

Power Grip Glove – Final Report [Rough Draft]

Mohammed Alafaisan, Ahmed Alfaifi, Ahmed Aljishi, Nawaf Alzahrani, Ben Maxey, and

Kishan Soni

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Executive Summary

There are a variety of medical conditions that can cause a loss of grip strength or gripping ability in the hand. One notable example of such a condition is cerebral palsy. Cerebral palsy is the result of brain injury during fetal development, and it can affect the generation of neural signals that control the hands. Abnormal generation of these signals can cause the hands to be locked stiffly in one position. Other conditions that can affect grip strength include extreme forms of diabetic and ischemic peripheral neuropathy, in which nerves in the hand are destroyed by high glucose levels or low oxygen levels in the blood, respectively. Our goal is to create an assistive glove that can restore function to the hands of people with such medical conditions. The power grip glove has the potential to positively impact the lives of hundreds of thousands of people struggling with impaired grip strength. Developing a glove that can restore normal hand function to these patients has the potential to dramatically increase their independence, productivity, and – most importantly – quality of life.

The design process began by separating the project into three distinct functional domains: force generation and transmission, the physical, material construction of the glove, and the control system. The first area is the force generation and transmission. For the glove to amplify grip strength or to hold a hand in an open position against tension, some force must be generated somewhere, and this force must be transmitted to the fingers of the glove. In this area, we will answer questions dealing with how the force itself is generated (motors, actuators, etc.), how this force is sent to the fingers, and how the system is powered. A few examples of issues that will arise are the necessary efficiency of the system, how much power is lost through transmission, and tradeoffs between battery capacity and size/weight.

The next functional domain is the mechanical and material design of the glove itself. This area concerns the physical structure of the glove, the material used to build the glove, and the integration of the elements of force transmission into the glove. We will be concerned with the level of comfort and safety provided by the material, the total weight of the glove and its attached components, as well as the friction provided by the gloves at the site of gripping (the fingertips). The final functional domain is the control system. The control system is responsible for detecting the intent of the patient either to open his or her hand, or to grip an object. Further, the control system must contain safety measures and fail-safes to ensure that the glove does not harm the patient in any way. For example, the control system should receive feedback on the actual force being applied through the fingertips so that excessive force is not applied to the

patient's fingers. If the grip cannot be released easily when a patient's hand is accidentally experiencing too much force, the glove could cause serious damage to the patient.

Within each functional domain, we explored several options to accomplish our objectives within our constraints. For force generation and transmission, the primary options we considered were hydraulics, pneumatics, and electromechanical force. An advantage of hydraulics and pneumatics is the ability to easily create a sustained force without the input of additional power. Once a pneumatic artificial rubber muscle is inflated, for instance, it remains inflated and provides force until the gas inside is released. The main disadvantage of pneumatics and hydraulics are the parts required; reservoirs, compressors, pumps, and tubing can be quite bulky, heavy, and costly. Electromechanical means are generally cheaper and more easily implemented. Ultimately, the force generation and transmission will be accomplished through cables attached to linear servos at one end and to the fingertips at the other. When the linear servos contract or extend, the cables pull the fingers closed into a gripping position. Cables located above the fingers are controlled by a second linear servo, and these cables pull the fingers open when not gripping.

For determining the patient's intent to grip and to release grip, two main options were explored. The first is manual activation, accomplished through a simple switch or button. The advantage of this route is that it is extremely simple to implement, not technically complex, and has low risk of failure. A major drawback is that it requires use of the non-gloved hand to operate the gloved-hand. A second option is electromyography (EMG), which measures action potentials at neuromuscular junctions. The main advantage of this method is that it is hands-free and more responsive to the user. Drawbacks lie in the technical complexity of implementation, as well as great noise inherent in EMG signals. We have chosen to pursue electromyography, reserving manual activation in case of technical difficulties.

After deciding on a high-level design, the final step in the design process was to select parts, conceptualize how each part connects to form a functional power glove, apply for IRB approval, and to draft a final budget. Overall, the cost to build one power glove will be approximately [do not have final number – will have in final report]. At this point in the project timeline, we have finalized the parts and detailed design for the glove, and we are prepared to begin ordering parts and assembling a first prototype to test.

Introduction

As the culminating project for undergraduate degrees in mechanical engineering and in electrical engineering, designing and prototyping the power grip glove will incorporate and test several domains of knowledge in these disciplines. The physical, mechanical workings of the glove rely on basic statics and dynamics as well as knowledge of materials and motor functioning. Basic load requirements for the motors must be calculated from the desired tension in the cables at the fingertips, but this is impacted by the angles at which the fingers are held and the frictional losses in transmitting force from the motors to the fingers. Once the load requirements have been calculated, knowledge of motor types is essential in choosing the best option for driving the load.

Although the control system for the glove may seem simple at first glance (turn a switch on to make the glove close), it requires a more sophisticated knowledge of control theory and signal processing. Using a biomedical reading as an input signal to the device makes the control non-trivial, as this signal has inherent noise that must be filtered out, and the signal must be smoothed appropriately. Further, a more complicated control system than an on/off switch must be used to enable multiple responses from a single continuous input. Of course, a basic understanding of microcontrollers is also required to implement the control scheme once it is designed.

Perhaps most importantly, this project reinforces our design abilities and team dynamics. While most engineering classes provide the background knowledge to be able to generate a design, the creativity and problem-solving skills required to solve such an open-ended problem can only be learned through experience. Developing the power grip glove is a fantastic exercise in pure design, team management, and risk management. The skills reinforced and developed by this project will translate directly to success in real-world engineering positions.

