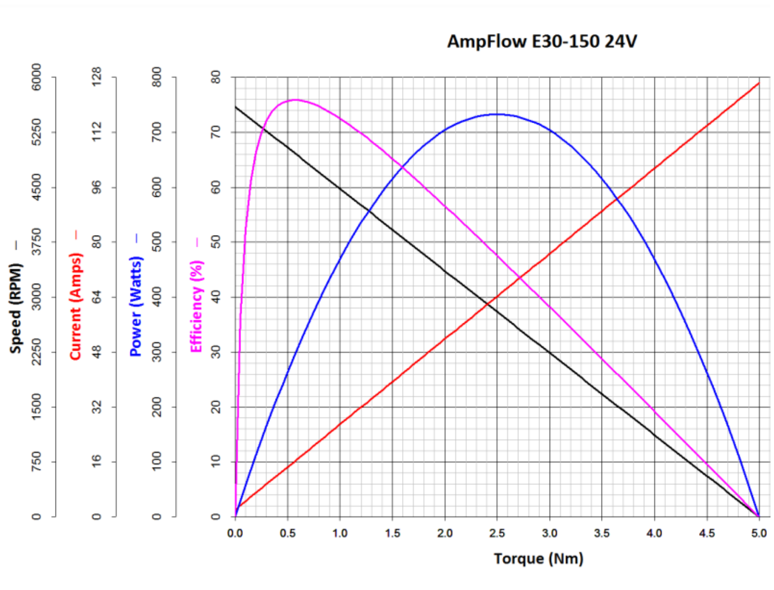
Figure 5 - Motor Fitness Graph



The AmpFlow E30-150 was selected for its low cost, relatively low weight, and low current operating point [**Fig. 6**]. Given a larger budget, a maxon motor would have been chosen. The AmpFlow's operating characteristics were then verified by hand to ensure the values supplied by the fitness graph were correct [**Fig. 7**].

Figure 6 - AmpFlow E30-150 DC Motor

Figure 7 - Motor Specifications Graph

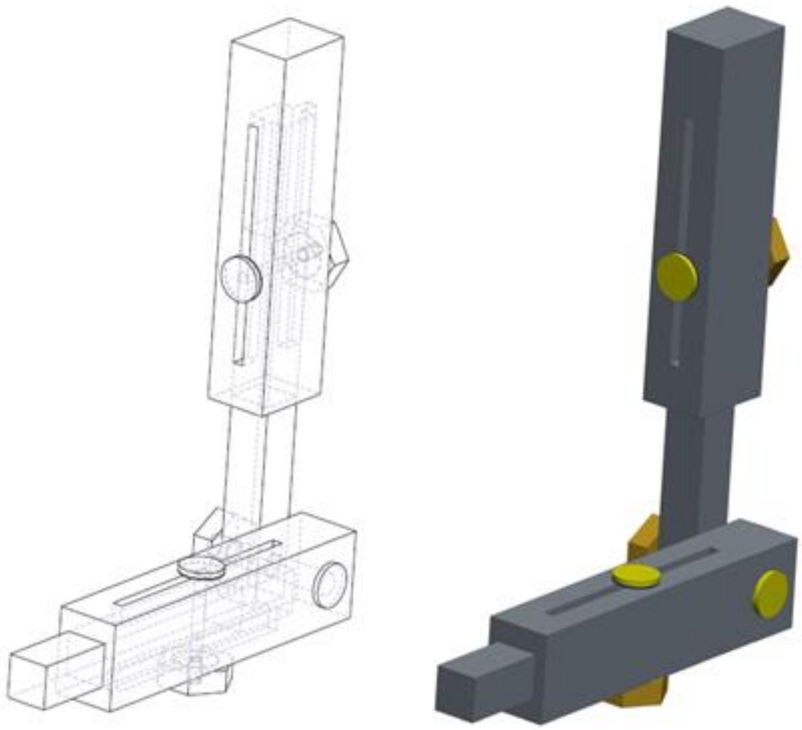


5.2 Frame Design

5.2.1 Initial Frame Design

The main component of the orthotic that our team has been working on is the frame of the arm. It incorporates a sliding bar mechanism for the forearm and upper arm that has 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 [**Fig. 8**]. This will allow 95% of the world population to be able to use the orthotic. The frame also has 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 10 lbs, the frame of the orthotic cannot plastically deform at any time. It must also be made out of a material that has a greater stiffness than the human forearm to safely handle the load.

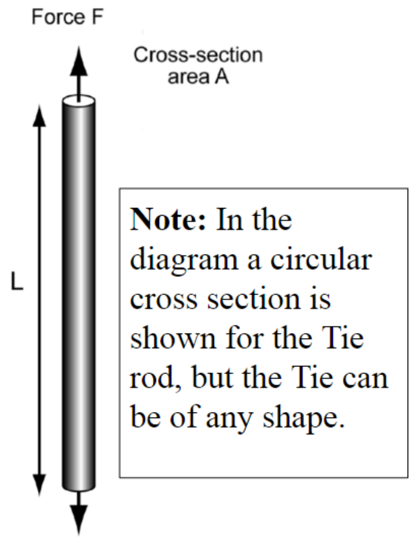
Figure 8 - Original Frame Designs with Two Slider Bar Cranks



5.2.2 Material Selection

For the general design of our orthotic, the arm was simulated in two basic mechanical systems. The first is a light, strong, stiff Tie rod [**Fig. 9**], 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 with a known thickness of the beam [**Fig. 10**]. 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. From knowing these two designs, an analysis was performed for the material selection using the coupling equations (**Eq. 5 and Eq. 6**). These relate a materials specific modulus to its specific strength by a coupling constant, for a tie rod and a cantilevered beam. [2]

Figure 9 - Light, Strong, Stiff Tie Rod

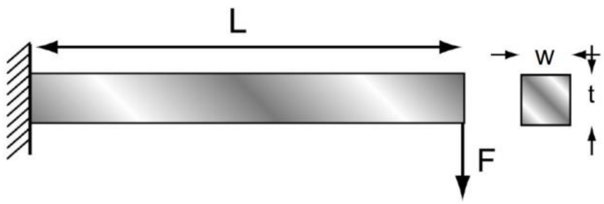


$$\frac{E}{\rho} = \left(\frac{L}{\delta}\right)\left(\frac{\sigma_y}{\rho}\right)$$

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.

