Nudge Control Switch for Upper Extremity Prosthesis
Final Report

ME 450 Winter 2009

Project 3
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Executive Summary

Our group has been given the task of improving the Sierra Nudge Control. The nudge control is a prosthetic elbow locking mechanism used by upper extremity amputees that require prostheses due to amputation above the elbow. The device, when depressed by the chin, pulls a cable that disengages a lock in the prosthetic elbow joint and allows the lower arm to swing freely. The idea of redesigning this apparatus was presented to us by Alicia Davis of the University of Michigan Hospital Orthotics and Prosthetics Center.

In an interview with Ms. Davis and a patient who previously used the nudge control, we discussed the many challenges and specifications associated with this outdated design and developed the project requirements. These requirements are to minimize the force required to lock and unlock the elbow, provide feedback to the patient when elbow is locked and unlocked, keep the device hands free, cheap, discreet, cosmetically appealing, lightweight, and quiet. Discomfort was the main reason that an interviewed patient switched to an electric prosthetic arm, so this is the main improvement we have focused on for the project.

We developed engineering specifications by testing and measuring the current mechanism. We measured the force required to pull the cable and determined a force of at least 4.670 ± 0.222 lbs is needed. From this data we set a goal to develop a system that requires only 2.3 ± 0.3 lbs, thus reducing the current load by over one half. We also measured the geometry of the current device and wanted to keep the new system's maximum height off of the arm as 0.5 inches.

We developed an electronic system to build our prototype. Here, the chin activates an electronic button sending a signal to a linear actuator which pulls the cable to activate the elbow. This design meets all of our engineering specifications and introduced the least complications into the project.

A series of tests were performed on this initial prototype with a 24 volt power source. From the testing we determined the cycle time for the actuator complies with our requirements. We learned that the actuator is capable of pulling the force necessary to unlock the elbow, and that as the voltage powering the system increased, the time required to complete the task decreased. During testing, a DPDT toggle switch was used to operate the actuator.

Our final prototype incorporated three 9 volt rechargeable batteries (store bought). We also used a pushbutton DPDT switch, which we connected to the actuator and battery such that when pushed, it extends the actuator, and when released, it retracts the actuator. We used a spring connected in series between the actuator and cable to alleviate the cable's tension, and a circular foam button to increase the surface area of the pushbutton switch. This prototype reduces the input force to less than a pound, with an activation pad that is wider and shorter than the original, fulfilling our design requirements.

Project Background

Alicia Davis of the University of Michigan Hospital Orthotics and Prosthetics Center has given our group the task of improving the Sierra Nudge Control. The nudge control is an elbow locking mechanism used by upper extremity amputees that require prostheses due to amputation above the elbow. As our group sponsor, Ms. Davis has asked our team to improve on this 50 year old technology for use in the orthotics and prosthetics community. The hope is that a viable solution to the specified problem will eventually turn into a marketable product, and that we will be able to present our design at some medical conventions to raise awareness on our findings including possible ideas for the future.

The nudge control is a device that sits on the shoulder of a prosthetic arm, and when depressed by the chin, disengages a lock in the elbow joint allowing the lower arm to swing freely. The idea of redesigning this apparatus was presented to us because, while it does not fail to work properly, the mechanism is a problematic and finicky piece of machinery. In researching this product, we looked at several case studies where people used the nudge control [1]. Case study number 1 claimed that the nudge control had a tendency to fail mechanically. However, in talks with Ms. Davis, she claims that this has never happened to one of her patients. In case study number 6, the patient claimed that it created problems with the person's clothes by sticking out too far and catching on the fabric. Both of these situations need to be considered when creating our prototype. We conducted an interview with an upper extremity amputee [2] who previously used the nudge control, but switched to an electric arm after only two uses. The patient discussed "extreme discomfort", and a bruise appeared on the chin the next day because of the excessive amount of force required to depress the button. Because this patient was amputated just above the elbow, the activation button had to be mounted to the shoulder which caused discomfort by digging into the skin as well.

A patent search revealed a patent on a 'Remote Alternator for Selective Actuation of Prosthetic Limbs and Surgical Appliances' [3]. This patent is for a device that can lock or unlock devices such as elbows, shoulders and wrists from remote locations. The interesting aspect of this mechanism is that it can be placed in varying locations for activation by the hand, elbow, or chin. Another patent took the wires associated with the hinge in the elbow and passed them through the forearm [4]. The third one that we found was for myoelectric elbow control [5]. While interesting, this is slightly more complicated than we intend our project to be. The fourth design was a thesis paper which used a similar design to a bicycle brake where the user pedals backwards to brake [6]. However, this design incorporated the redesign of the entire elbow, while we will be focusing solely on the activation method.

In interviews with Ms. Davis [7] and an upper extremity amputee [2], we discussed many of the challenges associated with the current nudge control. Ms. Davis' expertise as a prosthetist as well as the feedback from a former user of the device made invaluable contributions to our research. These conversations revealed several of the typical issues involved in using the Sierra Nudge Control. The most commonly addressed complaints are that the device requires a large amount of force to activate, and that exerting that force has a tendency to create sores on the chin. While the case study mentioned the product failing on several occasions, Ms. Davis and the patient had never experienced one of these devices malfunction. Her other main concerns involved the cost of the product and potential noise involved with an electronic system.

There are few options today for patients when it comes to mechanical elbows and the devices that control them. This is due to the relatively small size of the field, and is one of the main reasons that the

Sierra Nudge Control has been in use so long. Two other elbow systems on the market right now are the Utah Arm and the Dynamic Arm. These mainly concentrate on the elbow, and not the component that allows them to move. The Utah Arm has a similar hinge mechanism to standard elbows. The Dynamic Arm, on the other hand, balances itself with a strap and pulley cam mechanism allowing for significantly more arm positions.

Project Requirements and Engineering Specifications

The main goal of our project is to redesign the current nudge control device to make it easier for the patient to use. With the help of our sponsor Alicia Davis, we developed a list of project requirements our new design must meet. The results of this analysis are displayed in the QFD diagram in Appendix A. The project requirements for the device are to minimize the force required to lock and unlock the elbow, provide feedback when elbow is locked and unlocked, keep the device hands free, cheap, cosmetically appealing, light, and quiet during operation.

The main engineering specification is the pull force required to lock and unlock the mechanism. In order to quantify this, we tested the prosthetic elbow in an Instron strain machine (Figure 1). We fixed the elbow to the table, and the cable to the force measuring clamp. We then slowly moved the elbow further away from the force clamp until the maximum force was reached and the elbow lock either engaged or disengaged. This test was run three times both to lock and unlock the elbow to compare each force. We then plotted force against displacement in Excel and determined the average maximum force required as seen in figures 2 and 3. To unlock the elbow it took 4.670 ± 0.222 lb and to lock the elbow it took 4.601 ± 0.447 lb. Our goal is to reduce this by one half, so our new target is a maximum of 2.3 lbs.

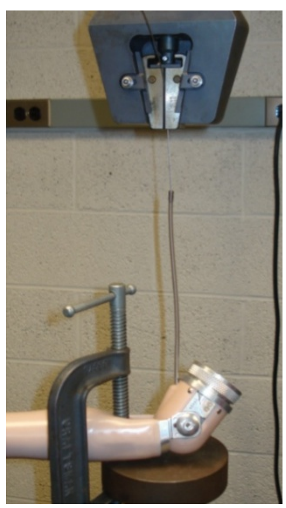

Figure 1: Elbow in Instron strain machine

Alicia provided us a maximum budget of $800 for this project, but a goal of under $500. To provide feedback, the device will vibrate, make a small beep, or click when a button is depressed. To keep the device hands free, it will be operated by moving the chin to activate a sensor or depress a button like the current Sierra model. We have aimed to maintain the same outer dimensions, weight, and noise level that the Sierra model has. Table 1 displays a list of project requirements and how they translate into engineering specifications.

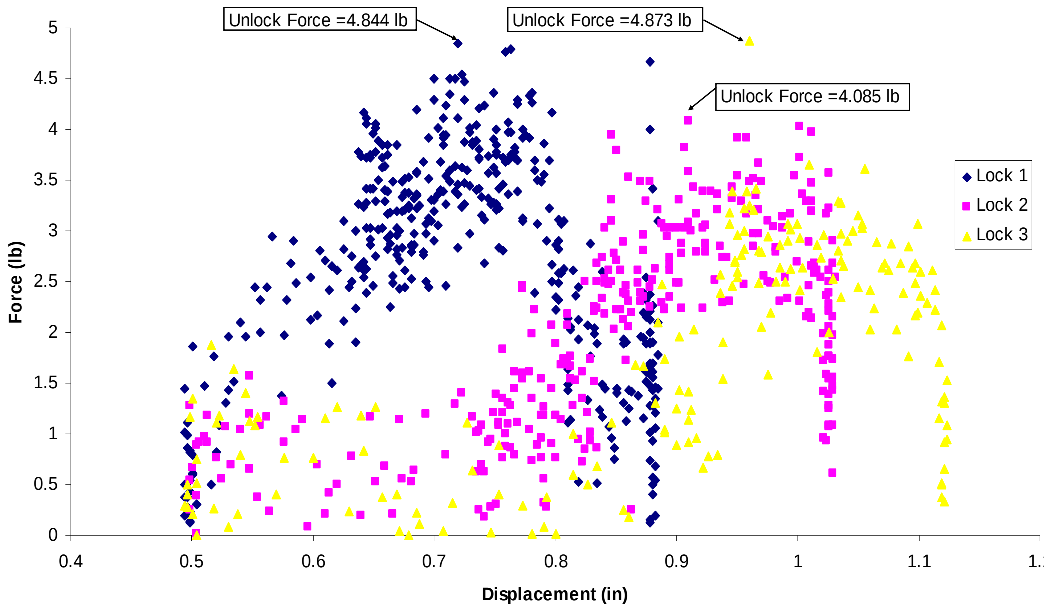

Figure 2: Average Force to Lock Elbow = 4.601 ± 0.447 lb

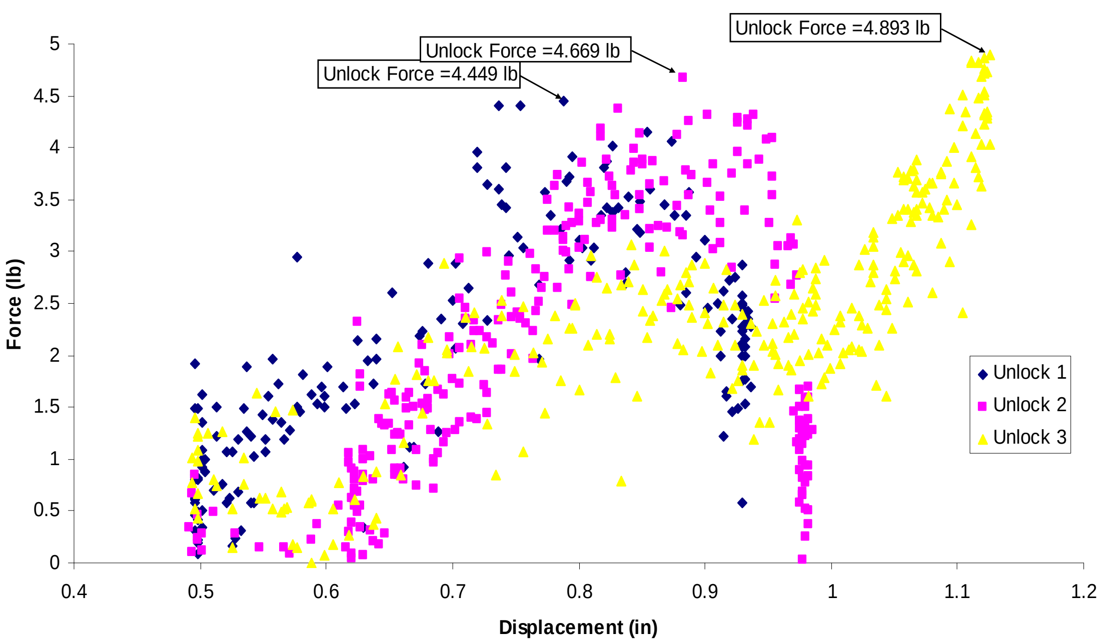

Figure 3: Average Force to Unlock Elbow = 4.670 ± 0.222 lb

Project Requirement	Engineering Specification
Reduce force to lock/unlock elbow	2.3 lbs maximum
Provide feedback when locked/unlocked	Vibration, beep, or click when activated
Cheap	Below $500 production
Keep or improve cosmetic appeal	Below 0.5” height
Hands free	Chin must activate device
Light-weight	Below 1 lb
Quiet	Must not be noticeable

Table 1: Engineering Specifications for Required Components

Concept Generation and Selection

In deciding how to create a working nudge control, we considered many options. We had two main tasks to accomplish in creating our design. These were to input some form of physical activation to the device from the body, and to cause the actual movement of the elbow lock. The constraints of the device activation included that it must be hands free and must provide some sort of patient feedback in the form of a noise or motion. These requirements led us to consider different motion sensors, buttons, touch pads, or even the levers that were already in place. In order to unlock the elbow, we considered ideas for mechanical, electronic, and hydraulic systems.

The first idea that came to mind when brainstorming designs was to improve upon the current mechanical system. By using a basic understanding of mechanics, we could find ways to reduce patient discomfort when using the nudge control device. For example, by creating a design where the button/lever is extended farther from the pivot (increasing *r* in Figure 4), we would reduce the amount of force needed to apply the same activation torque as before. In addition, if we made the button area larger (increase *A* in Figure 5), the applied stress would be reduced. However, enlarging these components would conflict with our size constraints. In the end, we decided to move away from the current lever system because of the problems associated with it. Also, while the mechanical system would be the simplest design, there is no innovation in using this method.

We removed motion sensors and hydraulics from our plan. Using a motion sensor, where a movement from the chin would activate the device without requiring physical contact, was an intriguing idea. However, our team felt that the technology would be difficult to incorporate if the patient was wearing clothing over the button. Also, an extra component would have to be implemented to provide patient feedback. The hydraulic system had a similar end. We felt that with this system, we would be able to manipulate the forces in the system by designing cylinders with different cross-sectional areas, allowing a smaller applied input force, to produce the same output force on the cable. After some research, however, we discovered that in order to have an output force N times bigger than the input force, the cylinder exerting the output force would need to have a cross-sectional area N times bigger than the cylinder moved by the input force. Also, the input cylinder would have to be N times longer. These conditions present considerable spatial problems. In addition, the equipment and incompressible fluid would be heavy and difficult to maintain.

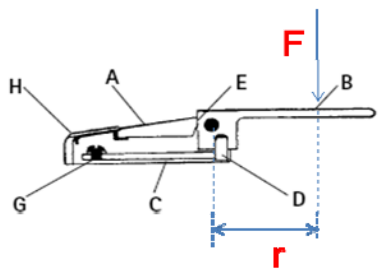

Figure 4: Increase pivot length *r*

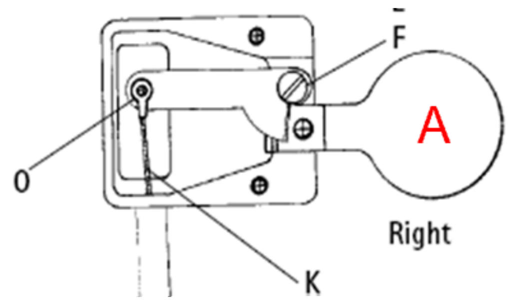

Figure 5: Increase button area *A*

Our idea for an electronic system uses a motor and linear actuator to pull the cord that unlocks the elbow. Actuators that are relatively small, ranging between 2 and 3 inches in length, can produce forces well beyond what is required to pull the cable. The actuator motor will be powered by a battery, so little to no force will need to be applied by the patient to activate the lock. We determined this device would be controlled by either a button or touch pad.

As a result of this work, our final plan ideas included either a button or touch pad similar to those found on lamp dimmers. We chose this as the activation device because they will be easy to incorporate into the system and will provide the necessary patient feedback. The device will unlock the elbow by sending a signal to the actuator, which does the work for the patient when the button is depressed.

Alpha Design

The following paragraphs identify the components of our alpha design system, with the function of each described in detail. A diagram of the system with all components is provided in Figure 6.