User Requirements

Our sponsor gave very few quantitative constraints for this project, which has afforded us much creative freedom in designing the glove. However, this project does have several primary, baseline objectives, of which *all* must be met for the glove to be considered a success:

- The glove allows a user to hold 5 pounds by friction alone
- The glove can open the user's hand against tension
- The system stabilizes wrist and hand movement

- Risk of harm to the user is minimized

The following are secondary objectives and constraints that our sponsor has indicated interest in, but has not made completely mandatory for the operation of the glove:

- Electromechanical components (i.e. motors, microcontrollers, wiring, batteries, etc.) are completely wearable
- User can operate each finger independently of one another
- The system functions for at least 24 hours before it needs to be recharged or its battery needs to be replaced
- Able to hold a light grip on delicate objects as well as a strong grip on heavy, durable objects
- Motion of the thumb is fixed
- Financial cost is as low as possible

Finally, as a group we have identified several objectives that were not explicitly given by our sponsor but that we would prefer for our final product:

- System weighs less than 7.5 pounds
- Glove itself is water and heat resistant
- The glove is flexible, comfortable, and resists sweat saturation
- The glove is easy to put on, and easy to control
- The system is marketable as a standalone product

The first tier of objectives has the highest priority, followed by the second, followed by the final tier. During the implementation phase of this project, it is likely that we will encounter obstacles regarding part availability, technical complexity, and unforeseen design errors. If and when we encounter these difficulties, lower-tier objectives may need to be sacrificed to satisfy the primary objectives for the glove.

Engineering Specifications

In this section, we describe the parts we will use to give functionality to the device, the specifications of each part, and how the parts will assemble to create the final product. The rationales for choosing each part as well as the theoretical basis behind each subsystem of the device are explained in the Design section.

The base of the glove will be a third-party thumb and wrist brace. We have chosen to use a Uriel Universal Size Wrist/Thumb Splint (Part 24-9029). This splint is designed with an inner aluminum rod to provide support to the wrist and thumb. The wrist is held in a functional position at an angle of 35° . The splint has Velcro straps around the wrist that allow for individual fitting. Aside from the Velcro, the entire splint is made of Neoprene. The total weight of the splint is 3 pounds. The approximate cost for this splint is \$35.00.



Figure 1. Uriel Universal Size Wrist/Thumb Splint

The splint serves as an attachment point for two sets of components: finger guides and cables. The finger guides are responsible for holding the four fingers and for routing cables from the wrist, across the palm, and to the fingertips. The finger guides will consist of several bands of elastic fabric that fit around each finger, connected by three elastic strips that run down the length of each finger, one on top of the finger and two below. The strips will be double-layered, and between the two strips will be the metal cables. The elastic fabric is an 85/15% polyester-rubber blend, and it can be found on Amazon for \$7.99 for 2.75 square feet of fabric.

Each finger is surrounded by three cables: two below and one above. All cables run the length of each finger, then meet at two attachment points (one above and one below) on the wrist splint near the forearm. There are two main options we have finalized on for the cables. The first is a standard push/pull control cable from McMaster-Carr. This would cost \$40.00 for a complete cable with mounts and a clevis/pin connection (Part 3125K22). The second option is to create a custom Bowden cable from Teflon tube and either standard steel wire or fishing line. The Teflon tube, functioning as the outer sheath would be purchased from Thomas Scientific and would cost approximately \$4.00. The fishing line is purchased at a standard sporting goods store and is rated at 50 pounds, costing \$7.00. The steel wire could also be purchased from McMaster-Carr for approximately \$5.00, varying slightly based on wire diameters.

For force generation, we have chosen two 140mm Stroke 44lb Thrust Light Duty Linear Servos (Part L16-R-140-150-6) from ServoCity. These brushed DC motors are rated for operation at 4.5 to 7.5 V with a drain current of 650 mA at stall, and they offer a dynamic thrust of 200 N (approximately 44 pounds). The stroke length is 140 mm, and the motors have a maximum speed of 8 mm per second. As they are servo motors, they are controlled through a PWM signal with an amplitude rated between 3 and 5 V. The total weight for one motor is 3.50 oz. The full dimensions of the motors are given in the schematic below.