Figure 10 - Light, Strong, Stiff Cantilever Beam

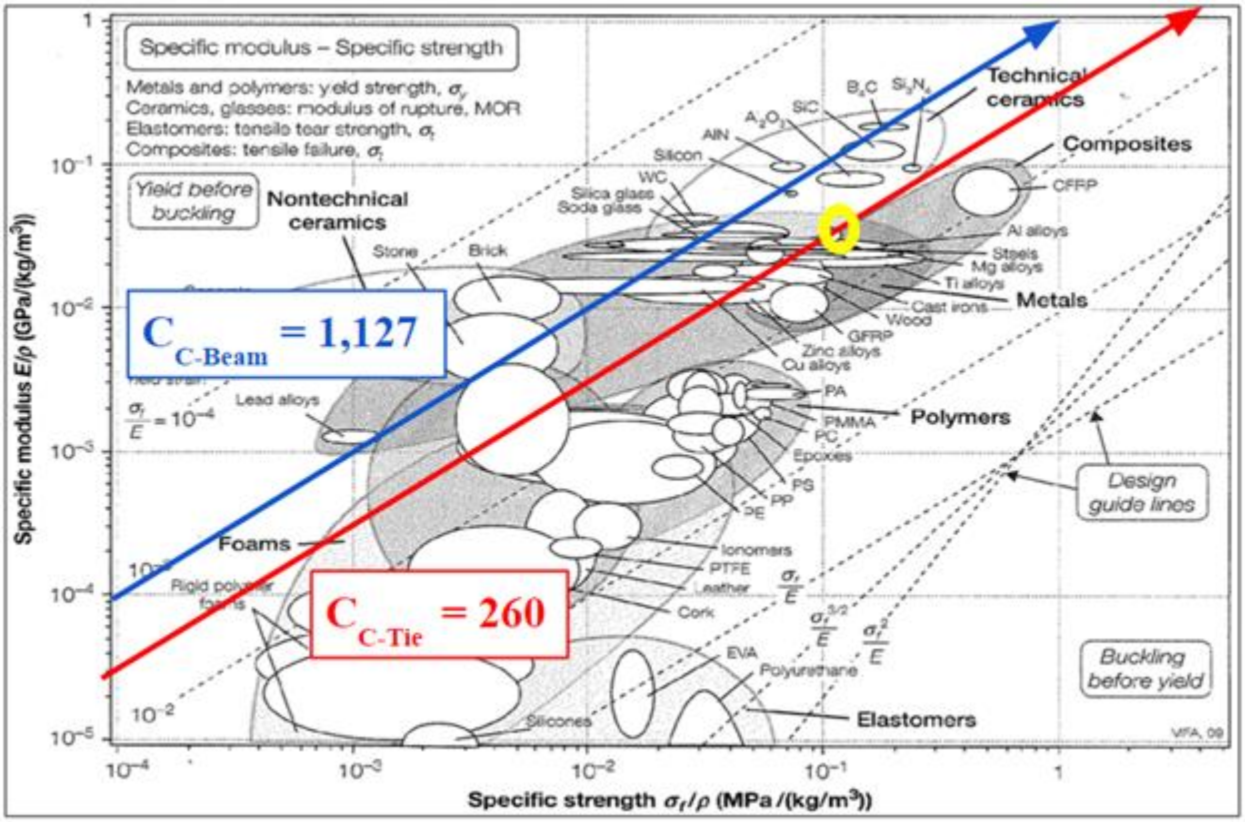


$$\frac{E}{\rho} = \left(\frac{4L^2}{6t\delta}\right)\left(\frac{\sigma_y}{\rho}\right)$$

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.

Figure 11 - Material Selection Graph



The graph shows the two coupling constant lines for the tie rod (red line) and the cantilevered beam (blue line) [**Fig. 11**]. 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. This shows 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. Due to their very low fracture toughness, these materials are also extremely hard to machine. Therefore, ceramics were ruled out as usable materials. Along the tie rod coupling constant line, the materials are metals and have very high fracture toughness. This allows for a very simple machining process. However, since we wanted materials 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 analysis, we decided to go with aluminum as it is at the top of the tie rod coupling constant line, and for its inexpensive cost. [2]

Table 4 - Material Mass and Thicknesses

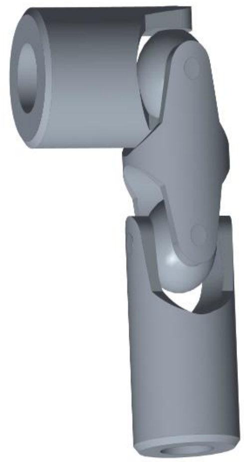
Calculation of Material Mass and Width for Al - alloy		
	m(kg)	**W(m)**
Beam		
Strength	0.218082	0.001808
Stiffness	1.083996	0.008985
Tie		
Strength	0.005592	0.005377
Stiffness	0.006414	0.006167

The mass and width for the generic design of the orthotic frame were calculated using aluminum as the material [**Table 4**]. Aluminum has a density (ρ) of 2.9 (Mg/m^3) a young's modulus (*E*) of 68 (GPa), and a Yield strength (σ_y) of 30 (MPa). After calculating, it was found that the max thickness would need to be 9 (mm) and the total weight would be 1.08 (kg). We calculated for a mass of the arm to be 1.08 kg, and the thickness of 9 mm is considered to be unrealistic as it is hard to machine and buy aluminum at that thickness. These values allowed us to design the frame of the arm. [2]

5.2.3 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 initially decided to use a double u joint [**Fig. 12**], 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 would have been 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.

Figure 12 - Double U Joint 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 maximum of 180 degrees and a minimum 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 centerpiece of 4 cm 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 [**Fig. 13**] 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 [**Fig. 14**]. At 35 degrees this design would stop the arm with an angled edge on the upper arm [**Fig. 15**].

Figure 13 - 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)

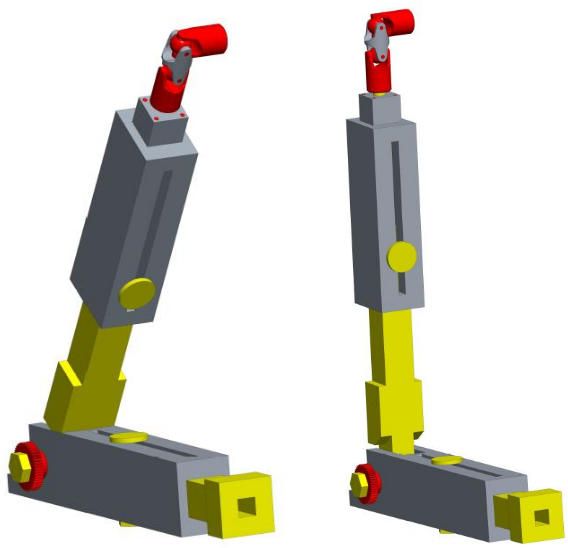
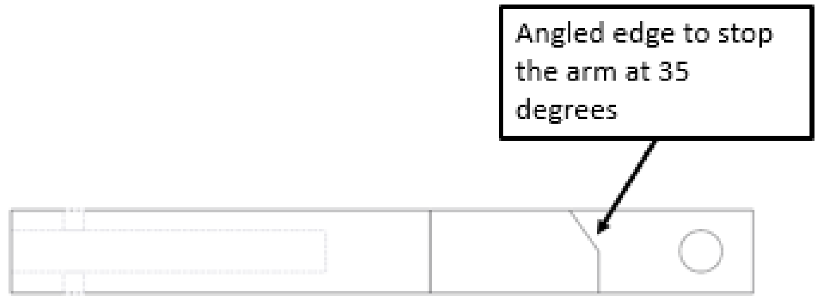


Figure 14 - Design 1 Side View of Forearm Elbow Joint with Bars to Stop the Arm at 180 Degrees

Figure 15 - 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 [**Fig. 16**]. 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 and with a socket sleeve in the upper arm [**Fig. 17**]. Also in both the forearm and the upper arm physical stop at 35 degrees is an angled edge [**Fig. 18**].