Actuator: We will use a Firgelli L-12 series miniature linear actuator, with the following options:

- 210 Gearing Reduction Ratio
- 30 mm stroke
- 12 volts
- Controller Option S

The actuator will use the rotation of the motor to extend to the desired position. A datasheet for this actuator model is found in Appendix C.

Actuator motor: We will use a Firgelli GM-12 Gearmotor with 210 Gearing Ratio and 12 volt input, the same as the actuator options. The motor uses the electrical power from the main battery and converts it to mechanical power in the form of rotation. This rotation is what causes the actuator to extend and retract. It is built in to the actuator. A datasheet for this motor is found in Appendix D.

Motor Limit Switch: According to the L-12 datasheet, for Controller Option S: "When the actuator moves to a position within 0.5mm of its fully-retracted or fully-extended stroke endpoint, a limit switch will stop power to the motor. When this occurs, the actuator can only be reversed away from the stroke endpoint. Once the actuator is positioned away from its stroke endpoint, normal operation resumes. For custom orders, limit switch trigger positions can be modified at the time of manufacture, in 0.5mm increments" (Appendix C). This means that when we apply a voltage to the motor, the actuator will retract to a point that we designate, then stop once this limit is reached.

Battery: This is the main battery in the system, which will provide power to the motor. For our alpha design, we will use the recommended 12 volts, but we plan on testing the performance of the actuator and motor at higher voltages and we may add extra voltage in future designs.

Push-button switch: This will serve as our activation device for our alpha design. We hope to have a different component in our final design that would be easier for the patient to activate, such as a touch sensor. This switch will close the activation circuit and initiate the entire process.

Activation Controls: This is an electric circuit (possibly with mechanical sub-components) that has yet to be designed or purchased. Firgelli sells a circuit board that can be programmed to carry out functions specific to different needs upon activation, which we may be able to take advantage of for our design. If we cannot use these controls, we will need to test the actuator and find the correct electrical motor input for our desired mechanical output. When the correct motor input is known, we will design the activation controls such that when the push-button switch closes the activation circuit, the battery-motor circuit will close and the motor will draw the needed input from the main battery.

Switch Battery: We may need a small battery for the switch to allow current to flow and the activation controls to work.

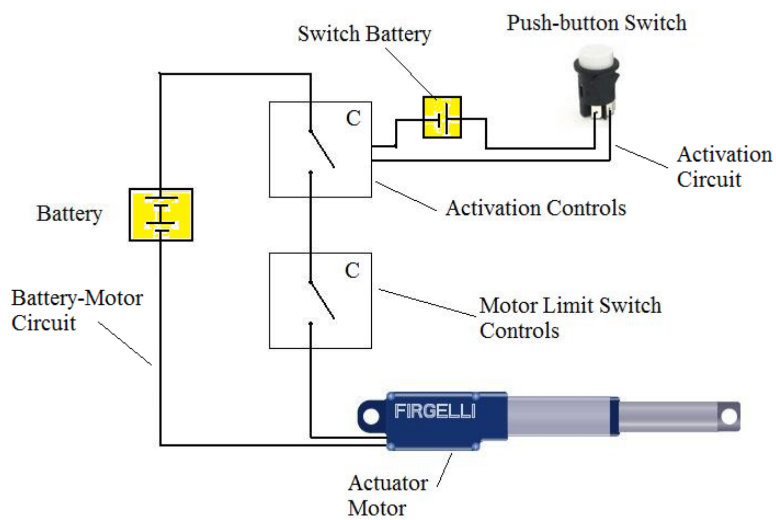

Figure 6: Electrical Circuitry for Nudge Control

In Figure 6 you can clearly see the two separate circuits, and each component described above. In the battery-motor circuit, the motor limit switch controls are shown outside of the actuator to better represent the layout of the system; however, in actuality, they will be built in to the actuator, along with the GM-12 gear motor.

Parameter Analysis

The initial parameters of our design were decided upon through meetings with our sponsor Alicia Davis, and one of her patients who previously used the nudge control device. With their advice we developed several design parameters which are listed in Table 1. The force required to pull the cable (4.6 lb), and the distance required to activate the elbow (0.5 inches) were our two main engineering parameters, and led to the choice of our motor, actuator, and battery. After much research, we found the smallest actuator that met our requirements and began to incorporate it into our prototype and eventual final design.

Our prototype was created purely for the purpose of testing the actuator to observe speed, noise, and safety of the system at several different voltages including some that exceeded the rated voltage of the motor. Because the rated voltage of 12V produced an undesirable speed of actuation, we decided to exceed the rated voltage for our prototype. Aesthetics and some other specifics were not taken into consideration in this original design because it was built purely for testing.

For our prototype, we connected the cable directly to the actuator, allowing some initial slack in the cable. For testing, we allowed enough slack for the actuator to activate the elbow at about 75% of its full stroke, leaving about 0.25 inches extra to pull. Once the actuator reached this position, the cable either pulled on the actuator mounts, or eventually came out of the crimp that was used to connect it to the actuator because the cable was taught and had nothing else to pull on. This design flaw led us to incorporate a spring into our final design that would connect from the actuator to the cable (figure 7).

Once the cable is taught and the elbow is actuated, the actuator will extend the spring the extra 0.25 inches instead of pulling on the mounts or the crimp.

To determine what specific spring we would need, we used Equation 1 where the force equals the spring constant multiplied by the distance traveled.

$$F = k * x \qquad \text{(Eq. 1)}$$

Our activation force for the elbow was less than 5 lbs, so we decided that our spring should apply a force of 10 lbs to ensure that the cable would be pulled, but that none of our other mounting components would fail. We knew that our spring had to extend 0.25 inches with an applied force of 10 lbs, which gives a spring constant of 40 pounds per inch.

For our initial prototype, we used the actuator mounts that were provided by the actuator manufacturer. However, due to the lack of a spring to make up for excess tension in the system, we observed some deformation in the mounts. This led us to incorporate a more rigorous stress calculation on the mounts. We decided that we would either have to create thicker, stronger mounts similar to the manufacturer provided ones, or seek other means of mounting the actuator to the arm.

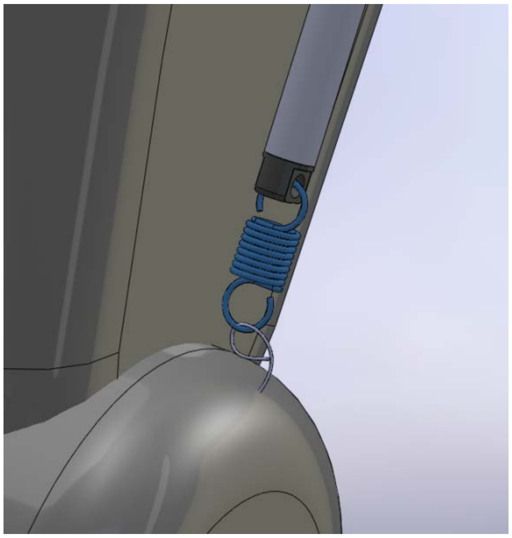

Figure 7: CAD model of spring connected to wire

Using the CES software, we were able to choose a material based on various material properties that we required for our design. Since the only pieces of our design that we actually manufactured were the button cover and the battery housing, we chose to use CES to pick our material for those two compnents. In order to pick these two effectively, we chose to make the battery housing as strong and as light as possible, and the button cover as malleable and light as possible. We were also able to choose the cheapest material possible by imposing our cost constraints and measuring those against the density of the material. We found that acrylic and polyehtylene foam would be suitable for the battery housing and button cover, respectively. Both of these materials fit our constraints as well as our price range, and were easily available to us from the machine shop and the UM prosthetics center.

We used the SimaPro Software provided to us to perform a rough environmental sustainability calculation for our project. In it we compared the environmental impact from our acryllic plastic battery casing and polyethelene foam button. We discovered that the plastic material had a much higher impact on the environment than the foam from several factors which is summarized in Appendix C. We were also surprised at the amount of factors that go into a full life cycle analysis of a material. We concluded that although our battery housing was sufficient, we could have chosen a more environmentally friendly material.

Prototype Description

Figure 8 shows a picture of our initial prototype. In it, the actuator, used to pull the cable connected to the elbow is a Firgelli L-12 series miniature linear actuator. The system is run by two 12 volt batteries that reverse their polarity through the use of a DPDT toggle switch.

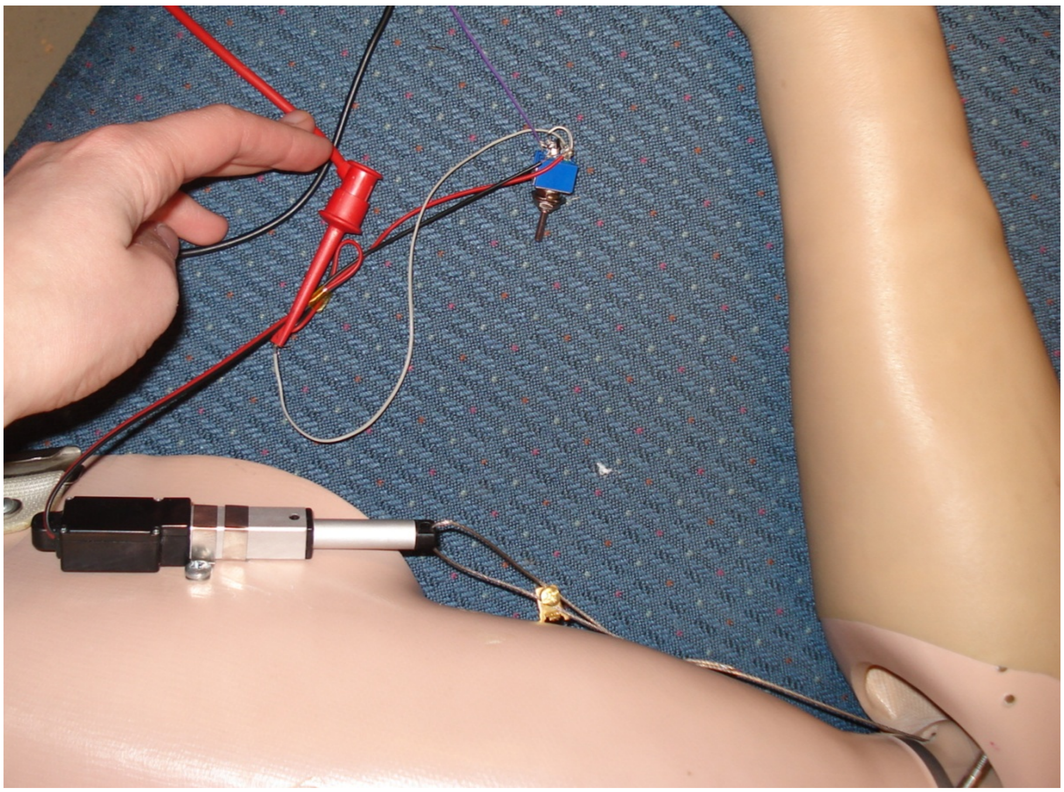

Figure 8: Prototype on elbow during testing

A schematic for the circuit is shown in Figure 9 [8]. Note that the limit switches shown in the schematic are built in to the actuator.

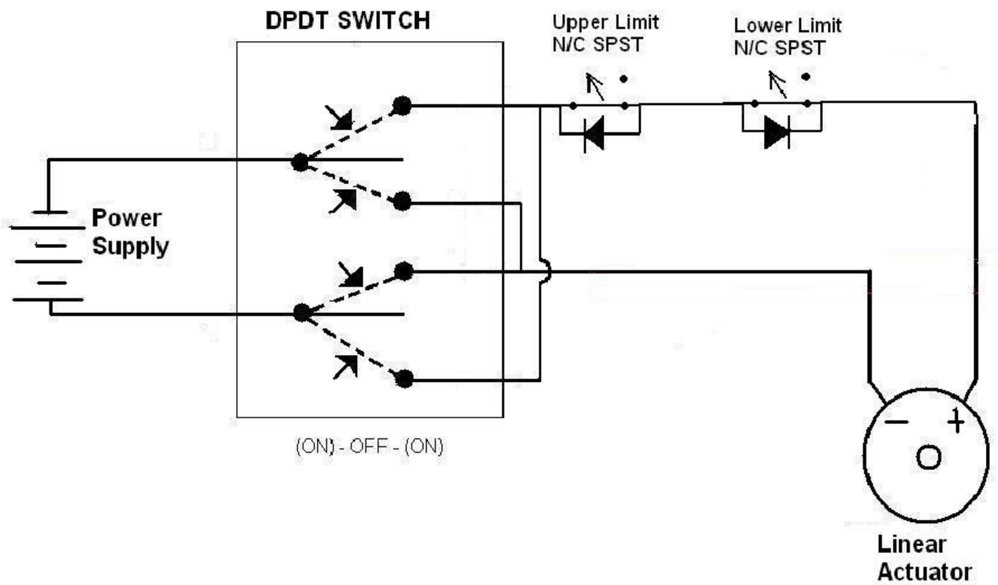

Figure 9: Prototype Circuit Schematic [8]

The prosthetic arm we used for our prototype is used by our sponsor for teaching purposes, and cannot be altered in any way that prevents it from being returned to its original form. This prevented us from drilling into it or applying adhesive to any surface on the arm. This negatively affected the design because it limited where the actuator, battery, and switch could be mounted. This arm was therefore not used for the final prototype. It was, however, used to test the prototype until the arm used in the final prototype could be obtained from the patient. All components were fastened using existing or removable means (see Fabrication, p. 14).

The final prototype is in Figure 10 on page 15. It incorporates a few small improvements of the same design:

Pushbutton activation: It is necessary to include a switch that can be activated by the patient's chin in the final prototype. This means a DPDT pushbutton switch. The button is held down by the user, closing the circuit such that the actuator retracts. When the elbow locks or unlocks, the button is released and polarity is reversed. The actuator extends, and the built-in limit switches stop current when it reaches its original position. No microprocessor is needed, as described in the alpha design. A picture of this DPDT switch is shown in Figure 10 on page 15.

Actuator and battery placement: The actuator and battery were mounted inside the hollow upper arm of the prosthesis. The cable passes from the outside to the inside of the prosthetic arm through a drilled hole toward the bottom of the upper arm.

Batteries and Battery Housing: we will use three 9-Volt rechargeable batteries connected in series. We built a housing for the batteries out of acrylic to allow for easy removal and strong mounting.

Switch Placement: The patient's prosthetic arm allowed us to mount the push-button on the shoulder, where it is easily accessed by the chin.

Upgraded Wiring: We used a stronger gauge of wire in the circuitry for the final prototype than what came with the actuator.

Spring: A spring was placed in series between the cable and actuator so that if the tension in the cable reaches an unsafe level, the spring will begin to extend and prevent the tension from increasing too rapidly.

Stronger Actuator Mounting: By drilling an extra hole, we took advantage of fastening the actuator with a screw through the provided hole in the rear of the actuator as opposed to using only the mounting brackets to take the entire load. This takes away the tensile force exerted on the mounting brackets, allowing them to only keep the actuator from rotating. The rotational load is much less than the tensile load caused from pulling the cable.

Fabrication

Since we were not able to drill holes or use adhesive to mount the actuator to the testing prosthetic arm, we used already existing holes. The existing nudge control was fastened to the arm with two screws in the shoulder region. We removed the Sierra Nudge Control and used these screw holes to mount the actuator. The elbow cable was soldered to the nudge control and had to be cut in order to remove the device. When it was removed, we mounted the actuator using the brackets provided with the actuator by Firgelli. We then looped the cable through the actuator and crimped it.

There is a space imbedded in the prosthesis for a myoelectric hand battery; we took advantage of this space to reduce the prototype's protrusions from the arm. For this prototype, we found an expendable foam material, cut it to the same shape as the battery port, fill the battery port with the material, and imbedded the toggle switch and battery into the material. To do this, we cut an outline of both the battery and the switch in the material before putting it in the battery port, wire all components as shown in figure 9, and insert the battery and switch through the bottom. This allowed the wires to connect underneath.

Using this fabrication plan, the fact that we could not cut or apply adhesive to the arm did not affect the functionality of the initial prototype, which allowed us to perform necessary testing.