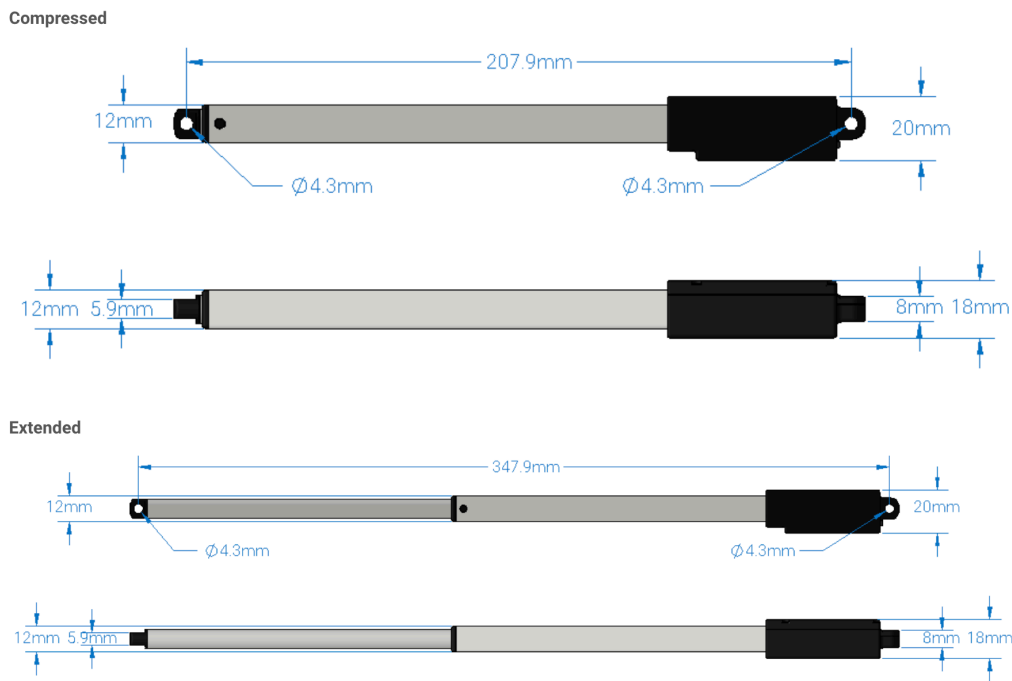


Figure 2. Dimensions of linear servos, both compressed and extended

The components of the control system are the microcontroller – an Arduino Uno board – and the sensors. The Arduino Uno uses an ATmega328P microcontroller, which has 32 KB of flash memory, 2 KB of SRAM, 1 KB of EEPROM, and a clock speed of 16 MHz. The microcontroller offers 14 digital I/O pins (with 6 configured for PWM output) and 6 analog input pins. The recommended input voltage is 7 to 12 V, and the operating voltage is 5 V. The cost for the Arduino Uno is \$22.00. The sensors we will require for the project are an EMG sensor and a pressure sensor. The EMG sensor will be the MyoWare Muscle Sensor (Part AT-04-001) from Advancer technologies. This sensor takes a 5 V supply and consists of three electrodes – two measurement and one reference. The board itself contains a rectifier and integrator circuit that smooths the raw signal before it is output. The cost of this sensor is \$37.95. Additional



Figure 3. MyoWare Muscle Sensor

biomedical sensor pads can be purchased in packs of 10 from Sparkfun for \$7.95. At this point, we are still searching for a pressure sensor that meets our constraints. Most pressure sensors with enough resolution to be useful are too bulky to be affixed to the thumb, which has been the major obstacle in locating a suitable pressure sensor [will have sensor part number and specifications in final report].

The battery we have chosen is [also to be determined – will have part number and specifications in final report].

Design

As stated in the Engineering Specifications section, the base of the glove is the third-party wrist and thumb splint, which functions to immobilize the wrist and thumb. Without any modifications, the thumb would be immobilized by the splint, but would not be in an optimal position for gripping. The splint contains an aluminum rod that runs the length of the wrist through the thumb restraint, and this rod can be bent to keep the thumb in an optimal gripping position. The splint itself is made of Neoprene, which is light, breathable, and water resistant. The glove base meets one of our primary objectives by immobilizing the wrist, and it meets several secondary objectives by being light (approximately 3 pounds) and comfortable. The decision to purchase a third-party splint as the base of the glove instead of building our own was largely motivated by time and complexity constraints.

The cable system utilizes Bowden cables, which preserve linear transmission of force despite any turns or twists of the

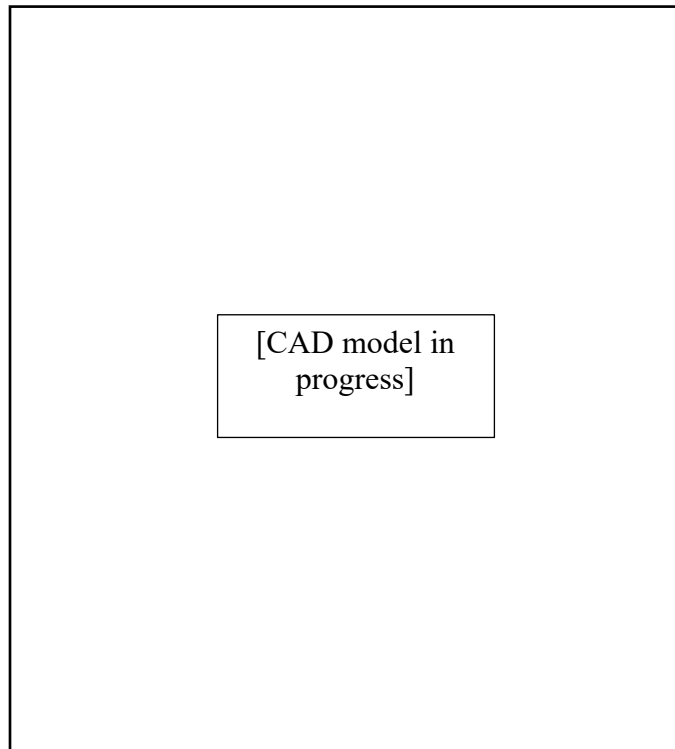


Figure 4. CAD model for the cable system. The glove includes two sets of steel wires that run below (2 wires) and above (1 wire). Each set of wires joins at the wrist, and is connected to the Bowden cable system

cable. The benefit of the push/pull cable is that is a complete item that would hopefully be plug and play for the assembly of the glove. The con is that this cable is strictly rated at 50 pounds and there may be higher friction losses through this type of cable. The benefit of the custom-made cable is that it is customizable and cheap. The inner wire could be altered of material or double-winded to increase the load capacity. There are also a variety of diameters for steel wire and Teflon tube. The con is that it may not look as visually appealing and it could complicate the production of multiple power gloves.

After doing a lot of research on motors, we were debating whether to use rotors or linear actuators. Rotors would be connected to a pulley, and the pulley would drive the cables attached to the glove. We discovered that rotors tend to be heavy and they take so much unnecessary space. Also, it would be difficult to control them. With more research done regarding motors, we found that linear servos work best for our project. Linear servos could come in many different sizes with many options regarding the force they generate. Linear servos are also easy to control and light. We would be using two different linear servos. One of which would be for gripping, and the other for releasing.