Figure 16 - Design 2 of the Orthotic with Circular Elbow Joint where it is Fully Contracted at 35 Degrees (Left) and at the Max Torque at 90 Degrees (Right)

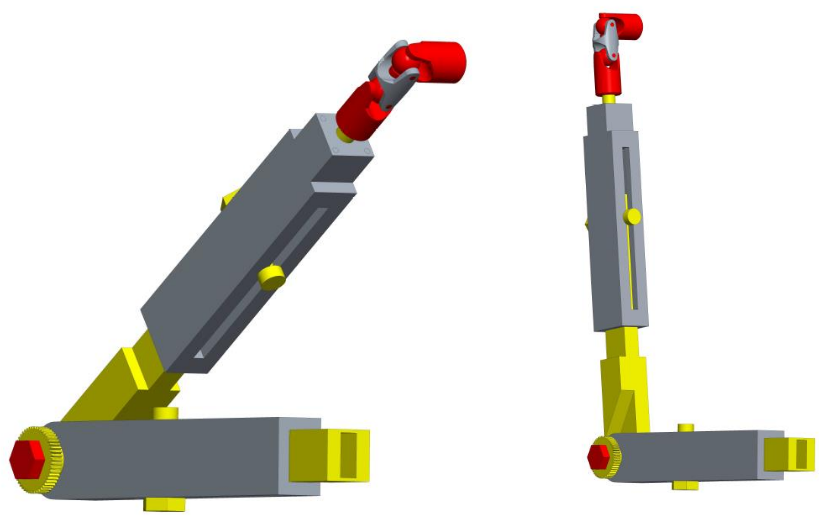


Figure 17 – Design 2 Side View of Forearm Elbow Joint to Stop the Arm at 180 Degrees and 35 Degrees with Internal Socket Slider and at 35 Degrees with Angled Edge

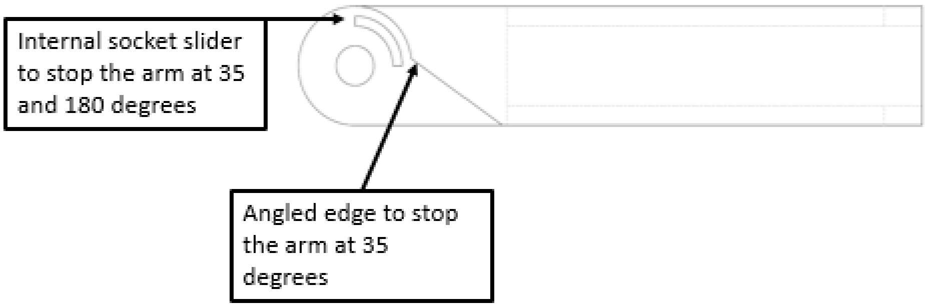
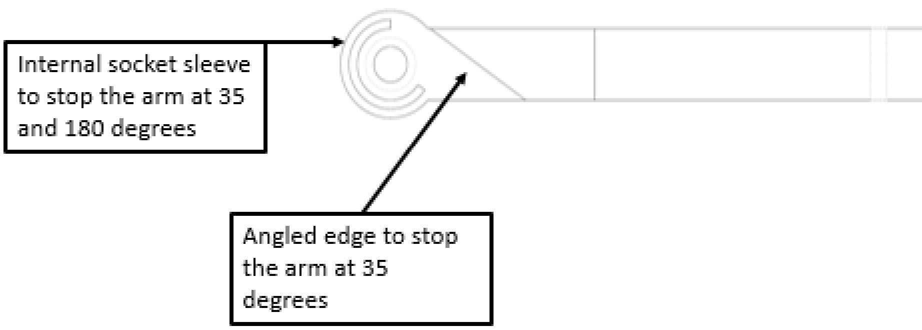


Figure 18 - Design 2 Side View of Upper Arm Elbow Joint to Stop the Arm at 180 Degrees and 35 Degrees with Internal Socket Sleeve and at 35 Degrees with Angled Edge



From these two frame designs, we decided on the second one with the circular elbow joint. Both designs would weight basically the same, and the strength of both designs are equal. 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.

However, after taking these designs to faculty members, the team was advised to cut the double U Joint from the design. This joint allows for multiple degrees of freedom. This was considered a safety concern, as the user might be able to harm themselves easier with the extra degrees of freedom. Another final design change that took place happened once we spoke to the machine shop we adjusted the forearm piece to be adjusted to the frame design to make the design machineable [**Fig. 19-20**].

Figure 19 – 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 and solid bar.

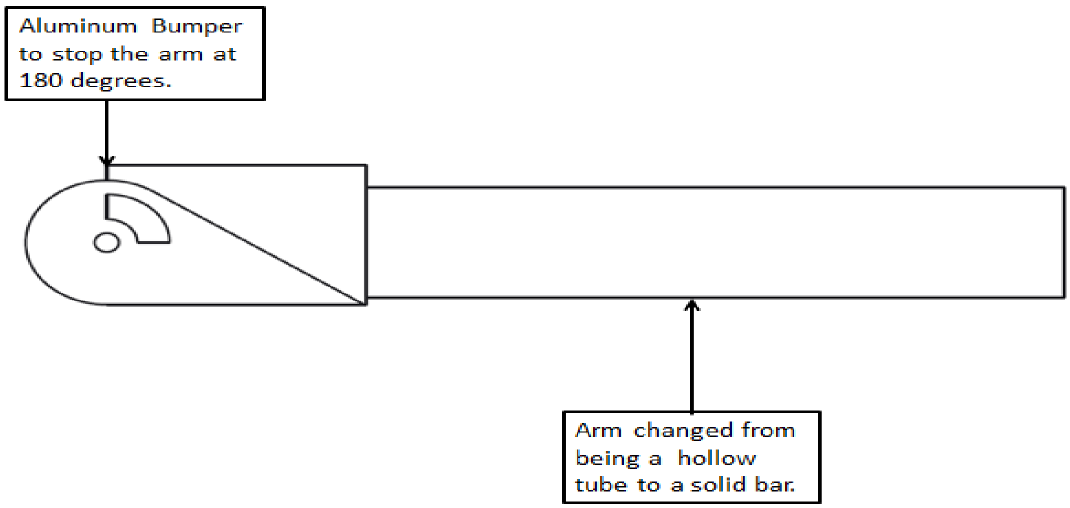


Figure 20 - Design 2 Side View of Upper Arm Elbow Joint to Stop the Arm at 180 Degrees and 35 Degrees with Internal Socket Sleeve and at 35 Degrees with Angled Edge