For the final prototype, the actuator was mounted on the interior of the upper arm, as shown in Fig. 11. It was put in upside down, with the extending/retracting rod pointing toward the shoulder rather than the elbow, because the geometry of the arm did not allow it to be placed in the orientation of our original design. This did not take away from the functionality or performance of the actuator, we just had to wire the actuator to extend, rather than retract upon activation. We drilled two holes to fasten the actuator with screws: one for the provided actuator screw hole, and one for the mounting bracket.

We created a housing for the battery (Appendix E) shown in figure 10, by laser-cutting a sheet of acrylic. This housing was made by gluing together 4 pieces of 0.125 inch thick acrylic to make a casing that measured 1 x 2 x 2.35 inches on the outside to hold our three 9-volt batteries.

We drilled a hole in the lower part of the upper arm for the elbow cable to pass through, and connected a spring in series between the actuator and cable. We marked and cut the cable such that when it connected with the actuator, it was barely in tension.

To increase the surface area of the square pushbutton and make it easier to push, we cut a circle out of foam provided by our sponsor (with a diameter of 1”) and glued it to the top of the existing pushbutton.

Final Design

Our final design consists of a linear actuator, motor, DPDT pushbutton switch, battery system, and a limiting spring, each of which is specified below. The differences between this design and our original prototype can be seen in Appendix J. Not including all of the extra devices that we purchased (details in Appendix F), our prototype costs $150 without shipping of components. If our prototype were to go into production, this number would change as components are purchased through suppliers and in larger quantities. These components are:

- Firgelli L12-30-210-12-S Linear Actuator, $70 (See Appendix C for specifications)
- Firgelli GM12-N20VA-05450-210-R Gear motor, included in actuator price (See Appendix D for specifications)
- Honeywell AML21BBA2CC push button, $36
- Three (3) 9-Volt Rechargeable Batteries with Charger, $30
- Limiting spring, $2
- Wiring, $5

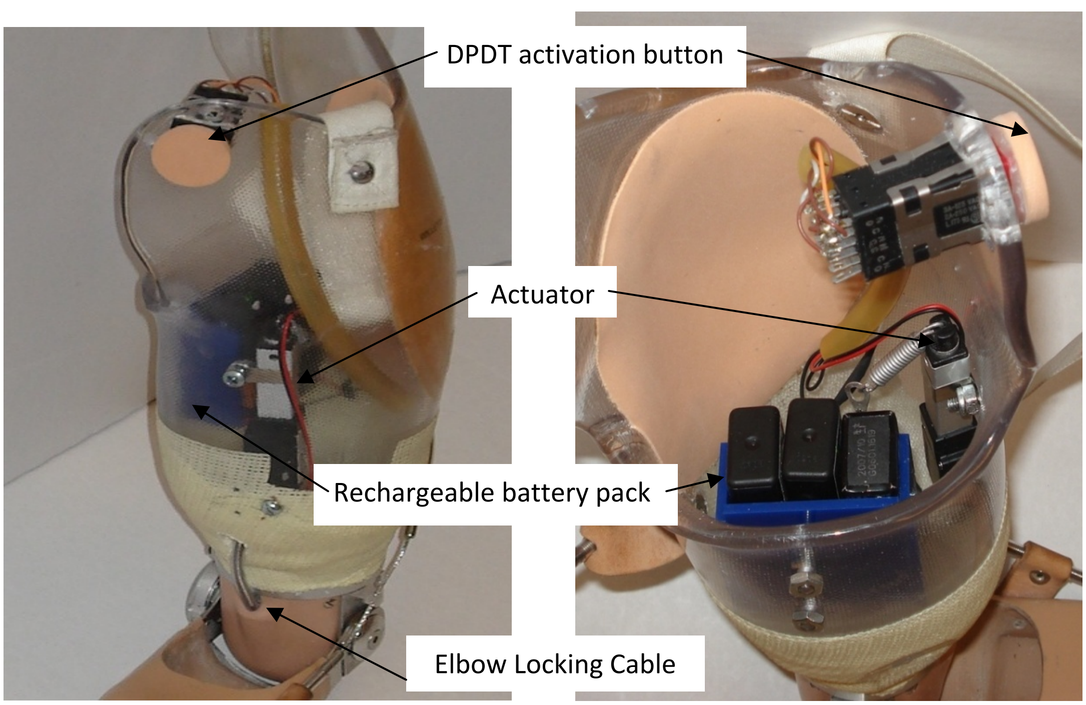

Figure 10: Final Design

Our final design concept (Figure 10), essentially replaces the current mechanical nudge control with an actuator system that pulls the elbow locking cable. The general design of the control is very similar to the original, as it will include a button that sits on the user's shoulder and is activated by the chin. The pushbutton switch is wired to the actuator and battery such that when depressed, it will cause the battery to send current in one direction, and when released, current will be sent in the opposite direction. In using the system, the device will begin with the actuator fully retracted and the elbow locked. The user will then push the activation button, which will trigger the actuator to extend, pulling the spring and cable. This continues until the actuator is fully extended and the elbow pin is unlocked. The user will then release the button, which will cause the actuator to retract to its original position while the elbow is still unlocked. The user will then rotate the forearm into the necessary position and repeat the process to lock the elbow in place.

We have specified the linear actuator such that the extension range is 30mm and the pull force is over 5 pounds in order to keep a safety factor during use. Also, the entire system will be wired to three 9-volt batteries to give power to the actuator motor. The configuration of the batteries is such that not all 27 volts are applied to the actuator. The final system uses a voltage closer to 24 volts, which was what we originally intended to happen. The limiting spring will be placed at the end of the actuator arm in order to remove some of the tension that is placed on the cable when it is pulled.

The advantage or our final design is its versatility. Having an electrical system as opposed to a purely mechanical system opens up many possibilities for improvement. The wiring of the design allows for each component of the system to be moved independently of the others, which allows for flexibility in placement of each part. Also, since each prosthesis is already custom made for each patient, the system can be incorporated into the design of the prosthesis itself, thus allowing further customizability. In order to preserve this, we chose the actuator, motor, and battery to be small enough that they could be placed inside of the prosthesis if desired, with the elbow locking cable running through a hole drilled in the limb.

Validation

The main concerns we had when developing our actuator design revolved around the physical size of our system, and the voltage required to run it. We were able to find a linear actuator that could pull the required force that only sits 5/8 of an inch high. Through attaching the system to an arm, we know that it is capable of pulling the 4.6 pound force necessary to disengage the elbow lock. In demonstrating our initial system to Ms. Davis, she has assured us that the noise created by the motor is perfectly acceptable, and that we will be able to reduce it on a situational basis using a cover or by placing the actuator inside the arm. This noise is also useful in that it serves as our feedback mechanism for the patient.

We ran speed tests in order to determine the optimum voltage to run our actuator at. These tests were performed by measuring the time it took to unlock or lock the elbow (Figure 11), and the time required for an entire unloaded cycle of the actuator (Figure 12). The specifications for the actuator that we purchased recommend that a 12 volt source is used, so we began using only 12 volts and raised the voltage by increments of 6 up to 30 volts for our tests. As predicted, we found that the overall speed of the system improved as voltage rose. We also noticed that the noise involved became more pronounced as the gears in the actuator began spinning faster. The slowest average time required to complete one pull was 3.58 ± 0.10 seconds at 12 volts. The fastest was 1.43 ± 0.09 seconds at 30 volts. Running a complete cycle at 12 volts took 10.46 ± 0.30 seconds and 30 volts took 4.54 ± 0.07 seconds. However, these values were found by testing the actuator while it was unloaded.

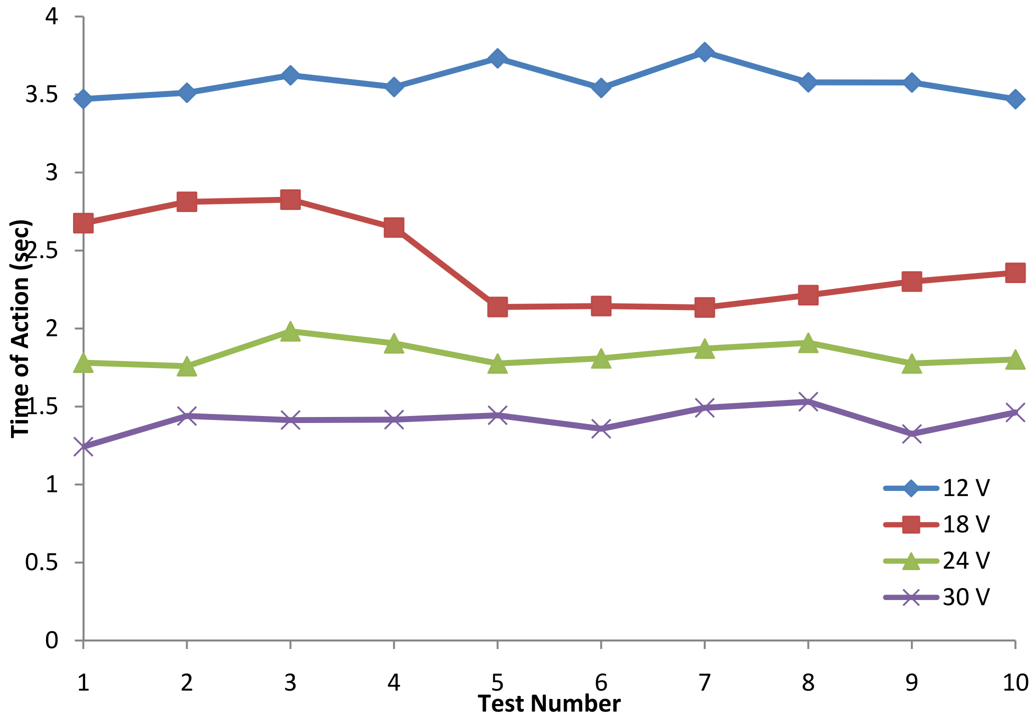

Figure 11: Time Required for Locking and Unlocking Elbow at Varying Voltages

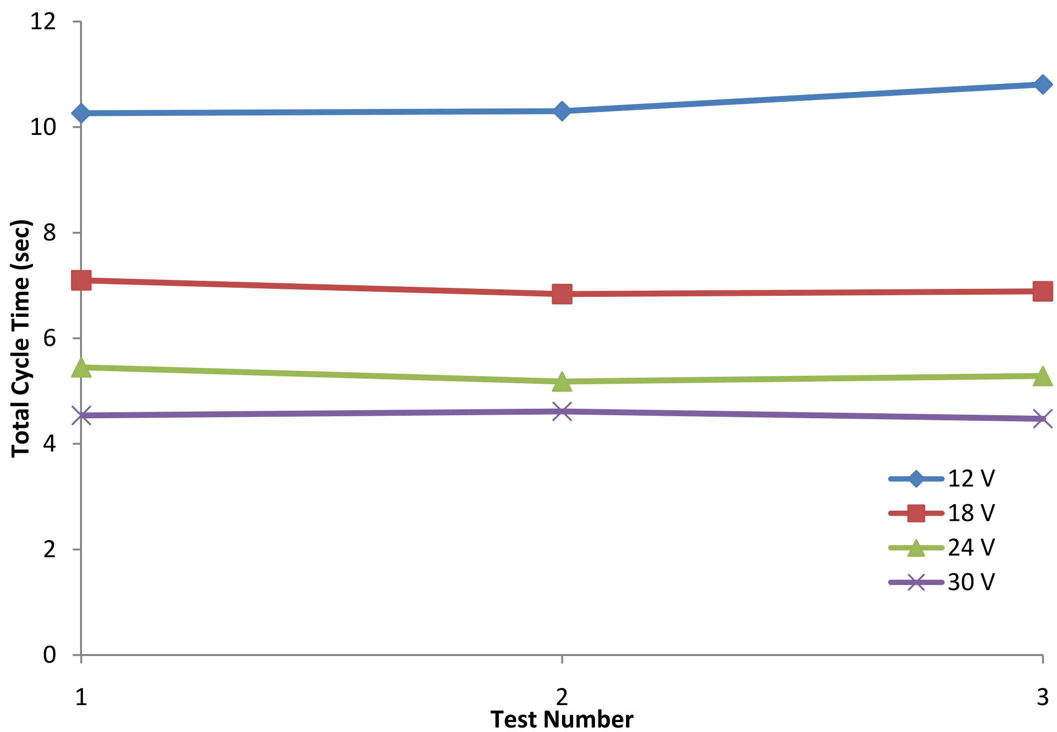

Figure 12: Time for Complete Unloaded Cycle at Varying Voltages

Using these values, we decided that a battery system having a voltage between 18 volts and 27 volts would be needed for the project. We finally chose to use three 9 volt batteries connected in series to combine for 27 volts. The 9 volts were chosen because of they are relatively inexpensive, common, and rechargeable, and because we were not able to purchase a custom built battery pack that would fit inside our budget. We decided to incorporate three of them because that allowed for a very fast actuator arm motion. We found out after connecting this set-up to the actuator, however, that not the entire 27 volts was running through the system. Given the configuration and low current capacity of 9 volt batteries, this makes sense. It also alleviates some of our concerns about running the circuit at high voltages.

Since the user would only be operating the system less than 20 times during the day, we were able to test the battery life by using the arm repeatedly for an extended period of time. We found that the actuator arm motion begins to slow after using the batteries for about 30-40 cycles, so even if the patient were to use their arm almost twice as much as predicted, the system would simply slow down to 2-3 seconds activation time as opposed to 1-2 seconds.

We found that the components weighed a total of .86 pounds, which is under our original specification of 1 pound. The majority of the weight is a result of the three batteries, which would be largely eliminated with a custom designed battery pack. In using the electronic system, we were able to minimize the force required to depress the activation switch. The original force required to lock and unlock the elbow was 4.6 pounds, and we reduced this number to under 1 pound and validated it using a simple force gauge. The 1 pound of resistance force was kept to ensure that the device does not malfunction or misfire when worn underneath heavy clothing.

As previously discussed, we kept the overall price of the device under our recommended $500. All of our components totaled to a final cost of $150, not including the chargers for the batteries. This number would increase if the product was sold commercially, but we estimate that the overall cost will still be well under $500 for a person looking to use this system.

A summary of how our prototype compares to the Sierra Nudge Control is shown in Table 2 below.

	Sierra Nudge Control	**Prototype**
Activation Force	4.6 lb	≤ 1.0 lb
Button Height	0.5 inch	0.375 inch
Button Diameter	0.75 inch	1.0 inch
Activation Time	1 – 2 sec	2 – 3 sec

Table 2: Comparison of Nudge Control vs. Prototype

Specific Challenges

The final prototype is an improvement on the Sierra Nudge Control device, but there are still some challenges to overcome to make the device compatible with all patients. Our prototype demonstrates that the linear actuator concept meets our goals, but could not be tested by the patient due to her specific amputation. Our original idea to place the actuator in the cavity in the forearm proved unsuccessful due to issues with altering cable tensions as the forearm was moved. We then chose to mount the components in the upper cavity of the arm due to its large space, but because the patient is amputated just above the elbow, she needs this space to hold her upper arm. The Sierra device is primarily used with patients who are forequarter amputees, and thus this space would be available for component placement in most prosthetic arms. However, improving some of the components in our design would allow every type of amputee to use this device.

The battery packaging that provides power to the actuator is not optimal for this application. We chose 9 volt batteries because of their availability and high voltage capability, but they have a low current capacity and thus the overall power of the system is lower than desired. We experienced that after several uses, the actuator would take longer and longer to reach full extension for quick, repeated uses. This is because rechargeable 9 volt batteries take a long time to reach their steady state voltage after they have been dissipated. The ideal power supply for our system should have a higher current capacity to allow the actuator to extend at the same rate even after quick, repeated uses.

Current arms that require a battery pack have a port to plug them into the wall at night to be recharged. Our prototype would require patients to unplug the 9 Volt batteries from the arm and put them into a charger at night. It would also be beneficial to develop a similar port so that our device could be plugged into the wall without removing any components.

The current DPDT button switch also prevents our patient from using the arm because it mounts into this same cavity. The wire leads on the prototype button are on the bottom of the switch, and because of the way the button is activated by the chin, there is a need for a button with leads on the side of the switch. This would allow for mounting on top of the arm and would eliminate intrusion of the button leads into the cavity. As seen in Figure 10 on pg 15, the right photo shows the button extending well into the cavity. Alicia Davis provided us with a button switch that fits this need, but the switch is not a DPDT switch and does not perform the necessary functions of the prototype button.