For detecting the patient's intent to grip or open his or her hand, we are focusing on electromyography (EMG). When the brain sends signals through chains of neurons to muscles, these signals are sent electrochemically. Because these signals are partly electrical in nature, they generate small electric fields, which in turn cause electric potentials that can be measured. The target muscle for a nerve impulse receives the signal as an influx of ions, and as the muscle

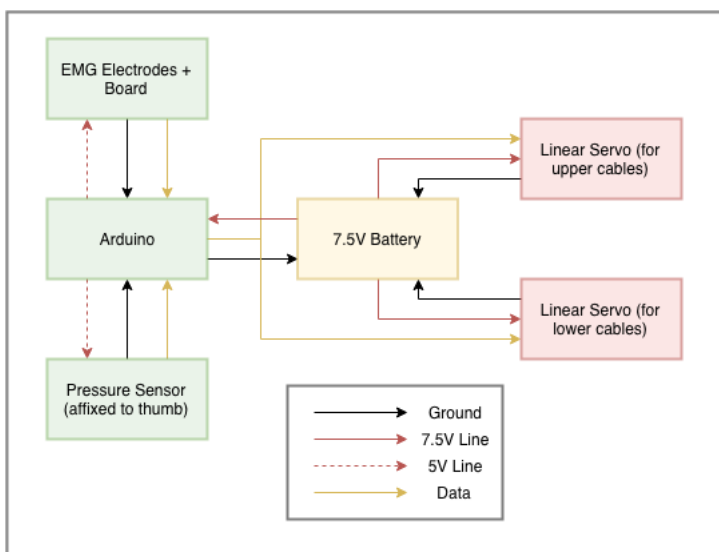


Figure 5. Circuit diagram for the device. The Arduino has an onboard 5V regulator, allowing it to take the same input voltage as the linear servos.

is stimulated more and more, the frequency and magnitude of these ion influxes increase. EMG electrodes measure the potential at the neuromuscular junction, and the variation in this potential can be used to determine when a muscle is being enervated. In our design, the patient would wear a set of three EMG electrodes – two measurement electrodes and one reference.

The electrodes are woven into a double-layered elastic band, which would fit snugly around the patient's muscle of choice. The electrodes themselves face the interior of the band and are in direct contact with the patient's skin, while the wires leading from the electrodes travel inside the two layers of the band so that the user is completely isolated from the wiring. Flexing the muscle to which the electrodes are attached would be the signal sent to the device's control system. The sensor we are using measures the raw voltage difference between the enervated muscle and the reference electrode, rectifies the signal, then integrates it to provide smoothing. It outputs the signal as voltages between 0 and 5 V. The Arduino's analog-to-digital converter reads voltages between 0 and 5 V and converts the signal to an integer from 0 to 1023, inclusive (a resolution of 4.9 mV per unit). The maximum read rate for the Arduino is 10,000 readings per second, which is more than enough time resolution for our purposes. A large portion of the signal processing required to use the EMG signal is accomplished on the sensor itself, largely precluding the need to process the signal obtained from the sensor board. A lowpass filter may need to be applied to the signal, as it can still contain high frequency noise despite being integrated on the sensor board.

A great advantage of this method is that it is very responsive. When the patient attempts to grip, the electrical signals sent from the patient's brain to their muscle of choice directly activate the control system for the glove. As long as the patient's neural pathways are intact, they will be able to activate the glove. A second advantage to this method is that the electrical components of the sensor can be completely separated from the body of the glove, which would isolate the electrical components from potential water damage. The muscle to which the electrodes attach does not have to be the muscles that normally control gripping motions. The patient could control the glove by flexing a bicep or a calf, for example. A major disadvantage of using surface EMG is that the EMG signal contains significant noise. The magnitude of the action potential at the neuromuscular junction is on the order of tens of millivolts, which can be obscured by noise. Another drawback is that the shape of the signal and calibration of the sensor will likely be dependent on the muscle to which the electrodes are placed. This could require additional signal processing and increase the difficulty of making a single glove design usable by multiple patients. The sensor is quite dependent on correct placement on the main body of the muscle, which would create additional difficulty in use for the patient.

A second option, which we are keeping in reserve as a fallback in the case that the EMG sensors are inadequate, is a simple switch. With a switch, the patient manually and directly

indicates his or her intention to close or open the glove. A switch would be quite easy to implement and would significantly reduce the technical complexity of the sensor subsystem. However, it would also require the patient to use their non-gloved hand to activate the glove, precluding a patient from using two gloves simultaneously. During the implementation phase, we will proceed with the EMG sensors, but we will have the manual switching option as a backup.

The addition of a pressure sensor provides a mechanism for feedback as well as an additional safety mechanism. In our design, a pressure sensor is affixed to the immobile thumb, and the wiring runs through the brace (prevented from contacting the patient's skin) back to the Arduino. When the glove closes, the thumb experiences the sum of the force applied to the object the glove is gripping. The pressure sensor enables a fail-safe in the case that the glove malfunctions and contracts with too much force. If the pressure reading goes above a dangerous threshold, the glove would immediately release. The pressure sensor also would enable a more sophisticated control system with feedback. Knowing exactly how much force is being applied gives a process variable that can be used to calculate error and to track a target applied force. This is discussed in greater detail with the implementation of the control system.