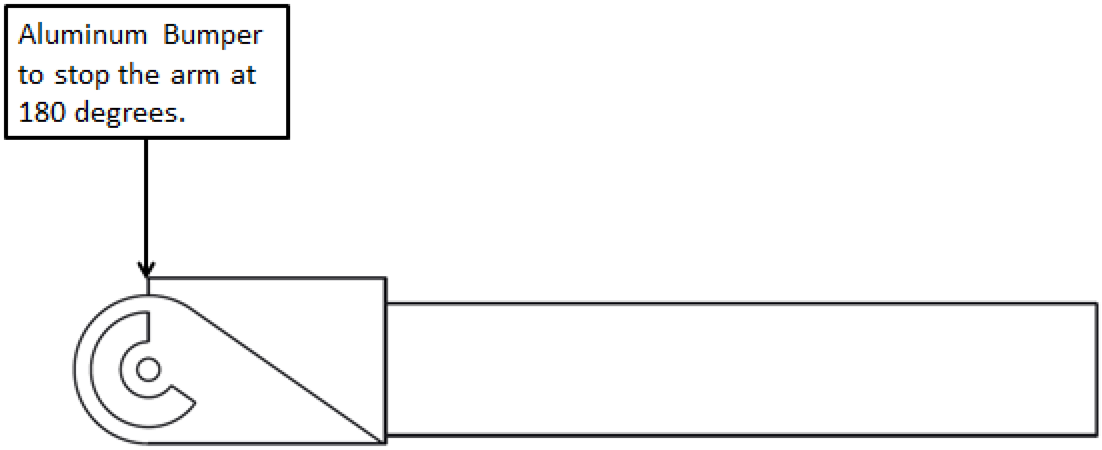


Figure 21 - Final Design Arm Frame at 90°

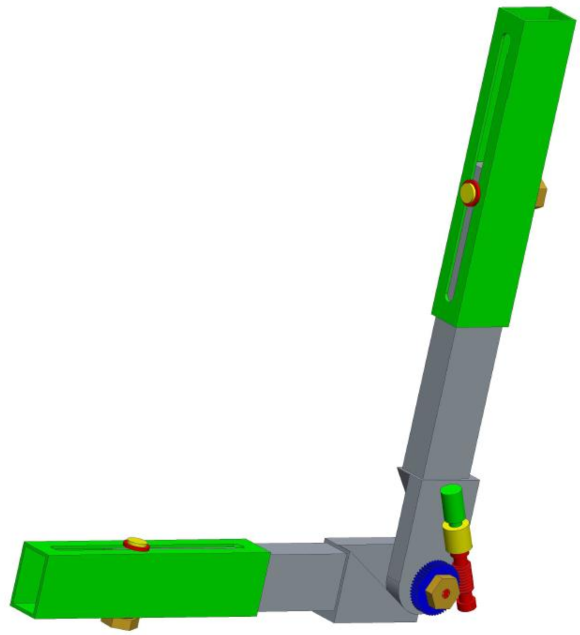


Figure 22 - Final Design Arm Frame at 35°

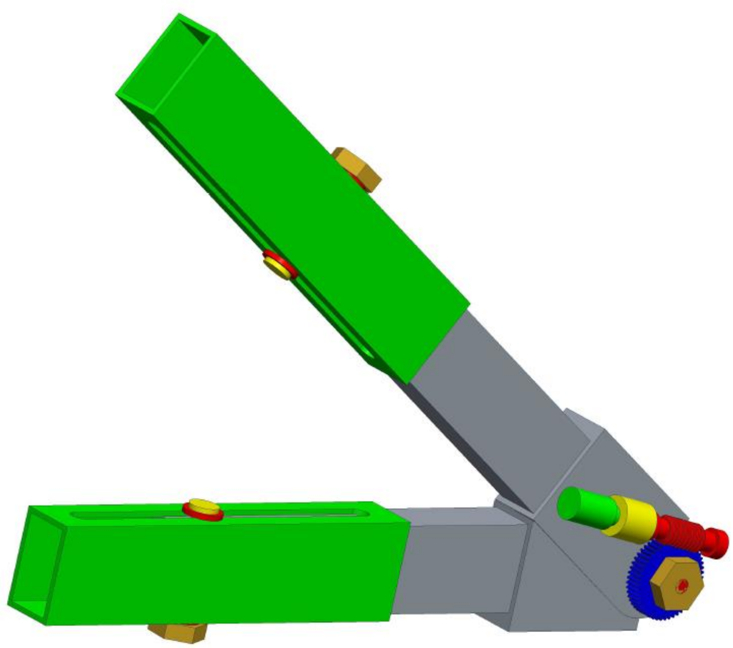


Figure 23 - Final Design Arm Frame at 180°

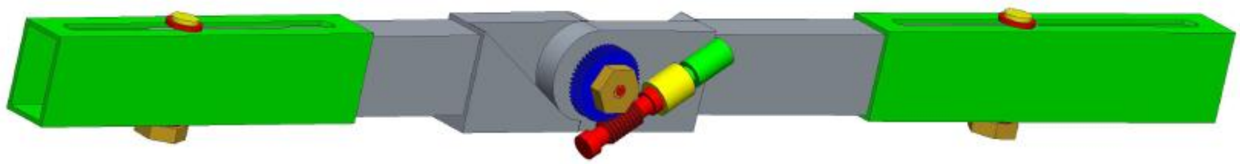
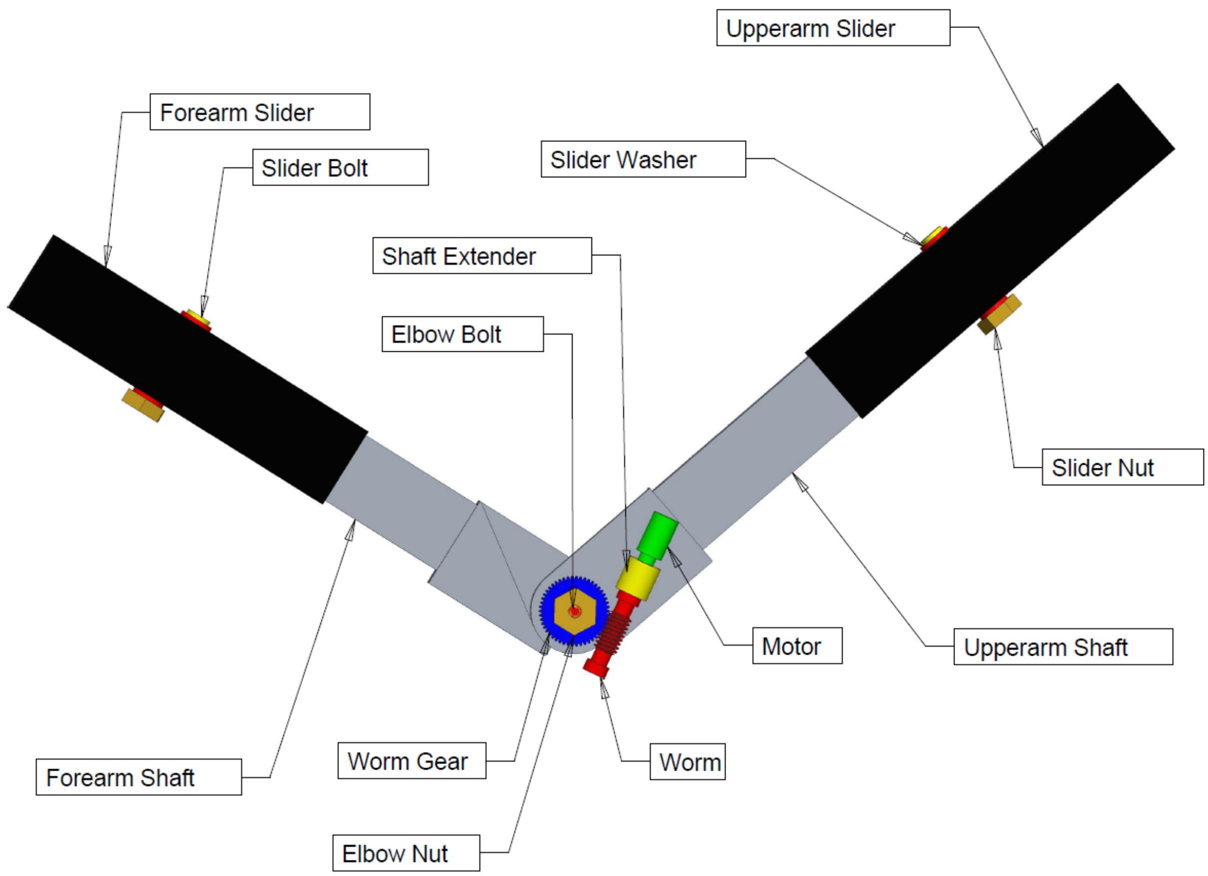
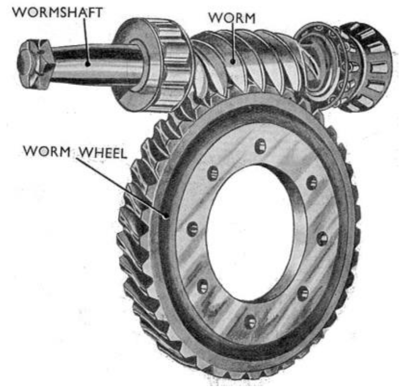


Figure 24 - Fully Labeled Final Design Arm Frame



We chose to apply torque through a worm and worm gear system for the strength assisting orthotic for the reasons that it will increases the torque on the arm, reduces the motor speed, and also won't allow the arm to backdrive [**Fig. 25**].