We demonstrated that our concept works, but can be improved. Because of time constraints, we focused on demonstrating our concept instead of searching for better options for the power supply and DPDT button. However, we are confident that these challenges can be overcome as our prototype is further developed in the future.

Future Project Plan

Over the course of this semester, we were able to stay on schedule according to our Gantt chart project plan in Appendix B. This started by measuring the various components of the arm in order to obtain the correct sizes for any parts that we would purchase, as well as finding the forces associated with operating the nudge control device. Completion of these tasks allowed us to obtain the items that we would need to purchase for the creation of our prototype.

We performed literature research as well as product benchmarking in order to gain some idea of the current product market and any new design innovations that may be useful. A primary source of information that we used were patient interviews, which were conducted by Aaron and Ryan on February 12 [2]. These interviews allowed us to talk with patients who had or were currently using the nudge control device, and find out their opinions towards our redesign. We will be using the information gathered in these interviews to perfect our final design. While we were not able to give the prototype to a patient to test it out, in the future we hope that users of this product will be able to give us feedback as to their opinions on our design. We are still trying to contact Hosmer and Liberating Technologies, Inc., both prosthetics suppliers, for any recommendations they might have as to our components. As Liberating Technologies has seemed very willing to help our team, we hope that they will be of assistance in possibly developing this product further.

As discussed in the section above, there are a few challenges to overcome, and we have a few ideas to improve the prototype. The two main concerns that we want to address are the button, and the power source. While our activation switch does what we want it to do, the switch that we have now is much too bulky to be a good option. While our current button would be acceptable in a situation where we are able to place all of our components inside the prosthetic arm; in a case where everything has to be attached to the outside, this would not be a viable option. We also want to move toward one-touch activation. With the way the current system works, the button must be depressed until the elbow is unlocked. This is due to the automatic current reversal of the circuit. If the button is released prior to this point, the prototype does not do its job. A one touch system would change this.

To improve our power source, we would like to replace our three rechargeable nine volt batteries with a custom battery pack. Doing this would allow us to specify the power we want, as well as create a good system for recharging the batteries. We also hope to be able to present our design to a few medical conferences over the summer. This idea of Alicia Davis' will give us the opportunity to get more input into the system, as well as inspiring other prosthetists to consider other ideas when incorporating the Sierra Nudge Control into a prosthetic arm.

Conclusion

Over the course of this semester, our team worked toward improving the Sierra Nudge Control, a device that controls the locking mechanism in a prosthetic elbow. With the help of our sponsor Alicia Davis, we have determined that the current nudge control mechanism needs to be redesigned because it is difficult to operate, uncomfortable to use and wear, and is a generally outdated piece of equipment.

With the help of Ms. Davis, we came up with several preliminary design ideas fulfilling the requirements that our prototype minimize the necessary force supplied by the patient, provide feedback to the patient when the control is used, and make it as user friendly as possible. We chose an electronic device with a touch button and linear actuator as our prototype design. After building an initial design, we found some flaws that needed to be addressed in our final design. These include incorporating the push button with additional circuitry, adding a spring to help with actuation, and mounting all components to the new prosthetic arm. Replacing the toggle switch with a push button allowed for easier activation, while still being able to reverse the polarity of the current in the system and causing the actuator to automatically retract after extension. Adding the spring between the actuator and the wire for the elbow provided a safety factor to prevent damage in the event that the actuator pulled too hard on the wire.

While our final design was originally slated to be specified to a specific patient, extenuating circumstances forced us to build the prototype in an idealized situation. Due to this, unfortunately, we were unable to get feedback from the patient. However, through testing, we have determined that our prototype is an improvement on the Sierra Nudge Control. The necessary activation force to be implemented by the chin has been reduced by at least 3 pounds. The button height off of the body has been reduced by 0.125 inches to 0.375 inches reducing its physical presence. The diameter is currently at 1 inch, meeting our requirements, but is easily customizable based on patient needs. Our team has used these components, among others, to improve the Sierra Nudge Control and create a new prototype for the prosthetic community.

Acknowledgements

We would like to thank our sponsor Alicia Davis for her continuous help throughout the project with advice, resources, and materials. She allowed us to borrow several components to use throughout our design that greatly improved the project. Professor Im helped us make some important design decisions throughout the process. Professor Gillespie aided us with several circuit and testing issues. Daniel Johnson also aided us in completing reports for design reviews and preparing our design expo presentation. We would to thank all of these people for their contribution to our project.

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Appendix A – QFD Diagram

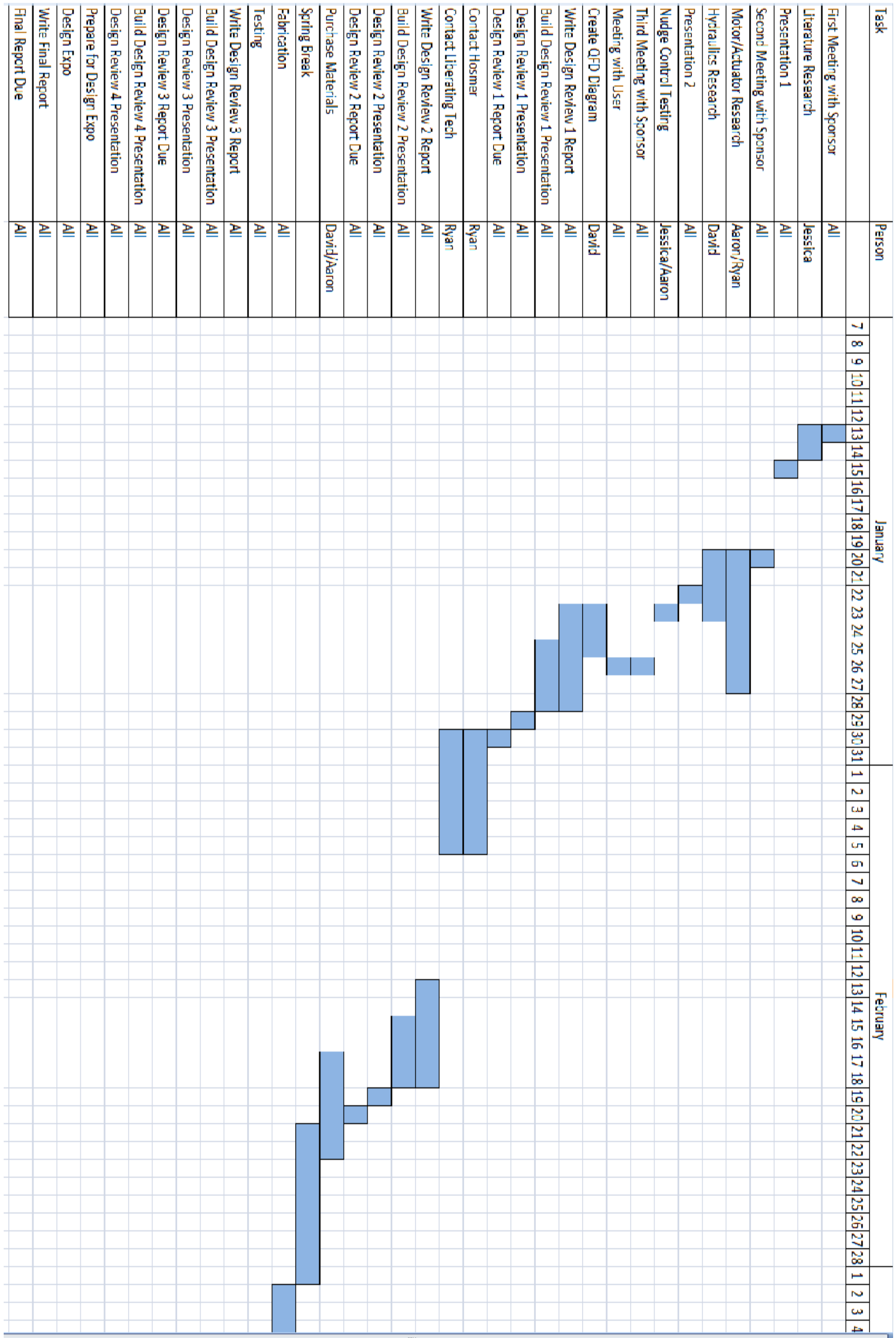
Project: Upper Extremity Prosthesis
Date: 1/29/09

	Button diameter (0)	Button height off chest (-)	Cable strength (+)	Motor power (+)	Motor size (-)	Number of components (-)	Loudness (-)	Weight (-)	Cable length (-)	Cable movement distance (-)	Force required to depress button (-)	Cost (-)	Size of housing (-)	Battery size (-)	Cable adjustability (+)	Cable thickness (-)
Button diameter (0)																
Button height off chest (-)																
Cable strength (+)																
Motor power (+)																
Motor size (-)				9												
Number of components (-)																
Loudness (-)					3											
Weight (-)					3	9										
Cable length (-)																
Cable movement distance (-)																
Force required to depress button (-)	3	3														
Cost (-)				3		9										
Size of housing (-)					9	3										
Battery size (-)								3								
Cable adjustability (+)											1					
Cable thickness (-)									9			3	1			

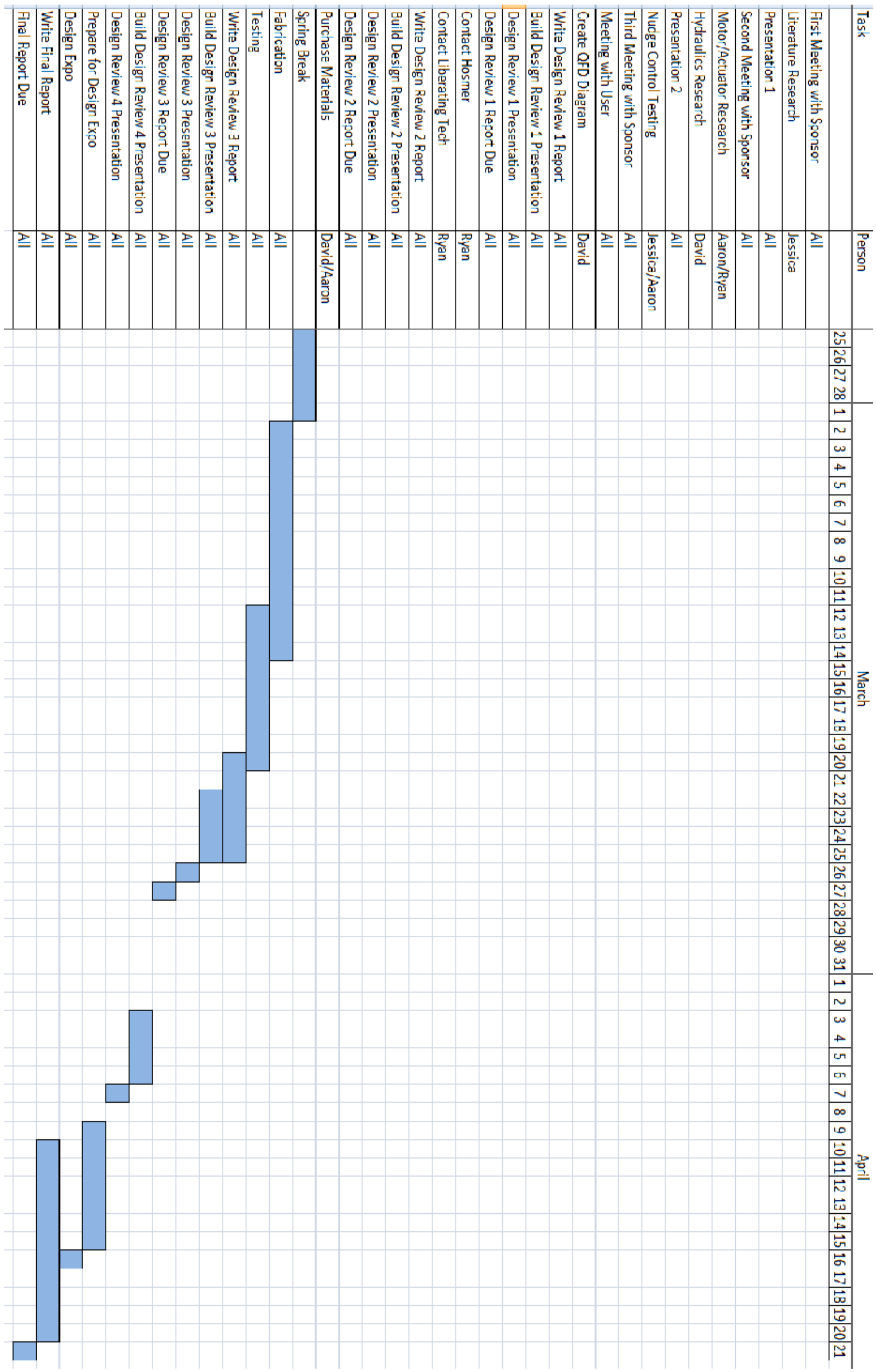
Technical Requirements

Customer Needs	Customer Weights	Kano Type	Button diameter (0)	Button height off chest (-)	Cable strength (+)	Motor power (+)	Motor size (-)	Number of components (-)	Loudness (-)	Weight (-)	Cable length (-)	Cable movement distance (-)	Force required to depress button (-)	Cost (-)	Size of housing (-)	Battery size (-)	Cable adjustability (+)	Cable thickness (-)
Easy to depress button	5	L	9	9							1	3	9					
Discreet	2	L				3	3		9						9	3		
Works with existing elbows	5	N						1			3	1						3
Comfortable to wear	4	N	1	1			3			9					9	3	1	
Comfortable to use	4	L	3	3									9					
Robust	2	DC			9									1				3
Gives feedback	3	DC							3									
Hands free use	3	N						1										
Looks good	1	DC	1	3			3							1	3	3	1	
Inexpensive	2	DC			1	9		3						9		3		1
Easy to master	2	DC						3					1					
Easy to install	1	N						3									1	
Customizable	1	L						1			1						9	
Easily assembled	1	L						9								1		
	Raw score		62	64	20	24	21	33	27	36	21	20	83	21	57	28	15	23
	Scaled		0.747	0.771	0.241	0.289	0.253	0.398	0.325	0.434	0.253	0.241	1	0.253	0.687	0.337	0.181	0.277
	Relative Weight		11%	12%	4%	4%	4%	6%	5%	6%	4%	4%	15%	4%	10%	5%	3%	4%
	Rank		3	2	14	9	11	6	8	5	11	14	1	11	4	7	16	10
Requirement Benchmarking	Dynamic Arm							15								1800 mAh		
	Boston Arm																	
	Nudge Control		0.5	0.75	200	-	-	15	-	62.4	-	0.51	15+	300		-	75%	3/64
Technical Requirement Units			Inches	Inches	Mpa	Watts	Cubic Inches	#	dB	Grams	Inches	Inches	Newtons	Dollars	Cubic Inches	mAh	%	Inches
Technical Requriement Targets			0.5	0.5	200			10	0	60			2	300			100	3/64
Technical Requriement USL			0.5	0.75	200			15		100	--	--	10	800			100	5/64
Technical Requriement LSL			0.25	0.25	100			5	0	--	--	--	0	--			25	1/64

Appendix B – Gantt chart (January to February)

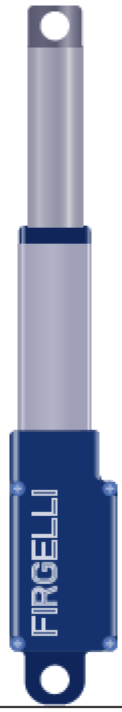


Appendix B – Gantt Chart (March to April)



Appendix C – Firgelli L12 Series Datasheet

Miniature Linear Motion Series • L12



Firgelli Technologies' unique line of Miniature Linear Actuators enables a new generation of motion-enabled product designs, with capabilities that have never before been combined in a device of this size. These small linear actuators are a superior alternative to designing with awkward gears, motors, servos and linkages.