There were multiple options for the control scheme for this device. The first option was a simple on/off signal from the EMG sensor. That is, a tensed muscle translates to the grip slowly closing, and a relaxed muscle translates to the grip slowly opening. An example of this control scheme is shown to the right.

The linear servos have a maximum speed of 8 mm/sec, and the difference in length of cable between a fully open hand and fully closed hand was measured at 48 mm. This means the maximum speed to fully close the grip should be around 6 seconds. A problem with this first control scheme is that there is no way to easily

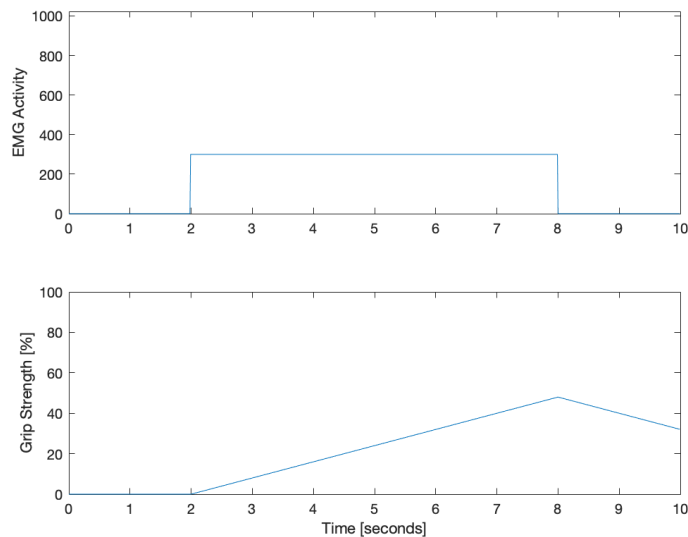


Figure 6. First control scheme - an "on" signal closes the glove, an "off" signal opens the glove

maintain a force. A sustained grip would require the patient to constantly tense and relax their muscles.

One solution to this problem is to use two EMG sensors: one for an “on” signal and the second for the “off signal.” This setup solves the main problem posed by the first solution, but it introduces undesirable challenges. This control scheme is more complicated for patient use, and it also requires additional equipment and wiring. Yet another solution is for the grip strength to be directly proportional to the activity of the EMG sensor. However, with this control scheme, maintaining force requires a constantly tensed muscle, which might tire out the patient depending on the muscle being used. A final solution is to use alternating pulses for “on” and “off” signals. The first time the EMG signal passes some threshold, the grip closes. The next signal that passes the threshold would be interpreted as an “off” signal. The main issues with this solution are that it is significantly more complicated for the user, and that noise from the EMG sensor has the potential to trigger “on” or “off” behavior in the glove unintentionally. The second issue could be solved by debouncing the signal. Ultimately, we have decided that the control scheme in

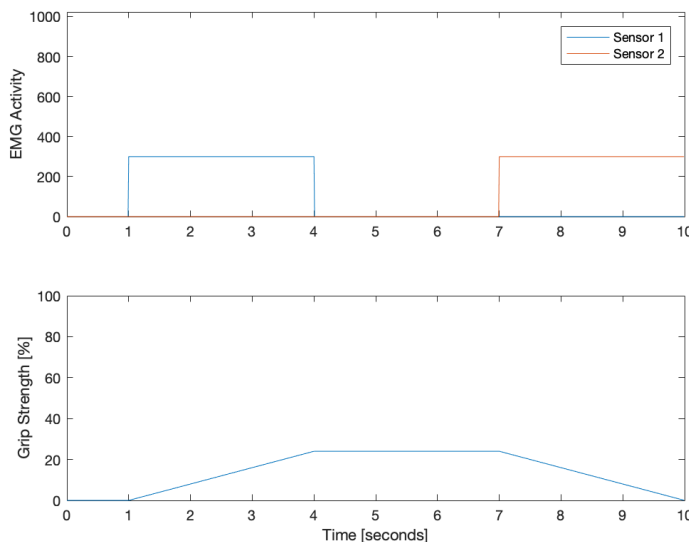


Figure 7. Second control scheme - sensor 1 closes grip, sensor 2 opens grip

which the magnitude of the applied force is directly proportional to the EMG sensor activity is the most intuitive for the user, most flexible, and has the fewest obstacles to implementation.

Once the Arduino receives the EMG signal, it must translate the signal into actuation of the linear servos. Ideally, the system will have a source of feedback (the pressure sensor affixed to the thumb) that can

drive the control of the servos. With this feedback, the control system can operate by smooth tracking of a target applied force, as it will know both the target force and real force. For this set-point control scheme, we will use a proportional-derivative (PD) controller, which excels at tracking set points in applications with no constant residual error. In the PD controller, the value

set for retraction and extension of the servo is dependent on the current error in the force being applied through the fingers and thumb. A block diagram of the system is shown below:

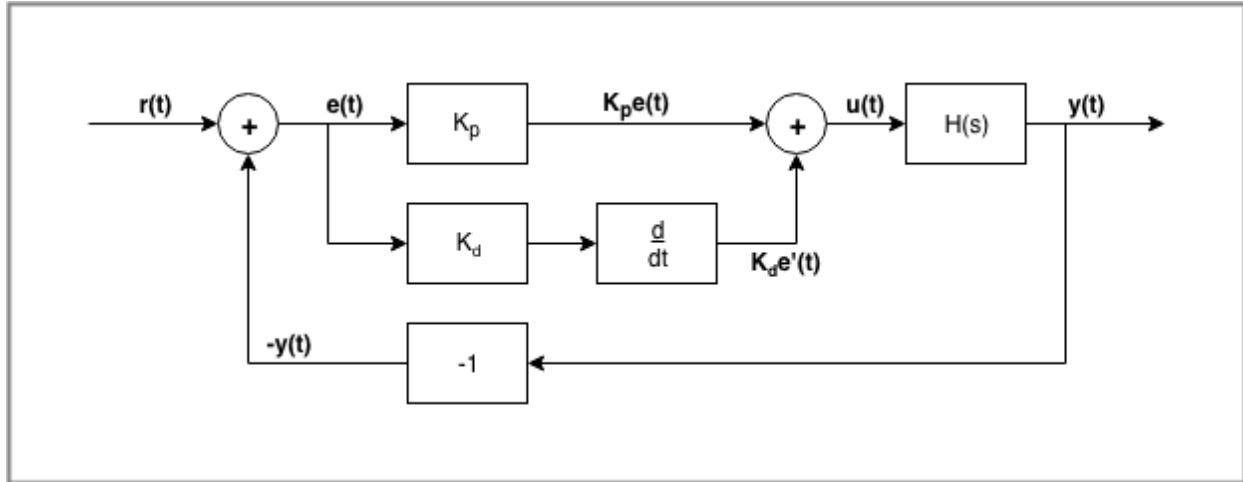


Figure 8. Block diagram of PD controller. $r(t)$ is the set point, $e(t)$ is the current error, $u(t)$ is the output of the controller, and $y(t)$ is the measured applied force. $H(s)$ represents the transfer function for the retraction/extension of the servo to the actual applied force.

The intermediate output of the system, $u(t)$, is the position to which a linear servo retracts or extends. $H(s)$ represents the transfer function for the servo position to the actual applied force. The input to the system, $r(t)$, is the set point read from the EMG sensor, while the output of the system, $y(t)$, is the applied force measured from the pressure sensor. $r(t)$ and $y(t)$ will of course be normalized to the same scale. The difference between $r(t)$ and $y(t)$, $e(t)$, is the error. The error value is what drives the calculation of $u(t)$. In a PD controller, $u(t) = K_p e(t) + K_d e'(t)$. In our case, $u(t)$ is a cumulative term. The servo position will be *updated* by a value of $u(t)$, not *set* to a value of $u(t)$. As $e(t)$ approaches zero, the update to the servo position, $u(t)$, also approaches zero. The proportional term directs the servo to decrease the error. For instance, if there is a large difference between the current applied force and the desired applied force, the motor retracts the cable quickly. The derivative term opposes fast changes in the applied force. If the error is shrinking quickly, the derivative term is negative and make the servo retract slower. This smooths the response and prevents overshoot of the target. An integral term would be necessary if there were a constant error that needed to be continually corrected by the motor. Because the servo should not move when the error is zero, there is no constant error and no need for an integral term.

Below is a simulation of the control system in MATLAB. Because the transfer function between $u(t)$ and $y(t)$ cannot be determined exactly without taking measurements with the

assembled glove, it is set to a constant multiplier in the simulation. The simulation is meant to demonstrate the function of a PD controller, not the final functionality of the glove.

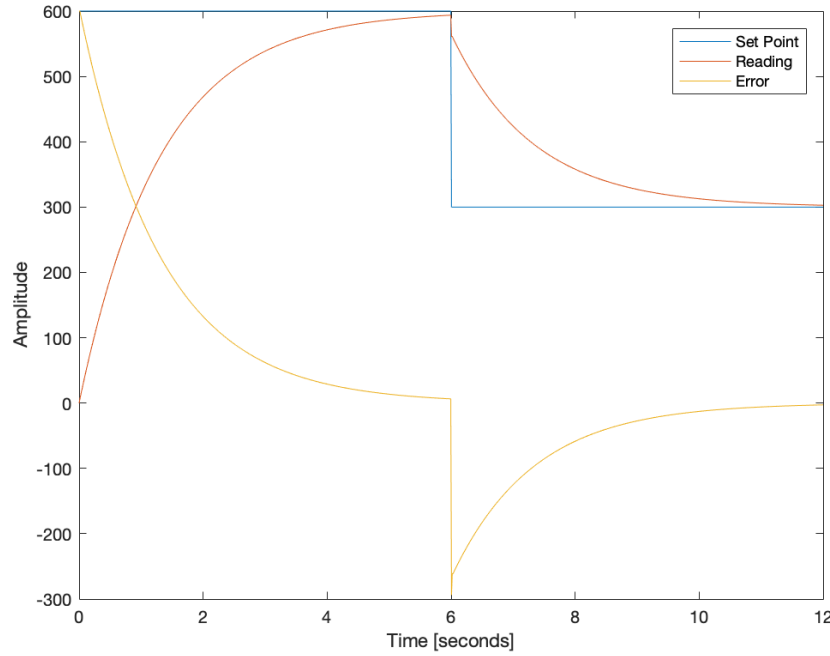


Figure 9. Model of PD controller. When the error is large, the system response is large and the same sign as the error. As the error approaches zero, the system approaches a steady state. The discontinuity at $t = 6$ is an artifact of simulating in discrete time.