Figure 25 - Worm Gear Diagram



Due to the extra weight on the user's arm, and the additional torque provided by the motor, the moment of inertia may cause the user to lose balance. To counteract this difference in the user's center of mass, our team decided to use a hiking backpack, which centers a heavy load to the hips, and down through the legs [**Fig. 26**]. This will allow the user to utilize the orthotic without falling over or feeling awkward lifting a mass.

Figure 26 - Backpack

5.3 Electronic Design

The microcontroller that was selected to run the motor through the motor driver is the Arduino Nano. The method of control that was utilized was a pushbutton for the curling direction and a pushbutton for the relaxing direction of the arm [**Table 5**].

Table 5 - Logic of Control System

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

5.3.1 Electrical Components

The motor driver was selected based off of the current needed to drive the motor, voltage specifications, safety features, and compatibility with the Arduino [**Fig. 31**]. Even though the driver is made for up to 50A continuous current usage, it can safely peak 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 the circuit diagram is different from the Syren motor driver selected, it will use the same pin setup shown [**Fig. 27**].

Both the stepdown voltage regulator and pushbuttons were generic electronic pieces that did not need intense work to select. The regulator needed to handle up to 24V and drop it down to 5V. The DROK LM2596 Voltage Regulator used in this device is able to handle 0-35V, which meets the needs of the design [**Fig. 28**].

The 24V battery will supply both the motor and the Arduino Nano [**Fig. 29-30**]. This saved money from having to buy a separate smaller battery for the Arduino Nano, as a voltage regulator to protect the Arduino is much more affordable. 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.

Figure 27 - Circuit Diagram

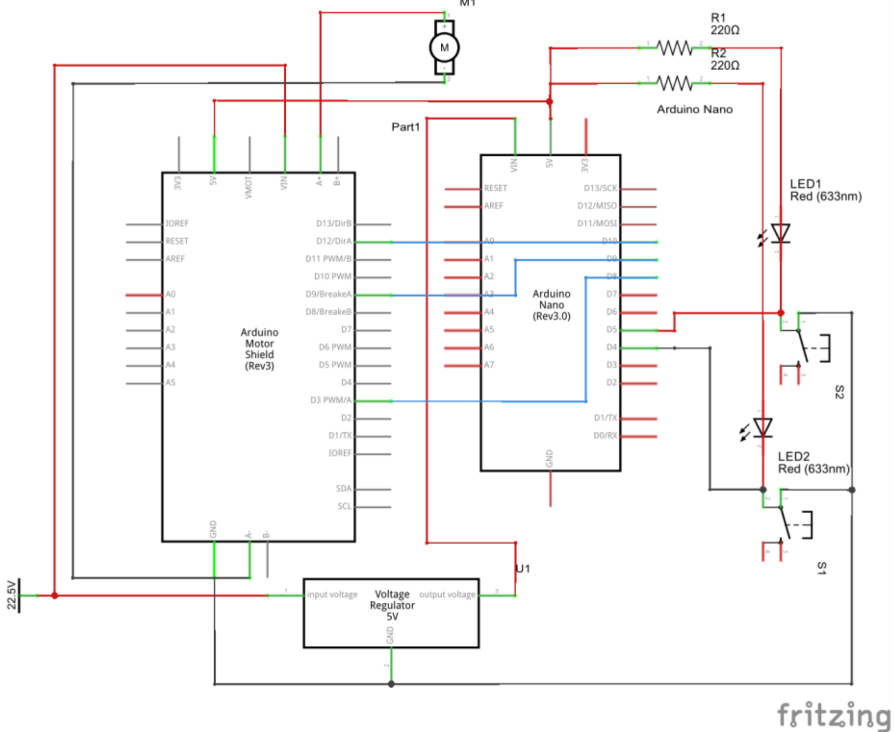


Figure 28 - DROK LM2596 Voltage Regulator

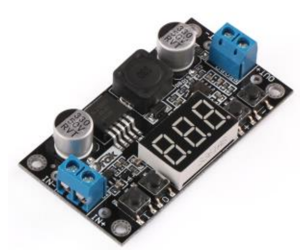
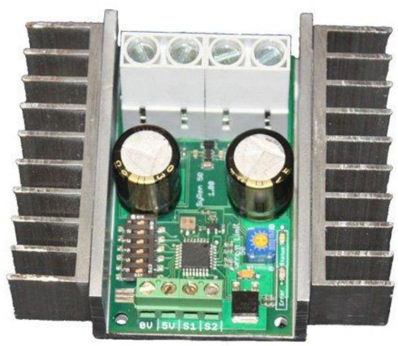


Figure 29 - Arduino Nano

Figure 30 - LiPo Battery (5000mAh, 24V)

Figure 31 - Syren 50 Motor Driver



5.3.2 Arduino Code

The Arduino code is used to drive the motor with the simple two push button control scheme. The full code is listed in the Appendix.

6. Test Plan/Risk and Reliability Assessment

There are a number of risks associated with this project. These risks are 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 were constructed in a supervised shop setting. Safety glasses, long pants, and close toed shoes were worn at all times during the construction process. Proper ventilation will be used during all soldering sessions. A buddy system was used during the construction process.

During the testing and operation of the device, a number of safety precautions were used. In order to combat the risk of fires, all tests were performed in a fire-resistant environment, with fire extinguishers present. A number of hardware and software failsafes were likewise be built into the device itself in order to prevent undesired operation. For mechanical tests, a minimum of three testers were present at all times. For electrical tests, a minimum of two testers were present at all times. Also in the interests of safety, a posable mannequin was used to test the device until the team can get approval from the Human Subjects Research Committee, which will take place in the next phase of the project. The testing itself will involve strapping the arm of the orthotic to the arm of the mannequin and attaching varying weight while measuring the current consumption of the motor. There will be three levels of weight: zero, five, and ten pounds. The current and voltage levels will then be recorded.

Since the device is using a high-energy lithium battery in order to operate, extra precautions were required. 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.

For the initial tests of the electrical actuation motor, the microcontroller was connected to the motor driver and motor, and power applied. When running the driver software, the motor performed as expected when the appropriate buttons were pushed. The time taken to speed up and slow down could also be varied in software.

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, and ordering of the parts for the project. Ryan designed and tested the motor control Arduino code, assembled the electrical systems, and made sure they were safe.

Robert Slapikas –Robert performed research and calculations vital to forward progress and gave vital insight into the mechanical process of the design. He made 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. Robert worked with the Physics Department machine shop to machine our frame expediently, and helped assemble the mechanical systems 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 and maintain the webpage. Derek also designed the circuit schematic in Fritzing and initial electrical setup for the overall system. Derek machined the hiking backpack frame and designed and built the control pushbuttons and emergency stop button, as well as assembled and soldered the electronics on the backpack.