Firgelli's L series of micro linear actuators combine the best features of our existing micro actuator families into a highly flexible, configurable and compact platform with an optional sophisticated on-board microcontroller. The first member of the L series, the L12, is an axial design with a powerful drivetrain and a rectangular cross section for increased rigidity. But by far the most attractive feature of this actuator is the broad spectrum of available configurations.

Benefits

- Compact miniature size
- Simple control using industry standard interfaces
- Low voltage
- Equal push/ pull force
- Easy mounting

Applications

- Robotics
- Consumer appliances
- Toys
- Automotive
- Industrial automation

L12 Specifications

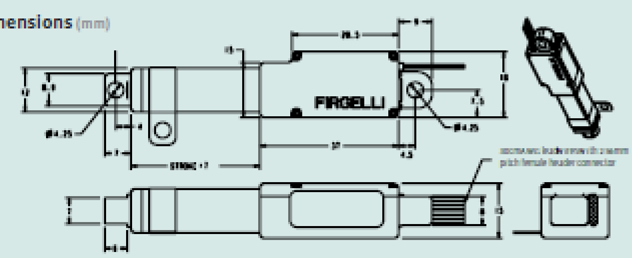
Gearing Option	50	100	210
Peak Power Point [1]	12 N @ 11 mm/s	23 N @ 6 mm/s	45 N @ 2.5 mm/s
Peak Efficiency Point	6 N @ 16 mm/s	12 N @ 8 mm/s	18 N @ 4 mm/s
Max Speed (no load)	23 mm/s	12 mm/s	5 mm/s
Backdrive Force [2]	43 N	80 N	150 N

Stroke Option	10 mm	30 mm	50 mm	100 mm
Weight	28 g	34 g	40 g	56 g
Positional Accuracy	0.1 mm	0.2 mm	0.2 mm	0.3 mm
Max Side Force (fully extended)	50 N	40 N	30 N	15 N

Mechanical Backlash	0.1 mm
Feedback Potentiometer	2.75 kΩ/mm ± 30%, 1% linearity
Duty Cycle	20 %
Lifetime	1000 hours at rated duty cycle
Operating Temperature	–10°C to +50°C
Storage Temperature	–30°C to +70°C
Ingress Protection Rating	IP-54
Audible Noise	55 dB at 45 cm
Stall Current	450 mA at 5 V & 6 V, 200 mA at 12 V

[1] 1 N (Newton) = 0.225 lb$_f$ (pound-force)
[2] a powered-off actuator will statically hold a force up to the Backdrive Force

Dimensions (mm)



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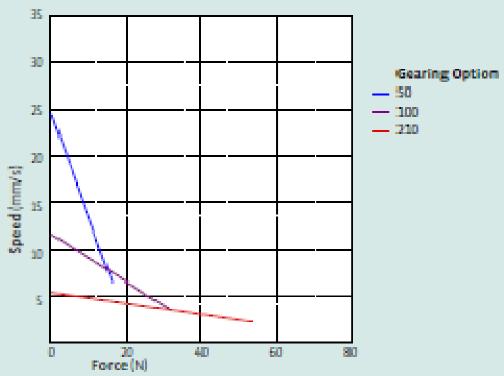
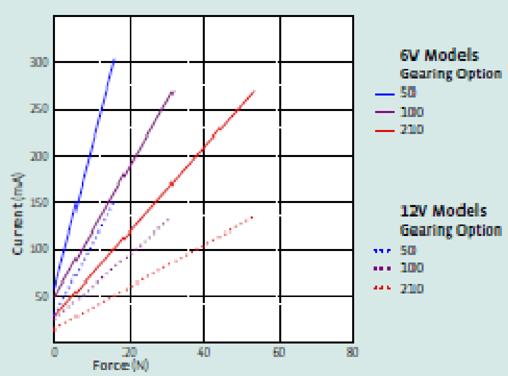
L12 Specifications

Load Curves



Current Curves



Model Selection

The L12 has five configurable features. L12 configurations are identified according to the following scheme:

L12-SS-GG-VV-C-L

feature	*options*
SS: Stroke Length (in mm)	**10, 30, 50, 100** Any stroke length between 10 and 100 mm is available on custom orders, in 2 mm increments.
GG: Gear reduction ratio (refer to force/speed plots)	**50, 100, 210** Other gearing options may be possible on custom orders.
VV: Voltage	**06** 6V (5V power for Controller options B and P) **12** 12V
C: Controller	**B** Basic 2-wire open-loop interface, no position feedback, control, or limit switching. Positive voltage extends, negative retracts. **S** 2-wire open-loop interface (like B option) with limit switching at stroke endpoints. **P** Simple analog position feedback signal, no on-board controller. **I** Integrated controller with Industrial and RC servo interfaces (see L12 Controller Options section). Not available with 10mm stroke length configurations. **R** RC Linear Servo. Not available with 10mm stroke or 12 volts.
L: Mechanical or electrical interface customizations	Custom option codes will be issued by Firgelli for custom builds when applicable.

Basis of Operation

The L12 actuator is designed to move push or pull loads along its full stroke length. The speed of travel is determined by the gearing of the actuator and the load or force the actuator is working against at a given point in time (see Load Curves chart on this datasheet). When power is removed, the actuator stops moving and holds its position, unless the applied load exceeds the backdrive force, in which case the actuator will backdrive. Stalling the actuator under power for short periods of time (several seconds) will not damage the actuator. Do not reverse the supply voltage polarity to actuators containing an integrated controller (I controller option).

Each L12 actuator ships with two mounting clamps, two mounting brackets and two rod end options: a clevis end and a threaded end with nut (see drawing on page 4). When changing rod ends, extend the actuator completely and hold the round shaft while unscrewing the rod end. Standard lead wires are 28 AWG, 30 cm long with 2.56 mm (0.1") pitch female header connector (Hi-Tec™ and Futaba™ compatible). Actuators are a sealed unit (IP-54 rating, resistant to dust and water ingress but not fully waterproof).

Ordering information

Sample quantities may be ordered with a credit card directly from www.firgelli.com.

Please contact Firgelli at sales@firgelli.com for volume pricing or custom configurations.

Note that not all configuration combinations are stocked as standard products. Please refer to www.firgelli.com/orders for current inventory.

L12 Controller options

Option B—Basic 2-wire interface

WIRING:

1	(red)	**Motor V+** (5V or 12V)
2	(black)	**Motor ground**

The –B actuators offer no control or feedback mechanisms. While voltage is applied to the motor V+ and ground leads, the actuator extends. If the polarity of this voltage is reversed, the actuator retracts. The 5V actuator is rated for 5V but can operate at 6V.

Option S—Basic 2-wire interface

WIRING:

1	(red)	**Motor V+** (5V or 12V)
2	(black)	**Motor ground**

When the actuator moves to a position within 0.5mm of its fully-retracted or fully-extended stroke endpoint, a limit switch will stop power to the motor. When this occurs, the actuator can only be reversed away from the stroke endpoint. Once the actuator is positioned away from it's stroke endpoint, normal operation resumes. For custom orders, limit switch trigger positions can be modified at the time of manufacture, in 0.5mm increments.

Option P—Position feedback signal

WIRING:

1	(orange)	**Feedback potentiometer negative reference rail**
2	(purple)	**Feedback potentiometer wiper** (position signal)
3	(red)	**Motor V+** (5V or 12V)
4	(black)	**Motor ground**
5	(yellow)	**Feedback potentiometer positive reference rail**

The –P actuators offer no built-in controller, but do provide an analog position feedback signal that can be input to an external controller. While voltage is applied to the motor V+ and ground leads, the actuator extends. If the polarity of this voltage is reversed, the actuator retracts. Actuator stroke position may be monitored by providing any stable low and high reference voltages on leads 1 and 5, and then reading the position signal on lead 2. The voltage on lead 2 will vary linearly between the two reference voltages in proportion to the position of the actuator stroke.

Option I—Integrated controller with industrial and RC servo interfaces

WIRING:

1	(green)	**Current input signal** (used for 4–20 mA interface mode)
2	(blue)	**Voltage input signal** (used for the 0–5V interface mode and PWM interface modes)
3	(purple)	**Position Feedback signal** (0–3.3 V, linearly proportional to actuator position)
4	(white)	**RC input signal** (used for RC-servo compatible interface mode)
5	(red)	**Motor V+** (+6 Vdc for 6 V models, +12Vdc for 12 V models)
6	(black)	**Ground**

The –I actuator models feature an on-board software-based digital microcontroller. The microcontroller is not user-programmable

The six lead wires are split into two connectors. Leads 4, 5 and 6 terminate at a universal RC servo three-pin connector (Hi-Tec™ and Futaba™ compatible). Leads 1, 2 and 3 terminate at a separate, similarly sized connector.

When the actuator is powered up, it will repeatedly scan leads 1, 2, 4 for an input signal that is valid under any of the four supported interface modes. When a valid signal is detected, the actuator will self-configure to the corresponding interface mode, and all other interface modes and input leads are disabled until the actuator is next powered on.

0–5V Interface Mode: This mode allows the actuator to be controlled with just a battery, and a potentiometer to signal the desired position to the actuator – a simple interface for prototypes or home automation projects. The desired actuator position (setpoint) is input to the actuator on lead 2 as a voltage between ground and 5V. The setpoint voltage must be held on lead 2 until the desired actuator stroke position is reached. Lead 2 is a high impedance input.

4–20 mA Interface Mode: This mode is compatible with PLC devices typically used in industrial control applications. The desired actuator position (setpoint) is input to the actuator on lead 1 as a current between 4 mA and 20 mA. The setpoint current must be held on lead 1 until the desired actuator stroke position is reached.

RC Servo Interface Mode: This is a standard hobby-type remote-control digital servo interface (CMOS logic), compatible with servos and receivers from manufacturers like Futaba™ and Hi-Tec™. The desired actuator position is input to the actuator on lead 4 as a positive 5 Volt pulse width signal. A 1.0 ms pulse commands the controller to fully retract the actuator, and a 2.0 ms pulse signals full extension. If the motion of the actuator, or of other servos in your system, seems erratic, place a 1–4Ω resistor in series with the actuator's red V+ leadwire.

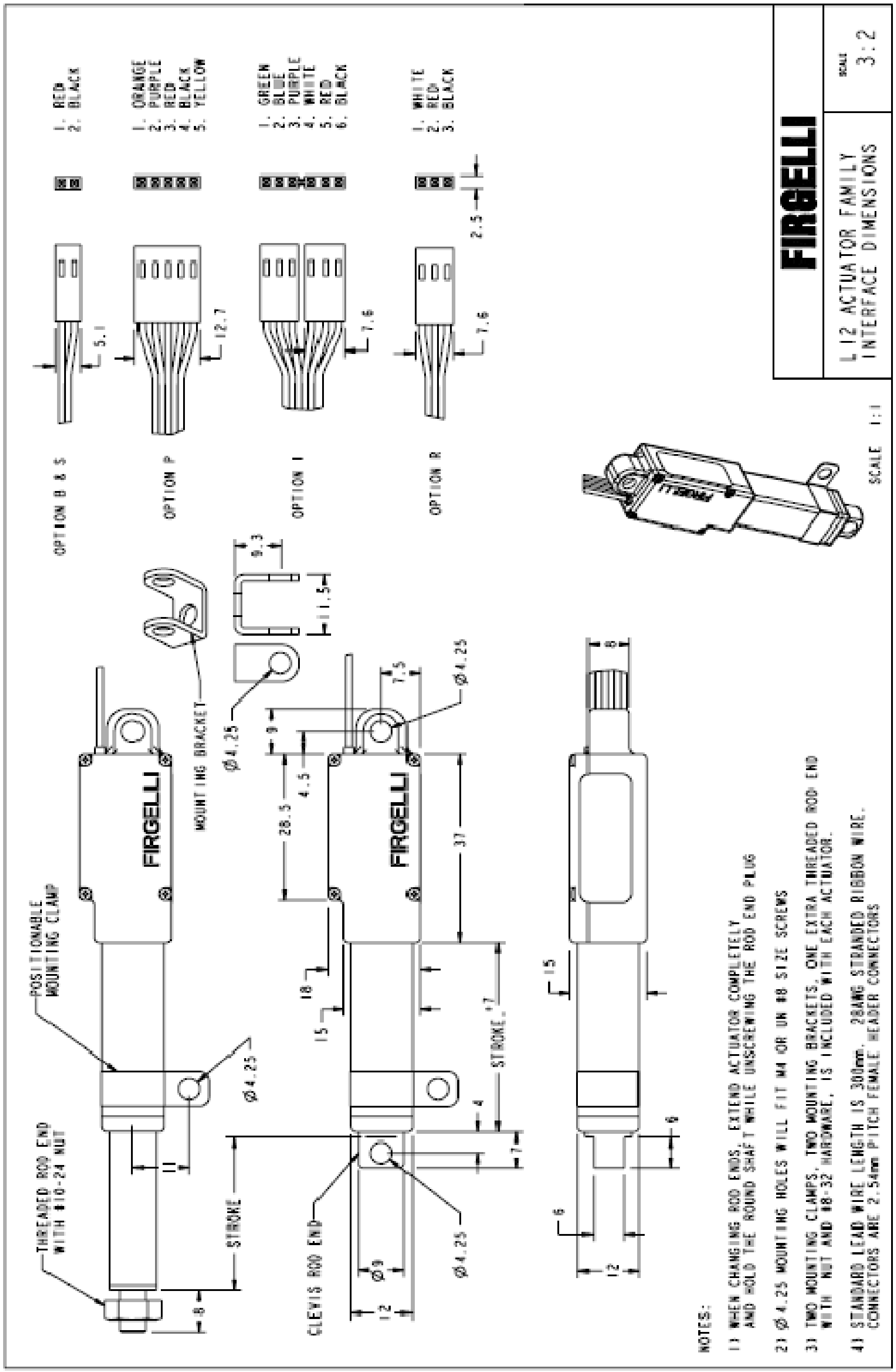
PWM Mode: This mode allows control of the actuator using a single digital output pin from an external microcontroller. The desired actuator position is encoded as the duty cycle of a 5 Volt 1 kHz square wave on actuator lead 2, where the % duty cycle sets the actuator position to the same % of full stroke extension. The waveform must be 0V to +5V in order to access the full stroke range of the actuator.

Option R—RC Linear Servo

WIRING:

1	(white)	**RC input signal**
2	(red)	**Motor V+** (6VOC)
3	(black)	**Ground**

The –R actuators or 'linear servos' are a direct replacement for regular radio controlled hobby servos. Operation is as above in RC servo interface mode (option I). The –R actuators are available in 6 volt and 30, 50 and 100 mm strokes only.