Implementing this controller on a microcontroller is straightforward. The only real change is that the controller must be in discrete time rather than continuous time. Using the first difference as an approximation to the derivative, the system's intermediate output, $u[n]$, becomes $u[n] = u[n - 1] + K_p e[n] + K_d(1/T_s)(e[n] - e[n - 1])$, where T_s is the sampling rate (0.0001 seconds on an Arduino Uno). A flow diagram for the software is given below:

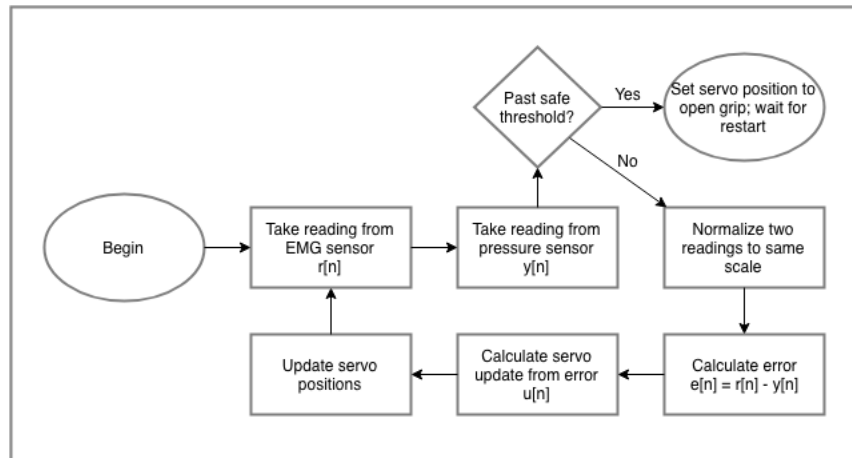


Figure 10. Flow diagram for software

Safety

When engineering a new product, safety should be the utmost priority for the engineer. Even if the product was working brilliantly, if there was a chance where the design would fail and cause problems, considerations must be made. For our design, a power grip glove, there are a lot of things to consider regarding safety. Our product consists of both electrical and mechanical components that are subjected to the possibility of failing.

One of the first objectives we agreed on when designing the product is that it should be water resistant. And we made sure that we insulate every electrical component to prevent any possible electrical shocks. Another thing we took into consideration is the amount of force that the grip could generate. We do not want the glove to produce excessive force that would be harmful for the user. For example, you do not want the user to be gripping on a doorknob so tightly that it would cause them any injuries. To avoid a problem like that from occurring, we chose a light duty linear servo that produces a small amount of force, capable of holding most objects. Moreover, the users would have the control on how much the glove should grip.

The users would be wearing the glove for a long period of time, so we made sure on choosing the right material to prevent the hands from overheating and sweating. Also, there are a lot of materials that are harmful for the skin when in contact, so that is another thing we took into consideration.

Because the glove is meant to be used on a human and because the EMG and pressure sensors are taking measurements on humans, the project must first be approved by the Institutional Review Board (IRB). The process requires human subject research training through CITI/NIH for each person involved in the project, as well as an application that will be reviewed by the IRB. We have completed the CITI/NIH training at this point, and we are currently in the process of completing the application for IRB approval.

Risk Assessment and Risk Management Plan

One significant risk in this project is a decrease in available manpower for the implementation phase of the project. Three of our members will not be continuing into the second semester, which cuts our work capacity in half. The best way to combat this known risk is through stricter scheduling and task assignment than was present this semester. Because our team will have significantly fewer people in the following semester, greater responsibility falls

on the remaining team members. Each member will need to have a clear understanding of their task responsibilities and the deadlines for completing these tasks. A prospective schedule and work plan are given in the Schedule section below.

Another source of risk is excessive technical complexity. In our current design, the functional domain with the greatest risk for excessive technical complexity is the control system. With the EMG electrodes, pressure sensor, and sophisticated control scheme, there is much room for error. Without having measured the sensors' sensitivities and resolutions, we cannot be completely certain that they will be sufficient for this application. Our contingency plan in this case is to scale down the complexity of the control system without sacrificing our primary objectives. The EMG electrodes and pressure sensor can both be replaced by a simple switch, as was discussed in the Design section. The simplest case would be a binary switch, with options for opening and closing. When the switch is in one position, the glove gradually opens to full, and when the switch is in the other position, the glove gradually closes to a maximum. There is much less risk of this control setup failing, and it still accomplishes our primary objectives. However, it does eliminate some of our secondary objectives (ease of use for the patient) and safety mechanisms, which is not ideal. On our proposed work plan, testing the sensors and control system begins as soon as all of the parts arrive. If the sensors appear to not work well enough, we will then have enough time to redesign and to incorporate a backup switch into the device.

Finally, there is risk of delay in receiving parts once they have been ordered. If there is any need for a redesign during the implementation phase, we will have to reorder parts, which will be an immense time sink. Our plan to minimize this risk is to complete all assembly and initial testing of the device by the end of the fourth week of the following semester. If we have to reorder parts, this will give us enough time to wait for the parts to arrive. Further, we have built in a four-week buffer period into our schedule to allow for unforeseen obstacles and unexpected wait times.

Schedule

The following Gantt chart displays our intended schedule for the following semester. Three of our group members will not be continuing into the second semester of Senior Design, so the remaining work is split among the three remaining members of the team. This proposed work plan is provisional, of course, as we cannot foresee the difficulties we will encounter. We

have placed ourselves on a tight schedule to keep ourselves accountable, but we have also incorporated nearly 4 weeks of buffer time at the end of the semester. The buffer time is meant to minimize risk. If we need to redesign an element of the project and reorder parts, for example, the buffer will allow us to still comfortably meet our final deadline.