Jared Andersen –Jared has performed research for both methods of actuation and helped with 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 worked on each presentation, and researched different electrical components for design of the project. This includes the battery, motor encoder, aluminum for the frame. He prepared the presentation for the Engineering Shark Tank competition, and contacted professors to schedule presentations throughout the semester.

Donglin Cai –Donglin has helped develop the artificial muscle design and added to the background research for this method. He also worked on each technical paper. He worked on the presentations and helped Ryan with controlling the motor with Arduino code. Donglin also found a Arduino library for the motor driver used in the design, which simplified the code significantly.

8. Communication

The main form of communication between team members were over Facebook, phone, and google drive, as well as through regular team meetings. Email was a secondary form of communication for issues not being time- sensitive. For the passing of information, i.e. files and presentations, Google Drive was the main form of file transfer and proliferation. Each group member had a working email for the purposes of communication and file transference. Members were to 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 were additionally be sent over email so it was very important that each group member checks their email frequently. If a meeting must be canceled, an email had to be sent to the group at least 24 hours in advance. Any team member that could not attend a meeting was to give advance notice of 24 hours informing the group of his absence. Reason for absence was appreciated but not required if personal. Repeated absences in violation with this agreement were not be tolerated. Communication was be polite and respectful at all time and all messages sent to advisors was cc'd to all team members.

9. Schedule

Our initial schedule for the fall needed much adjustment [**Fig. 32**]. The frame design was scheduled for late October through early November, with construction taking place through the end of the semester. The design of the frame however went through multiple iterations before the final design, with this design process lasting through January. The schedule for the Spring was adjusted accordingly, with better knowledge of how long processes would take. The Spring schedule was mostly accurate [**Fig. 33**]. The only change was testing the electrical systems, which lasted through early April.

Figure 32 - Fall Gantt Chart

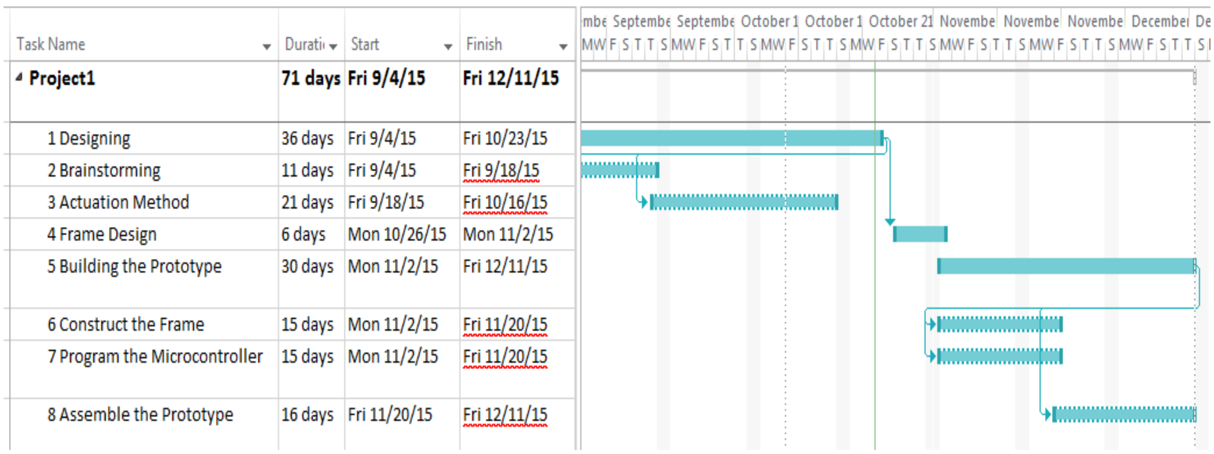
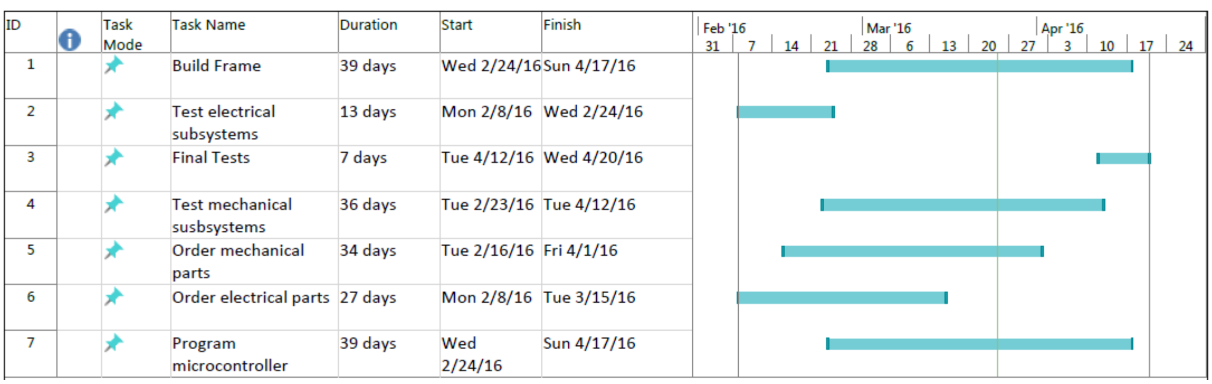


Figure 33 - Spring Gantt Chart



10. Budget Allocation

The team was given $1400 for the purposes of this project by the college of engineering. The initial budget analysis was a rough estimation [**Table 6**]. It included an expensive pancake motor, that was later discarded for the cheaper AmpFlow motor. The estimation for the cost of aluminum was very far from the actual cost. At the end of the project, the team spent $1164, leaving $236 left [**Table 7**]. This money left over allowed for a decent amount of safety in case something were to go wrong in the process of development.

Table 6 - Initial Budget Analysis

Name	**Price**	**Quantity**	**Total**
24V 6.24 N/m 150 Rpm Pancake Motor + Drivers	$859.25	1	$859.25
Arduino	$8	1	$8
Adjustable DC/DC Stepdown regulator	$10	1	$10
Aluminum Frame [$1.50 -1.70 per kg]	$100	1	$100
24V 5Ah Battery	$110	1	$110
TOTAL COST			**$1087.25**

Table 7 - Final Budget Analysis

Part	Cost of Design	Money Spent
Arduino Uno Nano	$8.88	$0
DC Voltage Step-down Regulator	$8.36	$0
AmpFlow E30-150 24V	$79.00	$79.00
Driver Board	$119	$119
Aluminum	$470	$470
24V Battery	$83	$83
Push Buttons	$4	$0
Worm Gearset	$92	$92
Back Mounted Frame	$100	$100
Mannequin	$221	$221
Total Cost:	$1,176.55	$1,164
Money Leftover		$236

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 contains little to no dangerous chemicals and is made mostly of metal.

12. Future of the Project

Year two of this project should focus on expanding the orthotic device to a fully wearable powered exoskeleton. This can include adding a second powered arm orthotic and adding powered leg orthotics. The team should continue attempting to obtain safety clearance to perform human testing from the FSU Safety Department. The mechanical engineers should find ways to optimize the current design, such as finding a stronger or more efficient motor. The electrical engineers should work on designing a biofeedback sensor input system, instead of using the pushbuttons as inputs. This sensor system should recognize the motion of lifting the arm, and run the motor as the arm lifts. Also, with a full budget next year, an upgraded motor can be added to reduce the weight on the user's arm. Lastly, due to the machining process we did not have time to include the internal locking mechanism, so a future goal would be to machine out the track and use a keyway.