OPTION B & S
1. RED
2. BLACK
OPTION P
1. ORANGE
2. PURPLE
3. RED
4. BLACK
5. YELLOW
OPTION I
1. GREEN
2. BLUE
3. PURPLE
4. WHITE
5. RED
6. BLACK
OPTION R
1. WHITE
2. RED
3. BLACK
5.1
12.7
7.6
7.6
2.5
FIRGELLI
L12 ACTUATOR FAMILY
INTERFACE DIMENSIONS
SCALE
3:2
SCALE 1:1
MOUNTING BRACKET
POSITIONABLE MOUNTING CLAMP
THREADED ROD END WITH #10-24 NUT
CLEVIS ROD END
STROKE
STROKE+7
Ø4.25
Ø9
28.5
37
NOTES:
1) WHEN CHANGING ROD ENDS, EXTEND ACTUATOR COMPLETELY AND HOLD THE ROUND SHAFT WHILE UNSCREWING THE ROD END PLUG
2) Ø4.25 MOUNTING HOLES WILL FIT M4 OR UN #8 SIZE SCREWS
3) TWO MOUNTING CLAMPS, TWO MOUNTING BRACKETS, ONE EXTRA THREADED ROD END WITH NUT AND #8-32 HARDWARE, IS INCLUDED WITH EACH ACTUATOR.
4) STANDARD LEAD WIRE LENGTH IS 300mm. 28AWG STRANDED RIBBON WIRE. CONNECTORS ARE 2.54mm PITCH FEMALE HEADER CONNECTORS

Appendix D – Firgelli GM12 Gearmotor Datasheet

GM12 • Gearmotor

5 Volt Models—Operating Specifications

Part Number	Gear Ratio	No Load Speed (rpm)	No Load Current (mA)	Max Efficiency Speed (rpm)	Max Efficiency Current (mA)	Max Efficiency Torque (g•cm)	Stall Current (mA)	Stall Torque (g•cm)
GM12-N20VA-08260-30-R	30:1	472	40	376	135	88	490	396
GM12-N20VA-08260-63-R	63:1	231	35	183	132	179	490	844
GM12-N20VA-08260-100-R	100:1	144	37	116	133	300	515	1505
GM12-N20VA-08260-210-R	210:1	69	33	55	127	600	506	3050
GM12-N20VA-08260-298-R	298:1	48	31	39	127	900	510	4480

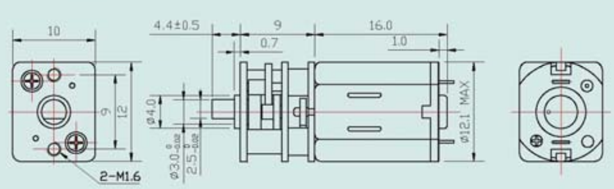
12 Volt Models—Operating Specifications

Part Number	Gear Ratio	No Load Speed (rpm)	No Load Current (mA)	Max Efficiency Speed (rpm)	Max Efficiency Current (mA)	Max Efficiency Torque (g•cm)	Stall Current (mA)	Stall Torque (g•cm)
GM12-N20VA-05450-30-R	30:1	538	18	420	64	113	200	514
GM12-N20VA-05450-63-R	63:1	256	16	203	60	226	200	1079
GM12-N20VA-05450-100-R	100:1	159	18	129	67	300	274	1569
GM12-N20VA-05450-210-R	210:1	75	18	59	65	700	242	3347
GM12-N20VA-05450-298-R	298:1	53	15	43	60	900	247	4701

Common Specifications

Dimensions (including output shaft)	10 mm x 12 mm x 29.4 mm
Weight	9.6 g
Operating Temperature	−10°C to +50°C at 70% relative humidity
StorageTemperature	−40°C to +80°C at 70% relative humidity
Insulation resistance	1.0 MΩ between motor terminals and motor housing
Impedance	53 Ω +/− 15%
Output shaft axial play	0.05–0.4 mm

Dimensions (mm)



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Appendix E- Dimensions of Final Design

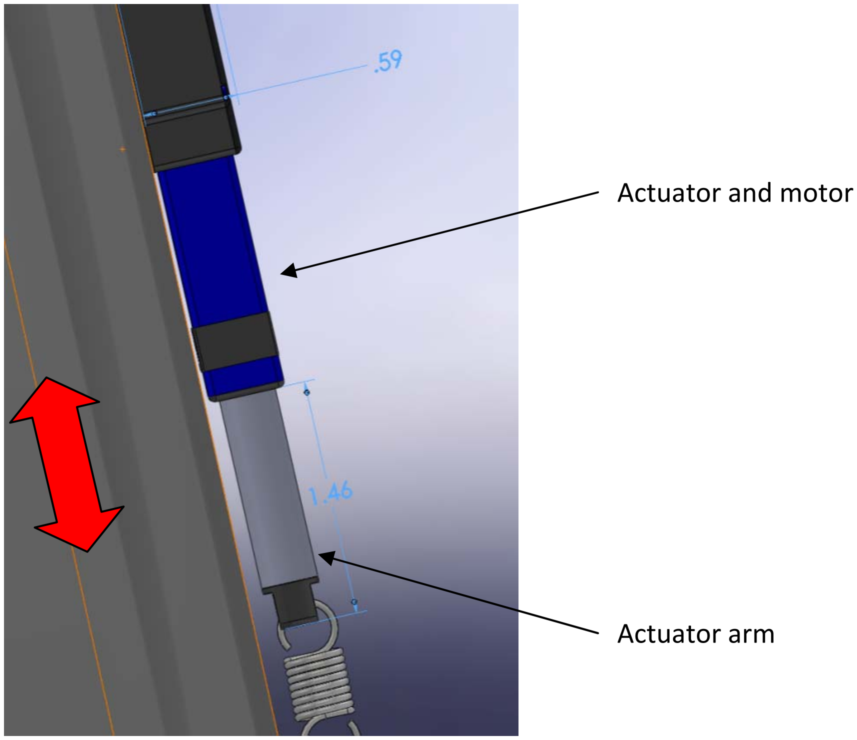


Figure E1: Actuator – dimensions shown in inches

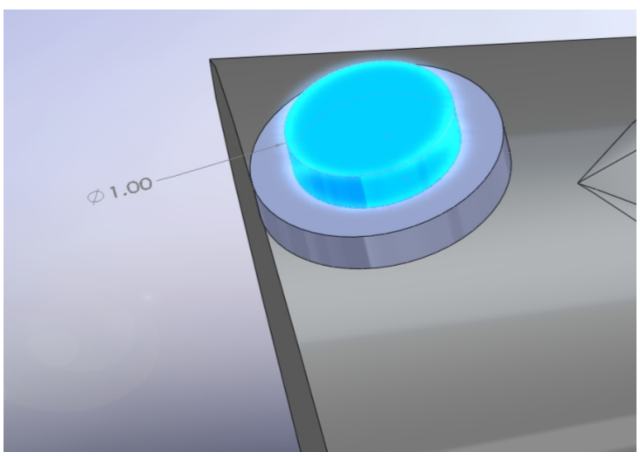


Figure E2: Activation Button – dimensions shown in inches

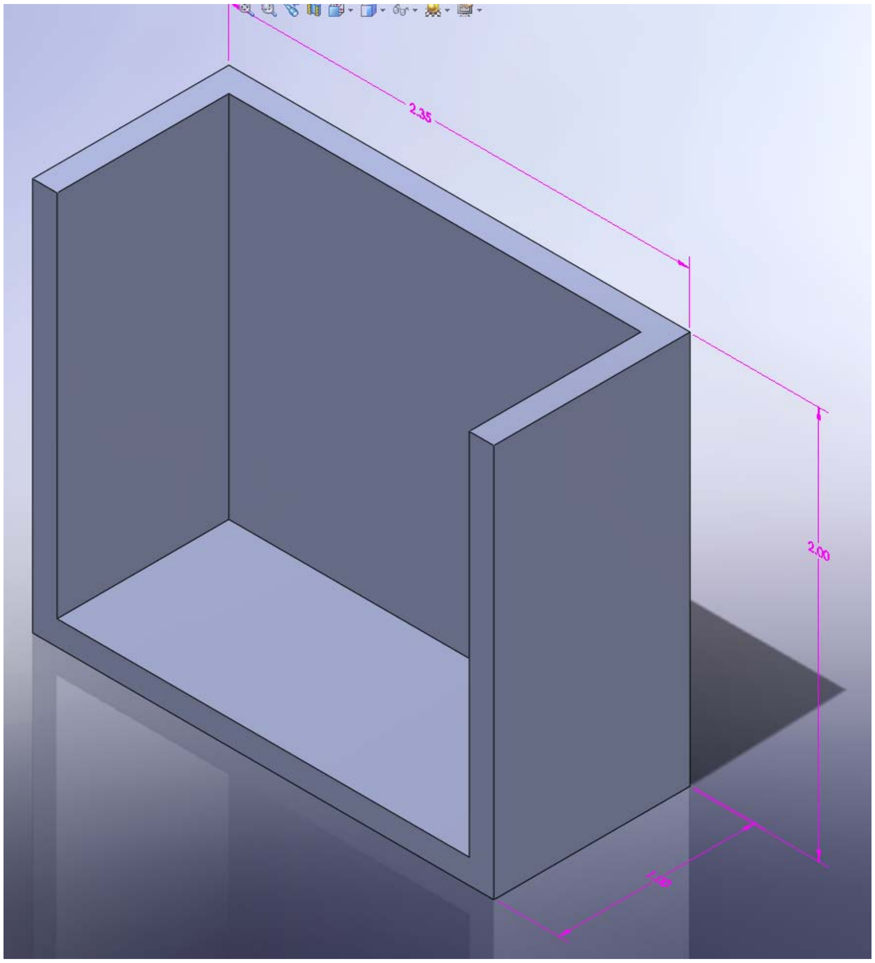


Figure E3: Battery Housing – dimensions shown in inches

Appendix F – Bill of Materials

Item	Quantity	Source	Catalog Number	Cost	Contact	Notes
Linear Actuator	2	Firgelli	L12-30-210-12-S	$70 ea	firgelli.com	Motor included
Gear motor	3	Firgelli	GM12-N20VA-05450-210-R	$13 ea	firgelli.com	Not used
Push Button	1	Honeywell	AML21BBA2CC	$35.99	honeywell.com	
Button Cap	2	Honeywell	642-2057	1 @ $2.79 1 @ $1.18	alliedelec.com	Two sizes
9-volt battery	3	Best Buy		$9.99 ea		
9-volt connectors	1 pack	Radio Shack		$2.69		3 used
12-volt battery	2	Meijer		$5.99 ea		Not used
Spring	5	Carpenter Brothers		$2 ea		1 used
Wire	1 ft	Machine Shop		$5 per ft		
Foam	1 sq ft	Alicia Davis		$2		Donated
Acrylic	.2 lb	Machine Shop		$2 per lb		
Toggle switch	1	Radio Shack		$3.99		Not used
Gator Clips	1 pack	Radio Shack		$2.99		Not used

Appendix G – Material Selection (Functional Performance)

1. The function of our battery housing is to support the batteries inside of the arm. Therefore, the housing will need to be specified such that it can hold a certain amount of weight and that it will not fail under the stresses imposed. The objective is to minimize the mass required to house the batteries, because we want as light of a system as possible as well. The constraints that are in place are that the areas of the faces and their lengths are fixed, and that the material must be as cheap as possible. Using this information, we developed a material index relating the maximum yield stress against the density of the material, shown in Equation X1 below. This was then converted into a logarithmic function in Equation X2 in order to create guide lines in CES, as shown in Figure X1 on page X. We also eliminated some of the undesirable materials by constraining the material density from .04 lb/in3 to .05 lb/in3 and the price range from $1 to $2.

   Equation G1: $M = \frac{\sigma_Y^{2/3}}{\rho}$ Equation G2: $\log \sigma_Y = \frac{3}{2}(\log \rho + \log M)$

   Using the guide lines, we were able to find the five most desirable materials to choose from. These materials were all glass fiber products, however, which made them expensive and difficult to machine. Therefore, after comparing the cheapest products that still fit our requirements in Figure X2 on page X, we decided to use Polymethylmethacrylate, or PMMA (Acrylic). Acrylic would fit all of our design requirements as well as fit our project costs.

2. The function of our push button foam covering is to be very soft and easy to depress with the chin, as well as to deform easily. The objective of the material index is to minimize the mass, as well as the associated cost. The constraints that are In place are that the area of the face of the button cover must remain fixed, as well as the height that it protrudes off of the chest of the patient. The equation defining our material choice is shown below as Equation X3, with its respective logarithmic as Equation X4. The guide lines we obtained from these equations are shown in figure X3 on page X. We also eliminated some of the undesirable materials by constraining the material density from 0 lb/in3 to .005 lb/in3 and the price range from $1 to $5.

   Equation G3: $M = \frac{E^{1/2}}{C_m \rho}$ Equation G4: $\log E = 2(\log C_m \rho + \log M)$

   Under these guide lines, we found that the most desirable materials were a variety of polyurethane foams. We then compared the price of the foams against the density, and found that Polyethylene Foam LD18 was the best choice to suit all of our needs. This is also the type of foam that is regularly used by the UM Prosthetics Center for purposes similar to ours, so the material was readily available.