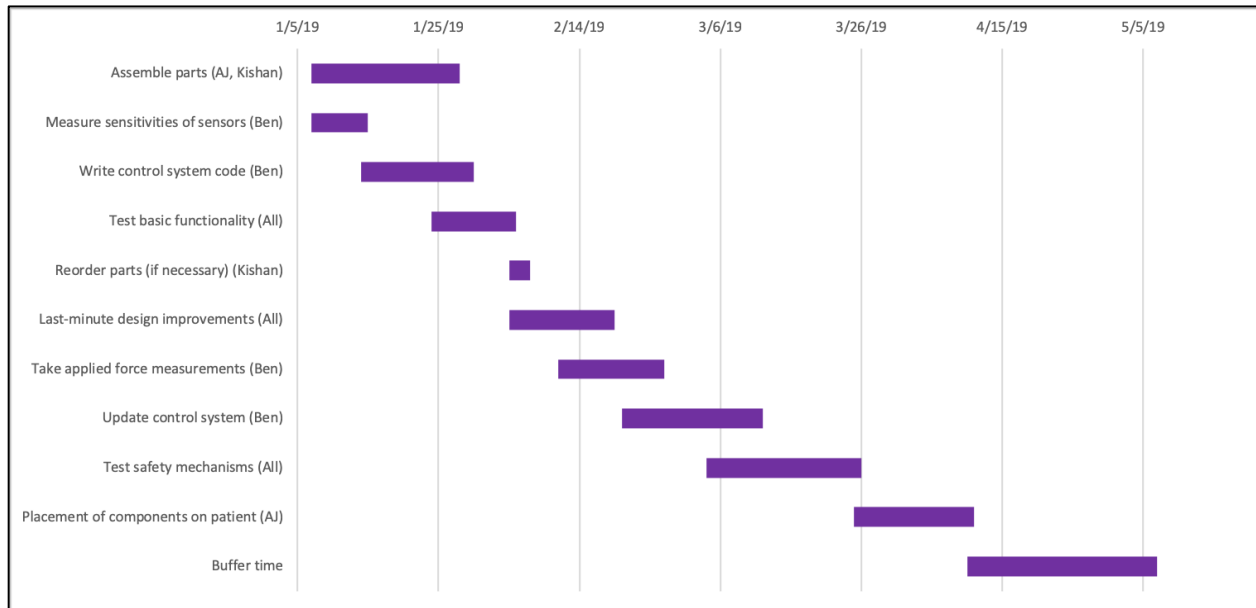


Figure 11. Work plan and schedule for the following semester

Budget

Item	Cost	Quantity	Total Cost
Uriel universal size wrist/thumb splint	\$35.00	1	\$35.00
Elastic fabric for finger guides	\$7.99	1 (2.75 sq. ft.)	\$7.99
ServoCity light duty linear servos	\$69.00	2	\$139.98
McMaster-Carr push-pull control cable	\$40.00	1	\$40.00
McMaster-Carr steel wire	\$5.00	1 ([length])	\$5.00
Arduino Uno	\$22.00	1	\$22.00
MyoWare muscle sensor	\$37.95	1	\$37.95
Sparkfun biomedical sensor pads	\$7.95	1 (10 pads)	\$7.95
[Undetermined pressure sensor]	[TBD]	[TBD]	[TBD]
[Undetermined battery]	[TBD]	[TBD]	[TBD]

Extraneous wiring, electrical connectors	\$25.00	-	\$25.00
Sewing materials	\$25.00	-	\$25.00
Contingency	\$160.00	-	\$160.00
Total	-	-	\$505.87

Greater Context

If this product were mass produced by a large company, it could have huge global impacts. In areas without access to state-of-the-art healthcare or with people who cannot afford more expensive solutions, the power glove could be an immense benefit. It could also be used for industrial purposes. Workers doing tedious work that involves gripping could use this glove to decrease the wear and strain on their tendons, increasing the quality of their work life. Stronger power gloves could even be created and used by rescue personnel to clear debris or move other objects that normally would be difficult to move. It's even possible that power gloves could be adopted by and adapted to militaries across the world. With heavy duty improvements, the power glove could be used as a weapon with immense crushing force. Although this is unlikely, the development of the ideal power glove could still have large implications for the world.

For the company, economic benefits could be immense. Due to the simple design and the inexpensive materials we chose to use, the glove would be far below the price point of other prosthetic devices. This would mean our power glove would be the main go-to solution for people with medical conditions who need to restore grip strength. From the progress made on this glove, it would also be easy to create similar prosthetic parts for other parts of the body such as the feet and arms. Assuming these are also made in a similar minimalist, low-cost fashion, the company could be the main supplier of affordable consumer prosthetics. This could potentially make the company one of the most valuable in the world. With the amount of research progress made, the company could also create luxury models of the glove with higher quality materials and sensors for a wealthier consumer market and could use these profits to offset and reduce costs even further for the mass version of the glove.

The environmental considerations for this project are minimal. None of the materials used in creating the glove are particularly toxic to the environment, and the batteries we plan to use can be recycled, but that is mainly up to the consumer who buys it. Since we are keeping materials to a minimum in the glove, less waste is involved in glove production. This makes the glove environmentally friendly.

The impact to society will also be large if the glove becomes a large-scale product. As stressed before, the glove will improve the lives of many people. In just the US, an estimated 500,000 people live with cerebral palsy, with almost 10,000 new cases each year. These gloves would help them perform useful physical tasks that could mean the difference between employment and unemployment. Development of different power prosthetics could make this improvement even more dramatic. However, this could also raise certain ethical questions. Some people might argue that this type of technology can become dangerous if not regulated properly. As a popular theme in Sci-Fi movies, exoskeletons are seen by some members of the public as weapons. However, heavy FDA regulation on prosthetics makes this problem not likely, at least not on a large scale.

If adapted on a large scale, the power glove could have many positive effects on the world. Not only would it immensely help hundreds of thousands of people, but it would set the technology in motion to develop versions of the power glove for other parts of the body. Eventually a person might be able to be completely rehabilitated. From there, the technology could go even further by finding uses in industry and the military, making dangerous tasks much safer than before.