13. Conclusion

This paper outlined the research and development of this team's attempt at a wearable strength-assisting orthotic over the course of a year. During this time period, multiple actuation methods were considered, tested, and discarded as the need arose. It was decided that a brushed DC motor would serve as the actuator, and the appropriate electronics were selected to support the motor selected. The electrical system was constructed as designed and tested successfully.

For the mechanical portion of the project, aluminum was decided upon for the composition of the frame. A worm gear drive was decided upon for the arm joint, as it would allow for both increased torque and remove the need for a latching mechanism to keep the arm in place when power to the motor was removed. The team went over a number of different designs for the mechanical portion of the arm, and a design that satisfied as many constraints of the project as possible was finalized and constructed from two sets of metal stock.

14. References

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Appendix A

Table 8 - Bicep Curl Time Sample

Test Subject	Up (seconds)	Down (seconds)
1	1.8	1.71
2	1.6	0.78
3	2.7	1.55
4	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	

Full Arduino Code

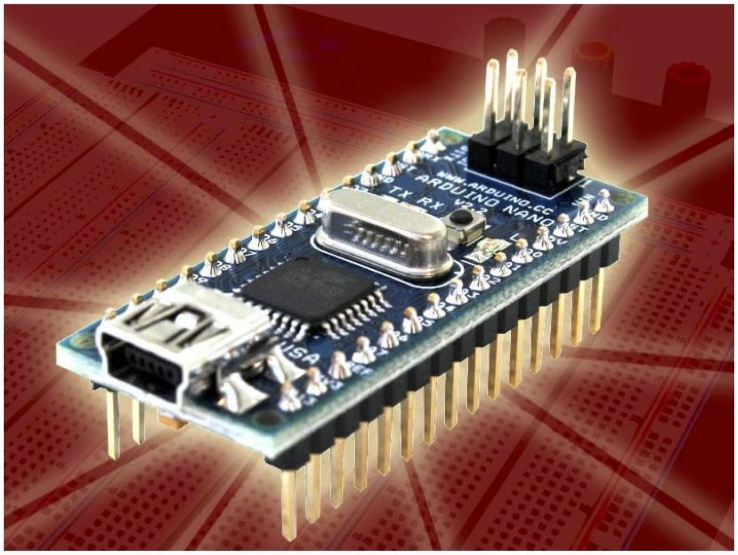
```
/* Start button is Digital Pin 7, SyRen S1 is connected to Arduino Digital Pin 1 (TX), Proximities are Digital
Pins 2 and 3, Pots are Analog Pins 1 and 2 */

#include <SyRenSimplified.h>
const int forwardbutton = 8;
const int reversebutton = 7;

SyRenSimplified ST; // Simplified Serial Mode. Baud rate of 9600. Arduino TX->1  ->  Sabertooth S1
Arduino GND    ->  Sabertooth 0V
                  // [ST.motor(1, X);  X of 0 is full reverse, 128 is stop, 255 full forward] <--- WRONG!  -127 full
reverse, 0 stop, 127 full forward

void setup()
{
  SyRenTXPinSerial.begin(9600); // This is the baud rate you chose with the DIP switches.
  pinMode(forwardbutton, INPUT);
  pinMode(reversebutton, INPUT);

  //ForwardSpeed = map(ForwardSpeed,0,1023,102.7,1);  // set 102.7 in order to control the degrees from 0 to
145.
  //ReverseSpeed = map(ReverseSpeed,0,1023,-102.7,-1);



  ST.motor(1, 0);
}

int currentspeed = 0;
int maxspeed = 62;
int spinuprate = 10;
int moveforward = 0;
int movebackward = 0;

//direction is either 1 or -1
void spinup(int dir)
{
  while((abs(currentspeed) < abs(maxspeed)) && (moveforward == 1 || movebackward == 1))
  {
    ST.motor(1, currentspeed);
    delay(spinuprate);
    if(dir == 1)
      currentspeed++;
    else
      currentspeed--;
    moveforward = digitalRead(forwardbutton);
    movebackward = digitalRead(reversebutton);
```

```
  }
}
void spindown(int dir)
{
  while(abs(currentspeed) > 0)
  {
    ST.motor(1, currentspeed);
    delay(spinuprate);
    if(dir == 1)
      currentspeed--;
    else
      currentspeed++;
  }
}



void loop()
{
  moveforward = digitalRead(forwardbutton);
  movebackward = digitalRead(reversebutton);
  if(moveforward == 1)
  {
    spinup(-1);
  }
  else if(movebackward == 1)
  {
    spinup(1);
  }
  else
  {
    ST.motor(1, 0);
    currentspeed = 0;
  }
  delay(500);}
```

Appendix B - User Guides/Data Sheets

Arduino Nano *(V2.3)*

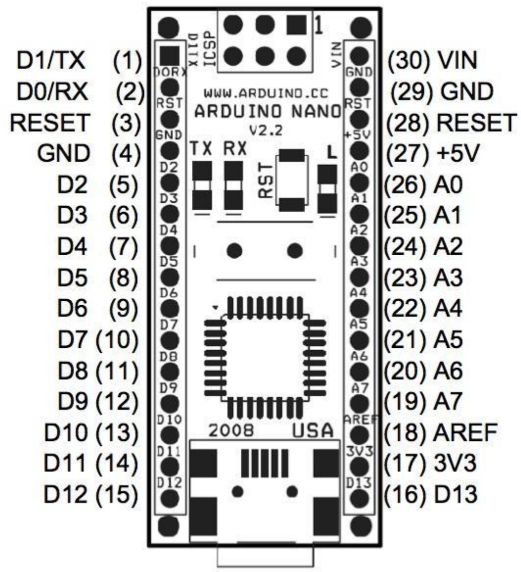
User Manual



More information:

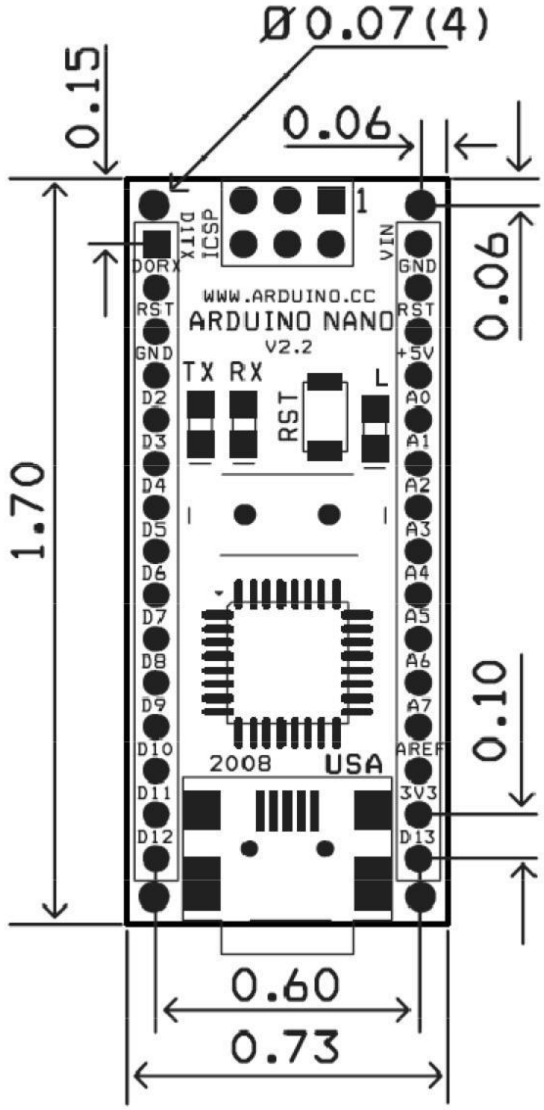
www.arduino.cc Rev. 2.3

Arduino Nano Pin Layout



Pin No.	Name	Type	Description
1-2, 5-16	D0-D13	I/O	Digital input/output port 0 to 13
3, 28	RESET	Input	Reset (active low)
4, 29	GND	PWR	Supply ground
17	3V3	Output	+3.3V output (from FTDI)
18	AREF	Input	ADC reference
19-26	A7-A0	Input	Analog input channel 0 to 7
27	+5V	Output or Input	+5V output (from on-board regulator) or +5V (input from external power supply)
30	VIN	PWR	Supply voltage