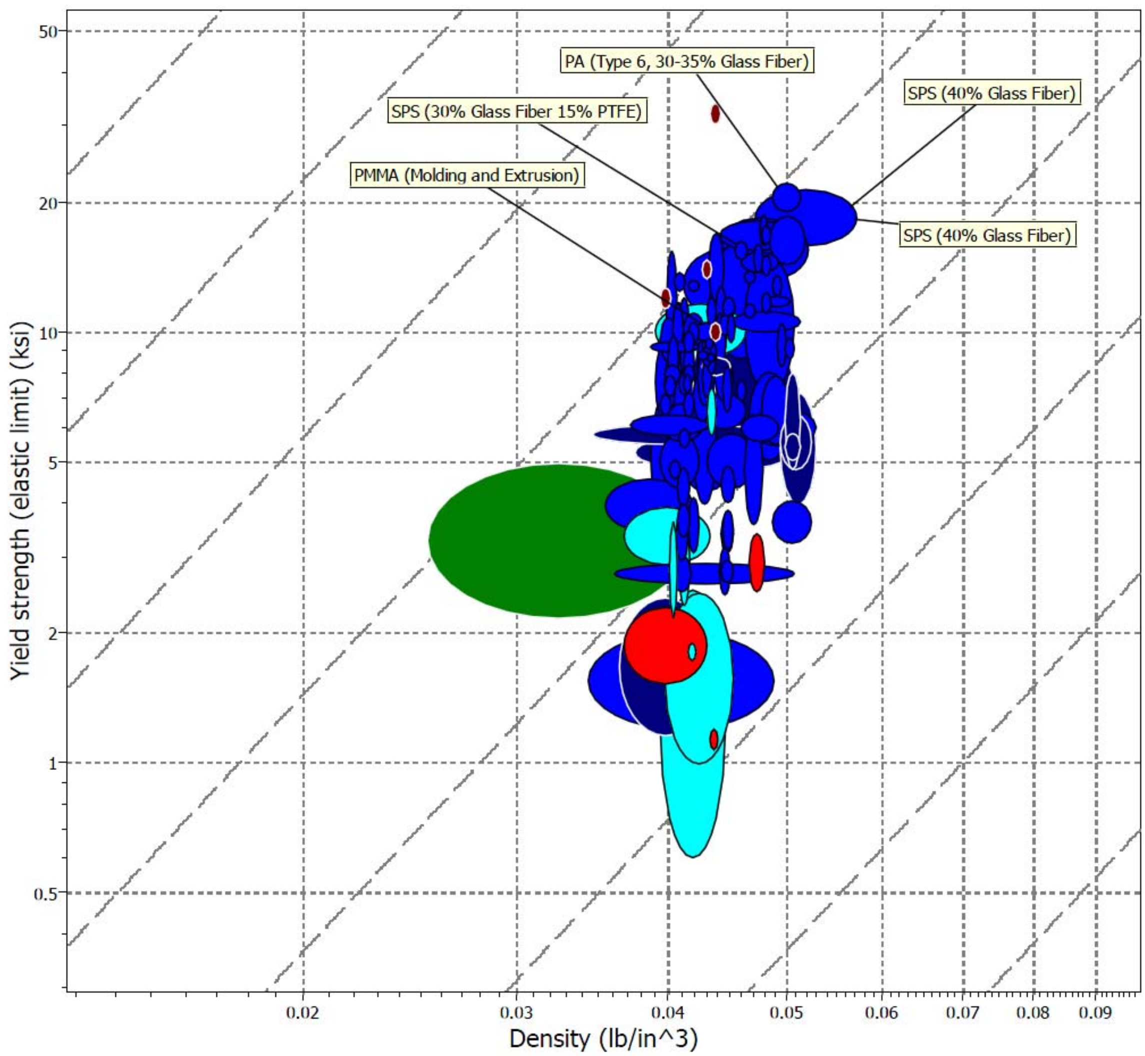


Figure G1: Battery Housing Yield Strength versus Density

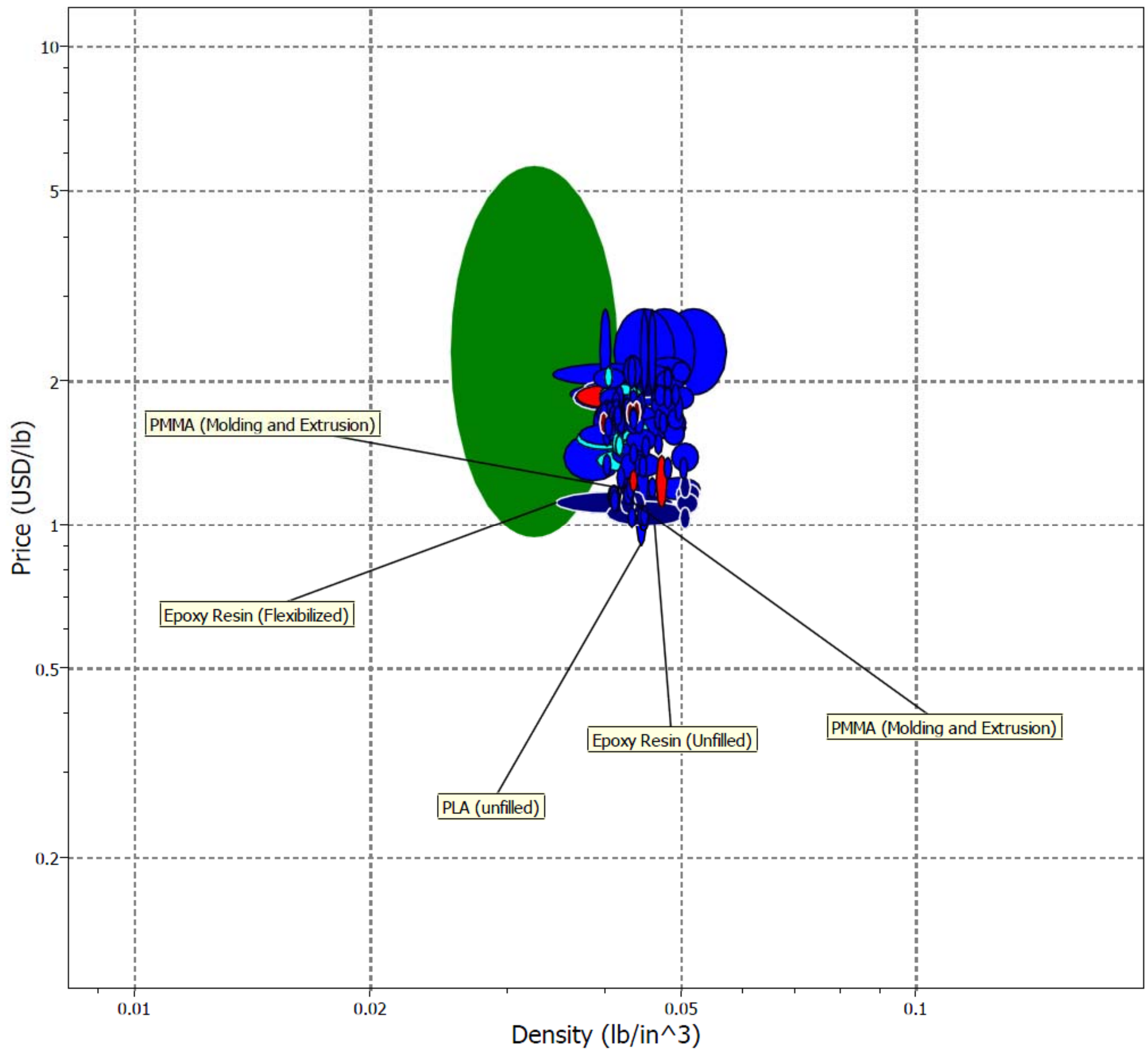


Figure G2: Battery Housing Price versus Density

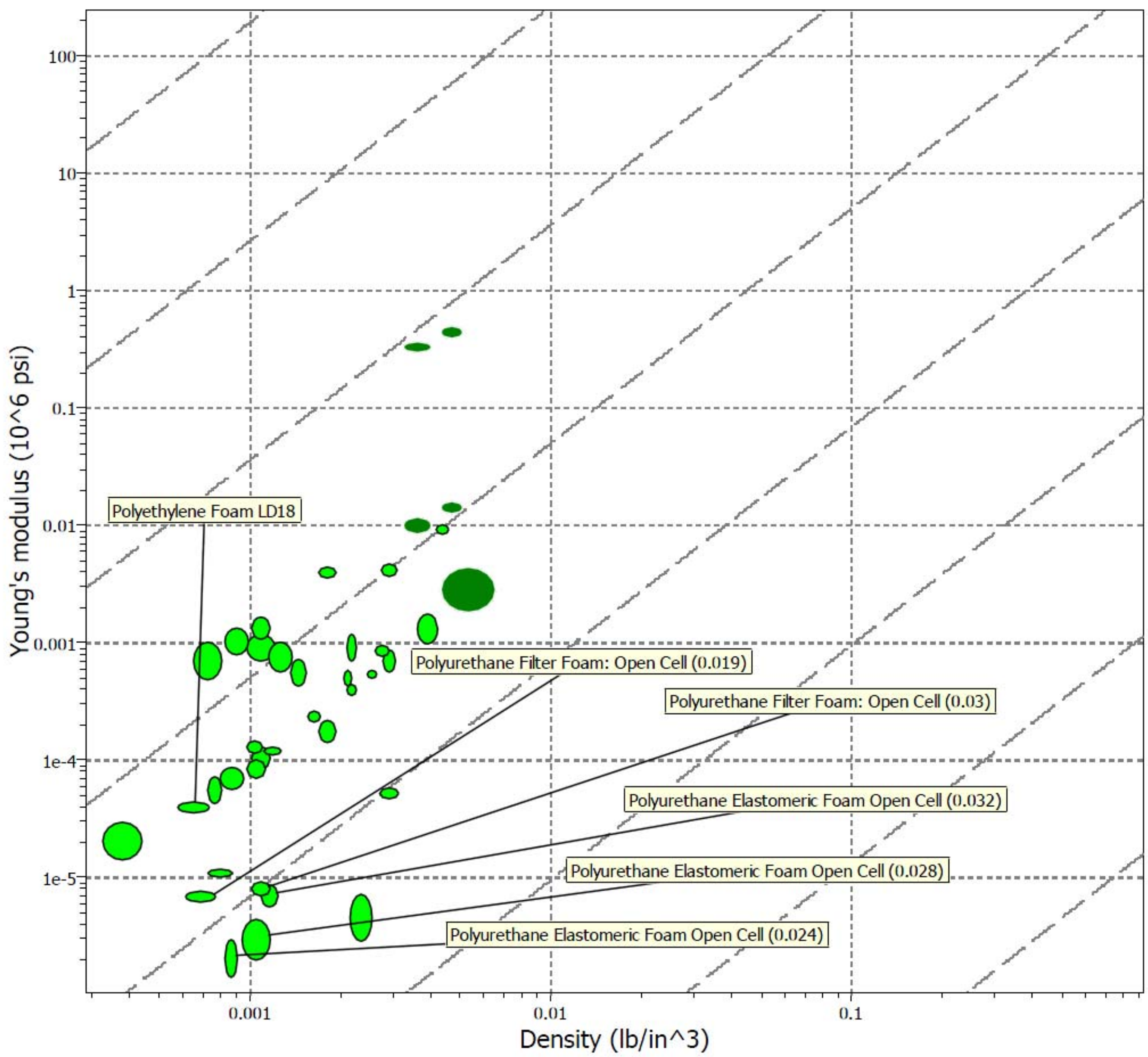


Figure G3: Button Foam Cover Young's Modulus versus Density

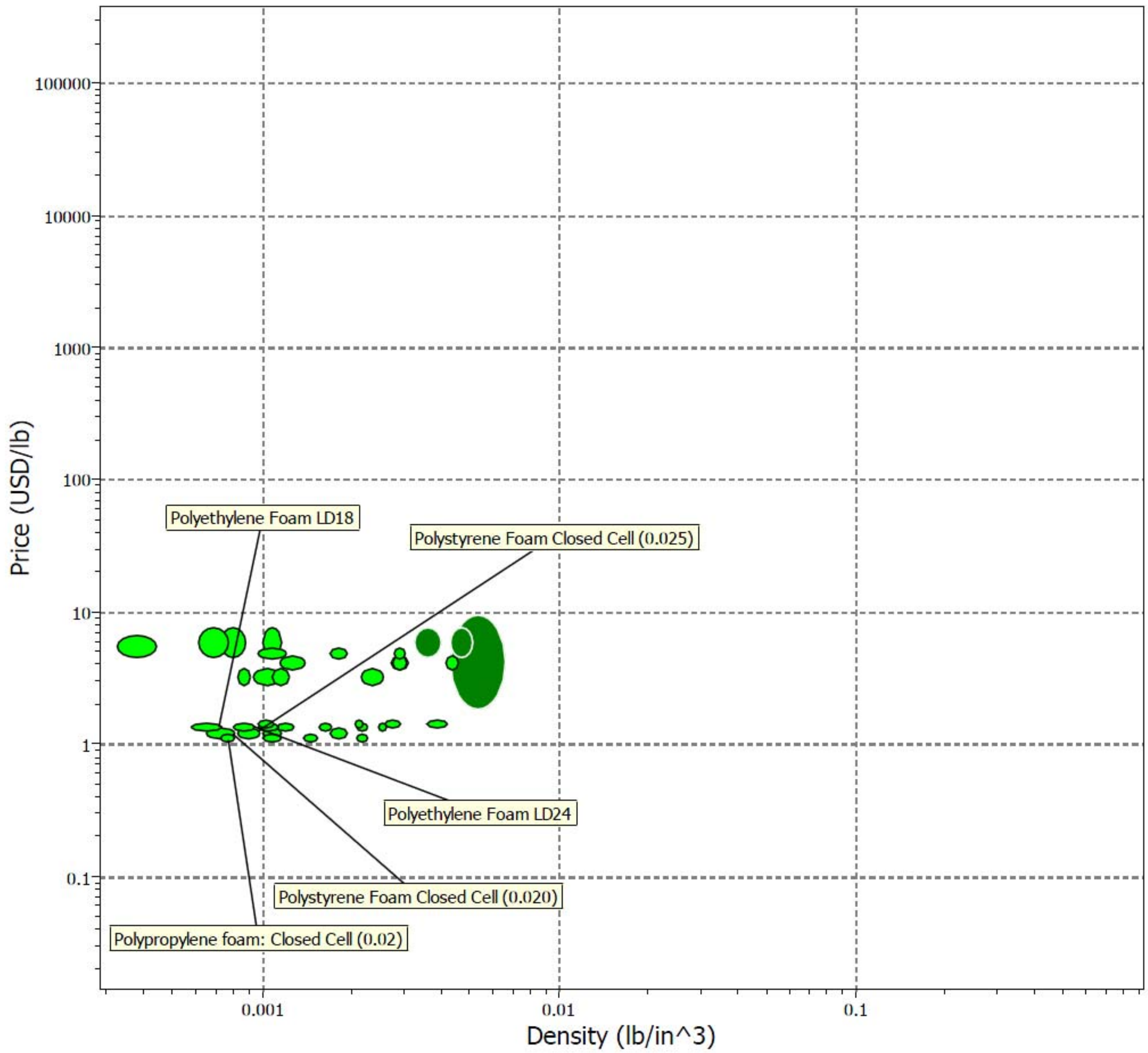


Figure G4: Button Foam Cover Price versus Density

Appendix H – Material Selection (Environmental Performance)

From our EI 99 point values, it appears that the resources category is most important. PMMA acryllic plastic has a point value of 10 mPt, while PE foam only had a point value of around 2.9mPt. When considering the full lifecycle of both materials the same conclusion can be drawn. The plastic material contributes about 85% of the total raw material and waste mass, and therefore is worse in a "cradle to grave" full life cycle analysis.

The PMMA acryllic plastic material is worse in every category, and is responsible for over 90% of the air and water emissions, so this material appears to have a higher impact on the environment. The foam material is used because it is very sterile and commonly used in various medical applications. In our project, this is important since it comes into contact with the skin, so we would not recommend changing this material. However, based on this analysis we do believe that there may be more environmentally friendly plastics that would still serve the same purpose of housing our batteries.

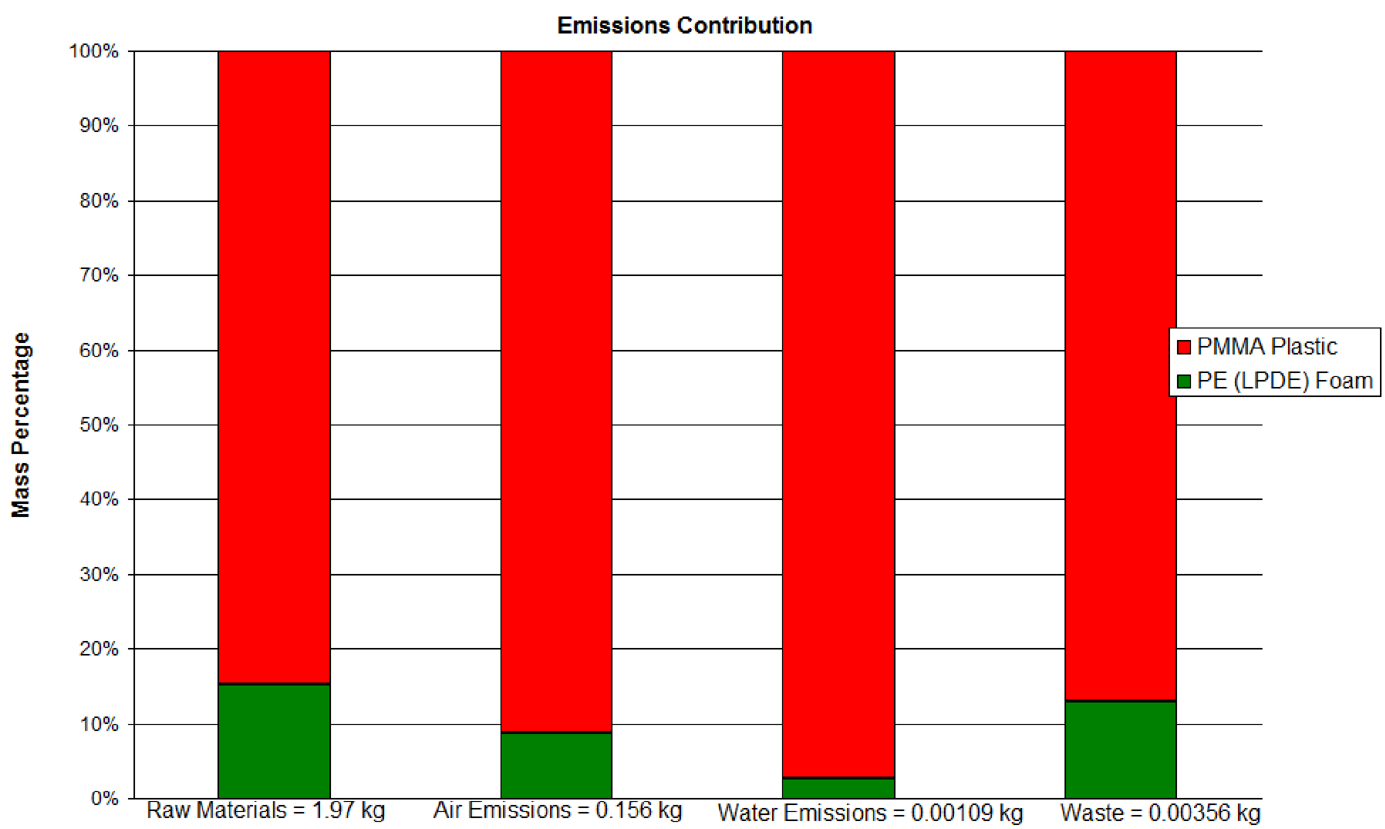


Figure H1: Emission Contributions

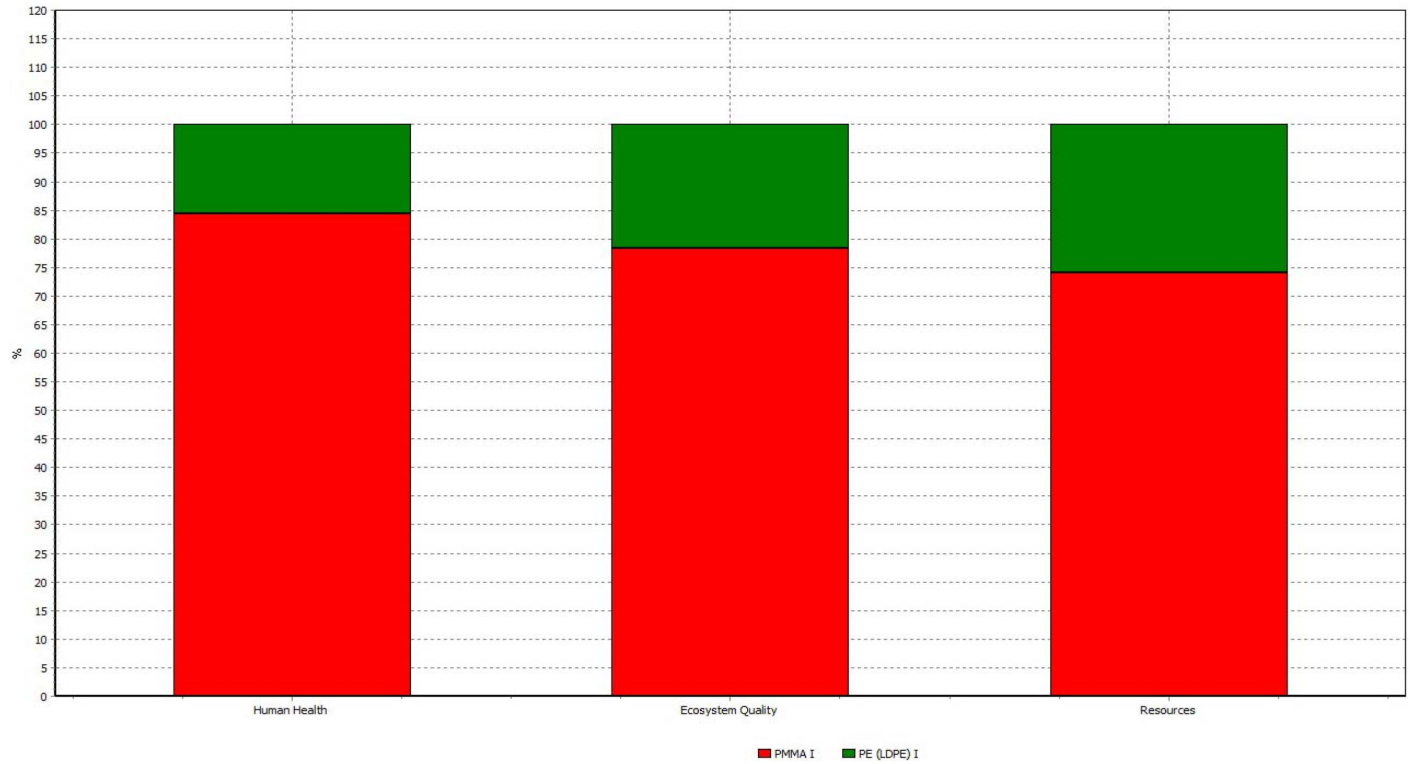


Figure H2: Damage Assessment

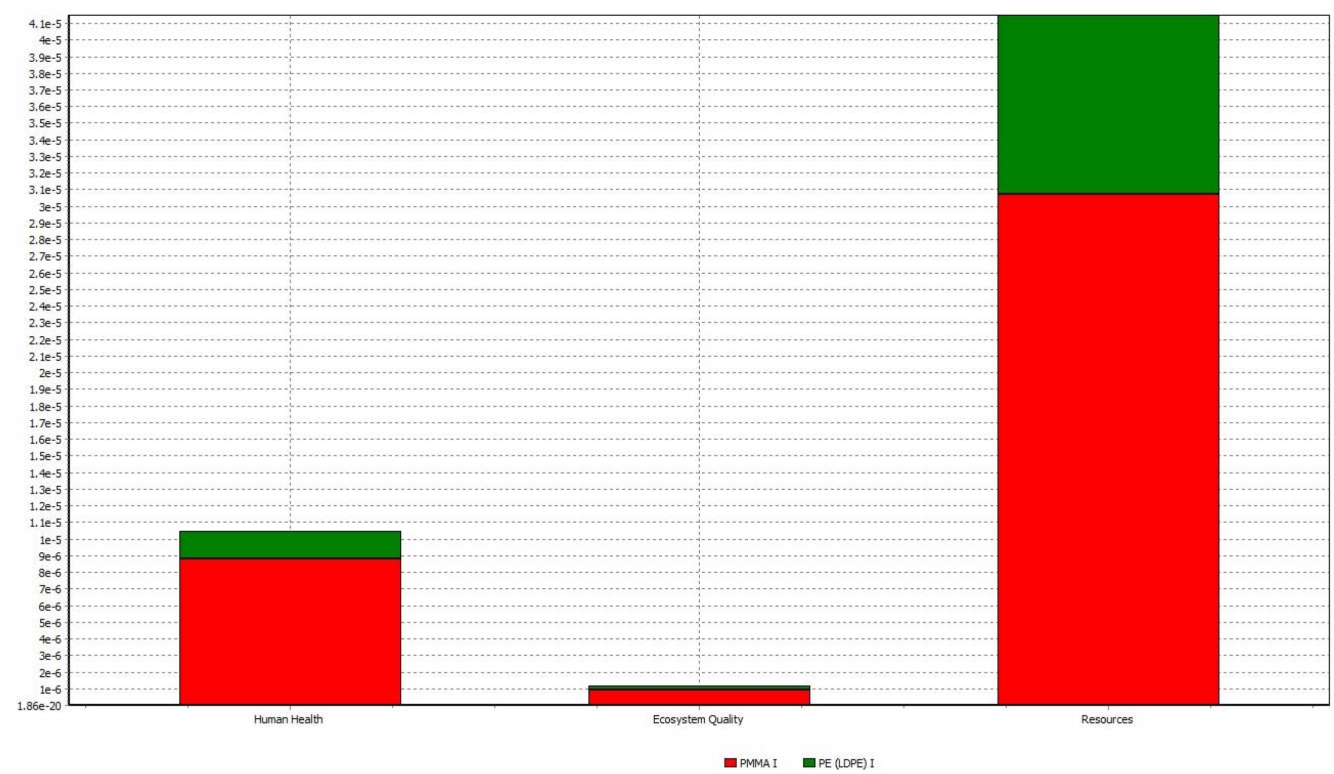


Figure H3: Normalization

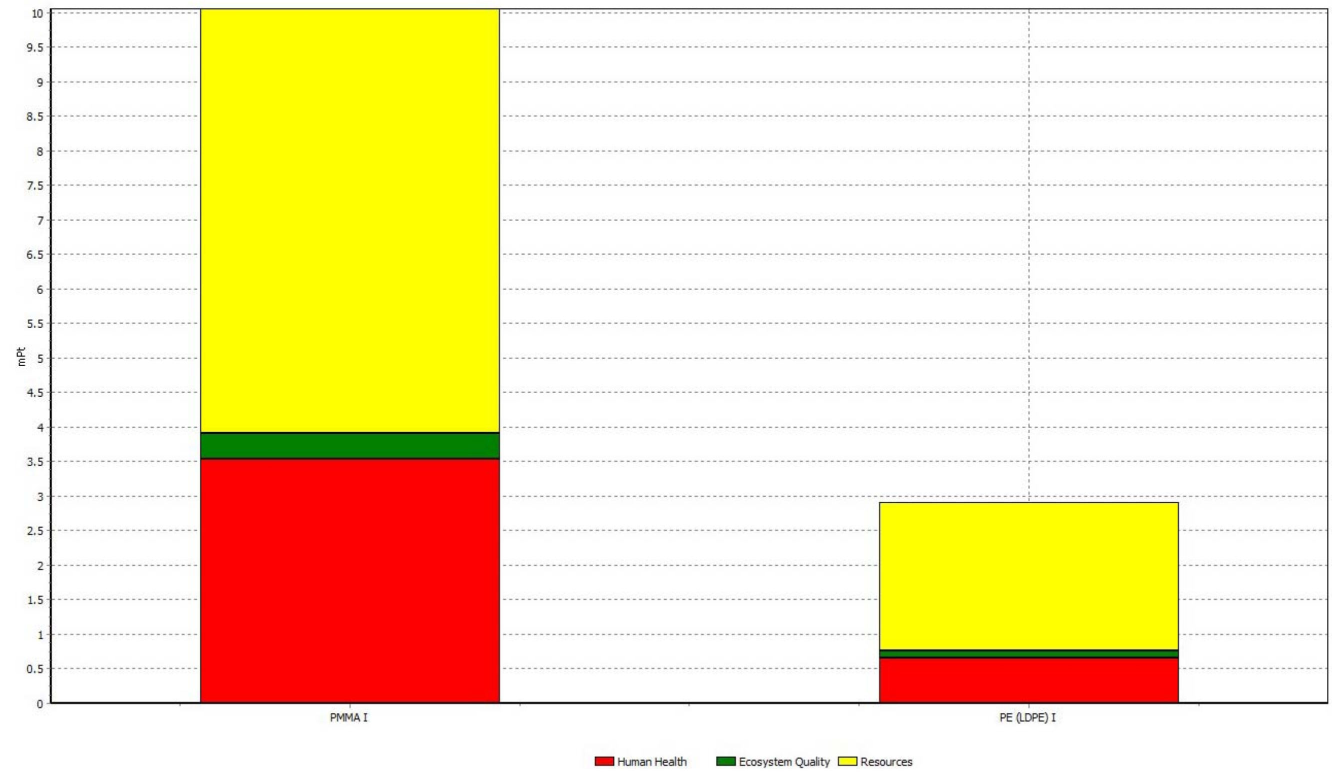


Figure H4: E1 99 Point Source

Appendix I – Manufacturing Process Selection

1. There are approximately 350,000 extremity amputees in the U.S., 30% of which are upper extremity amputees, and 30% of these are above the elbow [9]. This reduces to approximately 31,500 people with amputation above the elbow. Based on information from our sponsor, who told us that most people use myoelectric elbows, our group estimates that the maximum number of those amputees that would use our device is about 5,000. With this scale of production in mind, we researched which manufacturing processes would be best to produce the components of our project.

2. For the polyethylene foam circle, we would employ a jet cutter. We took the following input parameters into account when selecting our process with CES: the foam would be cut from a thin, flat sheet, and the surface would not be very smooth. After applying these limits, only water jet cutting passed. After investigating further, we read that, indeed, water jet cutting is used to cut polymer foams on a small scale in high volume.

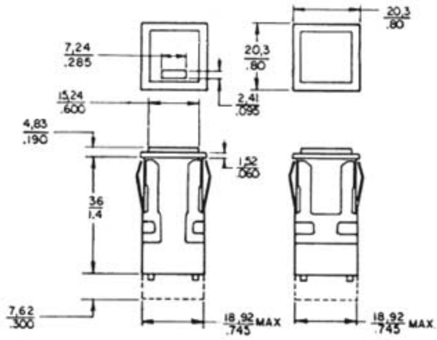
For the acrylic battery holder, we would employ a laser cutter. We determined the acrylic would be cut in sheet form into 4 parts, which would then be glued together in a separate process. We used the CES selector to see what processes could cut a thin, flat sheet with a smooth surface. The processes that passed were blanking and laser cutting. After further research, we found that blanking is fast and cheaper than laser cutting, but the material is too brittle to withstand this process. Laser cutting is perfectly capable of cutting polymer sheets, but the equipment is very expensive.

Though we selected manufacturing processes for these materials with CES, the majority of our design requires the assembly of our different components by hand. This is nothing new to the world of prosthetics; every prosthetic arm is custom-made to suit the individual patient. The Sierra nudge control, for example, could be mounted in many different positions on the arm, as long as it could pull the elbow cable; similarly, our design's components can be placed anywhere, as long as the actuator can pull the cable. This means that the components, which will be ordered and individually pre-manufactured, would simply need to be connected wires and mounted to the prosthetic arm in whatever way best suits the patient's needs. Most orthotics and prosthetics centers have machine shops where this customization can take place.

Appendix J: Description of Engineering Changes Since Design Review #3

WAS:

IS:



Notes: Replaced DPDT toggle switch with DPDT pushbutton (push = positive, release = negative)

ME 450	
Project: 3	
Ref. Drawing: Pushbutton Switch	
Engineer: R. Stubleski	3/16/2009
Proj. Mgr: Hong Im	3/17/2009
Sponsor: Alicia Davis	3/22/2009

WAS:

IS:

Notes: Replaced two (2) 12-volt batteries with three (3) 9-volt rechargeable batteries

ME 450	
Project: 3	
Ref. Drawing: Batteries	
Engineer: R. Stubleski	3/16/2009
Proj. Mgr: Hong Im	3/17/2009
Sponsor: Alicia Davis	3/22/2009

Appendix K: Safety Report

ME 450 Safety Reporting: Winter 2009

Project #: ____3_____ Date: _________April 1, 2009__________

Report Version #: _____1____

Project Title: ___Nudge Control Switch for Upper Extremity Prosthesis_______

Team Member Names:__Aaron Dodd, Jessica Messer, David Nelson, Ryan Stubleski_________

Team Member Uniquenames:__dodda, jecka, davidne, sturyan_________________________

APPROVAL:

Name: ___________________________

Signature: ___________________________

Date: ___________________________

Summary

In building our nudge control switch, our team will need to consider the voltage running through the circuit, and the lifetime and durability of the motor that runs our linear actuator. This report involves the testing required to answer these questions. We have minimized the risk to ourselves and the final prototype by selecting an actuator that runs at the low level of 6 volts. From the device specifications, we know that it should stall at a maximum of 450 mA, and that there is only a 0.1 mm mechanical backlash guaranteeing that the motion of the actuator won't harm anyone. The main hazards involved in this device involve the voltage and current running through the circuit, and it potentially affecting the functionality of the system, as well as it potentially harming the person that uses it. To eliminate the risk of the device harming a person, we have used a non-conductive button, and will ensure that any exposed wires will not touch the skin.

Experimental Plans

All of our intended experiments are necessary to determine the mechanical capabilities of our system. We intend to put a motor through voltage and current tests to determine the maximum values that it can withstand. We will also use this information to determine an optimum voltage and run speed for the motor, which we can use to determine the lifetime and durability of the device.

Purchased Components and Material Inventory

The components that we have purchased are listed below:

Actuator: The actuator that we have purchased is a Firgelli model L-12 linear actuator. This will be used as the driving force in pulling the spring locking mechanism.

Motor: We have purchased three motors from Firgelli, all with gearing option 250:1. These motors will be used in the linear actuator to convert electrical energy into mechanical motion and move the actuator arm. We have purchased three in the event that we harm any during testing.

Button: The button we have purchased is a DPDT push button from Honeywell. It is mounted in the upper portion of the arm, and allows for the actuator to extend when pushed, and retract when not pushed.

Batteries: We are using three rechargeable 9 volt batteries connected in series to supply 27 volts to our system.

Assembly

We will be assembling our components in the X-50 lab using screwdrivers and a soldering iron. Because all of our components are manufactured for use, we will not have to construct anything. Instead, we will be assembling the device from the components that we have purchased. We can be sure that the devices will not fail by comparing the specifications of the system parts with our own specifications. We have also spoken with the manufacturer of the actuator and motor system, Firgelli Associates. The engineers helped our team choose these specific models based on our requirements.

Manufacturing

We will be manufacturing a battery housing made out of Acrylic plastic that will be cut using the laser cutter. We will cut the walls of the housing and then glue them together with Cyanoacrylate (super glue).

Design Testing and Validation

We plan on completing our testing in the X-50 lab. In our testing, we will address the maximum voltage, speed, lift force, and max current that our system is capable of. The main goal of our testing is to discover the maximum voltage our motor is capable of, and at what speed the motor will operate at with that applied voltage.

We will set up our motor and actuator assembly on a fixed apparatus connected to the table such as a clamp or vice, and connect the end of the actuator to a spring, weight, or elastic band that will simulate our desired 5 lb lift force. We will apply a set voltage of 12 V from the power generator, measure the speed, and increase the voltage until our desired speed is reached. Once the desired speed is reached, we will allow the actuator to run through several cycles until the motor burns up and the lifetime is known. If the motor does not fail, we will increase the voltage to determine the motor's capability.

We will complete all of this testing using only the motor and actuator. If a OOpic microprocessor is available, we will also incorporate this into our testing. We will validate the entire system on an actual prosthetic elbow once a safe operating voltage is determined for our motor.

Our plan is to have a lab technician such as Bob Coury or Daniel Johnson view our initial test to ensure everything is set up correctly.