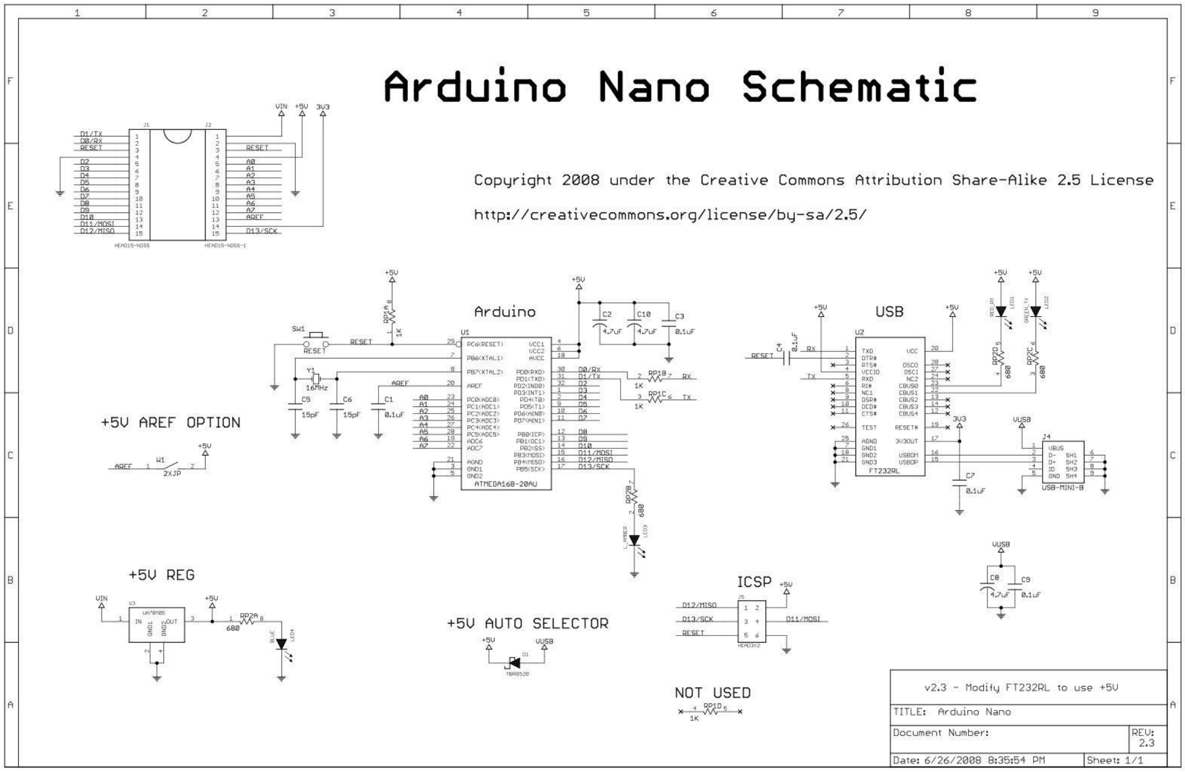
Arduino Nano Mechanical Drawing



ALL DIMENTIONS ARE IN INCHES

Arduino Nano Bill of Material

Item Number	Qty.	Ref. Dest.	Description	Mfg. P/N	MFG	Vendor P/N	Vendor
1	5	C1,C3,C4,C7,C9	Capacitor, 0.1uF 50V 10% Ceramic X7R 0805	C0805C104K5RACTU	Kemet	80-C0805C104K5R	Mouser
2	3	C2,C8,C10	Capacitor, 4.7uF 10V 10% Tantalum Case A	T491A475K010AT	Kemet	80-T491A475K010	Mouser
3	2	C5,C6	Capacitor, 18pF 50V 5% Ceramic NOP/COG 0805	C0805C180J5GACTU	Kemet	80-C0805C180J5G	Mouser
4	1	D1	Diode, Schottky 0.5A 20V	MBR0520LT1G	ONSemi	863-MBR0520LT1G	Mouser
5	1	J1,J2	Headers, 36PS 1 Row	68000-136HLF	FCI	649-68000-136HLF	Mouser
6	1	J4	Connector, Mini-B Recept Rt. Angle	67503-1020	Molex	538-67503-1020	Mouser
7	1	J5	Headers, 72PS 2 Rows	67996-272HLF	FCI	649-67996-272HLF	Mouser
8	1	LD1	LED, Super Bright RED 100mcd 640nm 120degree 0805	APT2012SRCPRV	Kingbright	604-APT2012SRCPRV	Mouser
9	1	LD2	LED, Super Bright GREEN 50mcd 570nm 110degree 0805	APHCM2012CGCK-F01	Kingbright	604-APHCM2012CGCK	Mouser
10	1	LD3	LED, Super Bright ORANGE 160mcd 601nm 110degree 0805	APHCM2012SECK-F01	Kingbright	04-APHCM2012SECK	Mouser
11	1	LD4	LED, Super Bright BLUE 80mcd 470nm 110degree 0805	LTST-C170TBKT	Lite-On Inc	160-1579-1-ND	Digikey
12	1	R1	Resistor Pack, 1K +/-5% 62.5mW 4RES SMD	YC164-JR-071KL	Yageo	YC164J-1.0KCT-ND	Digikey
13	1	R2	Resistor Pack, 680 +/-5% 62.5mW 4RES SMD	YC164-JR-07680RL	Yageo	YC164J-680CT-ND	Digikey
14	1	SW1	Switch, Momentary Tact SPST 150gf 3.0x2.5mm	B3U-1000P	Omron	SW1020CT-ND	Digikey
15	1	U1	IC, Microcontroller RISC 16kB Flash, 0.5kB EEPROM, 23 I/O Pins	ATmega168-20AU	Atmel	556-ATMEGA168-20AU	Mouser
16	1	U2	IC, USB to SERIAL UART 28 Pins SSOP	FT232RL	FTDI	895-FT232RL	Mouser
17	1	U3	IC, Voltage regulator 5V, 500mA SOT-223	UA78M05CDCYRG3	TI	595-UA78M05CDCYRG3	Mouser
18	1	Y1	Cystal, 16MHz +/-20ppm HC-49/US Low Profile	ABL-16.000MHZ-B2	Abracon	815-ABL-16-B2	Mouser


Arduino Nano Schematic
Copyright 2008 under the Creative Commons Attribution Share-Alike 2.5 License
http://creativecommons.org/license/by-sa/2.5/
Arduino
USB
+5V AREF OPTION
+5V REG
+5V AUTO SELECTOR
ICSP
NOT USED
ATMEGA168-20AU
FT232RL
USB-MINI-B
v2.3 - Modify FT232RL to use +5V
TITLE: Arduino Nano
Document Number:
REV: 2.3
Date: 6/26/2008 8:35:54 PM
Sheet: 1/1