Cybernetic Force Enhancing Smart Glove

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Executive Summary

Team Kracan, designated HEC4, is a student group based at the University of Texas at Tyler-Houston Engineering Center tasked with the design of an external assistive device in the form of a cybernetic glove. The group's design improves functionality by enhancing a user's ability to grasp, hold, and manipulate items. This is accomplished by improving the user's grip strength in a coordinated fashion with their hand motions. Applications of the glove extend to medical, sports, commercial and industrial use. As the sponsor specified, women who have strength loss, from nerve or muscle damage, due to aging, injury or illness are the initial target users. The student team, composed of six engineering seniors, has scaled the project to function and reach the desired target of 10% recovered force, within a limited budget of $1,500. Markets currently exist for a device like this and they are underserved. Future development in materials used for the glove and price reduction in assembly and construction allowed this team to standardize the product for commercial use in sports rehabilitation, nursing homes, retail environments and factories. The faculty at the Houston Engineering Center and a surgeon at Texas Tech University Health Services Center advised and reviewed the progress and made necessary adjustments when needed in cooperation with of team Kracan.

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1. Introduction

Having an adequate amount of hand strength helps a person complete daily tasks such as brushing their teeth, opening a door, or feeding themselves. Injury, illness, and aging have a negative effect on the ability to perform these tasks leading to a diminished quality of life. Assisting hand and wrist strength is critical for people to maintain quality of life and the ability to return to their full capability. Chronic functional mobility issues resulting from events and disorders like stroke or multiple sclerosis can decrease muscle strength and nerve signal propagation throughout the body. The focus of the project is to counteract strength loss in the lower arm that have damaged the nerves or muscles responsible for actuating hand movements.

There are currently several existing examples of devices to assist in rehabilitation and/or provide additive strength and support to the hand, and these broadly categorize by feedback, additive tension, and electric stimulation. However, many cannot support contraction and provides no data monitoring. The cybernetic force enhancing smart glove provides improved grip, data feedback and control. The electrodes in the cybernetic force enhancing smart glove only read muscle signals to provide the correct amount of strength to the user.

The primary purpose of the project is to create a glove that provides an additive strength system for people with low hand functionality at different stages of recovery from an illness, disease, and injury. By focusing on monitoring the muscle signals producing flexion and extension of the fingers to control servomotors, the glove assists the hand in creating additional grip force. The lightweight and biocompatible glove will assist through mechanically added force in support of user strength for grasping and manipulating tools and personal items in a functional manner. The current model is designed on aiding grip strength by 10% for women between 35 and 40 years old.

2. Requirements and Specifications

This section describes essential requirements for the device and how they applied to the prototype. The sponsor administered a set of guidelines for the design, manufacturing, and functionality of this device. After obtaining the specifications, the group found ways to apply each of them into the prototype device. Each requirement was carefully analyzed and researched to obtain the best application for it. The tables listed below demonstrate the required specifications as well as how they are incorporated into the prototype.

Table I. Project Specification

Spec	Purpose	Range	units
Sizing	Currently standardized to average female hand		
Force correction percentage	% standard range of provided additional force	≥10% of standard norm ≤ 130% of standard norm	
Force correction minimum (10% of prime standard female norm)	actual provided additional force minimum	1.3	lbf
Number of Joints	Movement allowance for hand	17	-
Degrees of Freedom	Movement allowance for finger	6	-
Weight: Glove	Mobility	<1	kg
Contact Temperature	Prevent burns and discomfort	Ambient ± 3	°C
Materials Biocompatible (not-toxic, hypoallergenic etc.)	Prevent toxicity and/or allergic reactions	-	-
Mains Powered	Provide power to device	-	-
Pressure Measurement	Measure grip and finger pressure	8	-
Interface to computer for adjustments and data reading	Calibration and usage review		
Minimum Sample Frequency	Needed to retrieve and respond to sensor data at high enough rate	2	kHz/sensor
Minimum Full Sample Frequency	Calculated frequency to encompass sensor input	26	kHz

Table II. Project specifications and their applications

	Specifications	Applications
1	Sizing	Adjustable tendon sleeves, elastic cord, TPU
2	Force correction percentage	10% of statistically accepted normal for a woman in the 35 to 40-year age range.
3	Force correction minimum	Applying a 1.3 lbf per finger
4	Number of Joints	Tendon Sleeves and their placement
5	Degrees of Freedom	Tendon Driven pulley system
6	Weight: Glove	Quantity and mass of materials,
9	Contact Temperature	Temperature Sensor
10	Materials Biocompatible (not-toxic, hypoallergenic etc.)	Nylon/spandex compression fabric
11	Rechargeable or Mains Powered	DC power supply with ground,
12	Charge time	Wall plug
13	Pressure Measurement	Ohmite FRS04BE
14	Interface to computer for adjustments and data reading	Microcontroller code and software interface
15	Minimum Sample Frequency	2khz/ sensor
16	Minimum Full Sample Frequency minimum	Currently 16MHz/13 Sensors (0.2% of processor bandwidth)

Table II provides details of how each specification was applied into the device. The application of the required specifications on this device provides the user with comfort, safety, and performance. A brief description of the purpose of each critical feature and its application on the device are listed below.

2.1 Sizing

The device is designed for to the standard size range for a woman's hand. However, parts of the device were made adjustable to allow different hand sizes to benefit. These components include an inner glove made of stretchable materials, hook and loop fastener straps to adjust tension and size and tendon sleeves (blue rings surrounding the inner glove) that can be stretched and flexed to conform to different hand sizes.

2.2 Force correction percentage

The grip strengths from a study incorporating over 32,000 people was analyzed to obtain an average standard range by gender and age [1]. The initial target for force increase was set at 10% of the calculated average for a woman at an age where her grip would be at its peak. This provided a target minimum of 1.3 lbf per finger. As muscles can be stimulated electrically to contract on average with 30% more force than when under normal mental control, the decision was made to limit the force correction to no more than 130% of the user's baseline to allow safety and control. The force correction is applied by using a servo motor with a metallic gear head capable of 12 kg/cm of torque at 7V.

2.3 Number of joints

Joint mobility is accomplished by placing tendon sleeves in proximity to every joint in each finger. As the fingers are actuated each phalange is pulled by the servos to obtain the desired grip strength. This specification is to account for the number of artificial tendon sleeves required.

2.4 Degrees of freedom

The considered degrees of freedom for the fingers represent bidirectional motion along the x and y-axis (flexion and extension). Degrees of freedom in each finger are achieved by developing a tendon-like movement system that controls each finger independently. The system consists of servomotors providing linear actuation of Kevlar cord. Attached to the fingers by artificial tendon sleeves, the force is transferred enhancing flexion ad extension motions.

2.5 Weight of glove

Taking into consideration the strength of the designated users, it is essential to make the device to be as lightweight as possible. Heavy materials and excessive components would restrict the mobility of the user. The group's goal is to minimize the components added to the device

without trading off the device's performance. The weight of the device is additionally balanced by placing the heavier components towards the upper forearm.

2.6 Materials

Using biocompatible materials for the device prevents toxicity and allergic reactions to the user. The material used for the inner lining of the glove is a breathable, nylon/spandex compression material that is biocompatible. These materials make the overall soft structure of the glove that makes skin contact with the user.

2.7 Mains of power

An important key feature for this device is its ability to provide power and remain functional for various amounts of hours. A DC power supply with the ground provides the device with the necessary power to function. This power supply provides +5V and +12V with less than 125 Watts and less than 16 Amps at a maximum draw. The power supply plugs to a wall outlet and provides the user with an unlimited amount of charge time.

2.8 Pressure measurements

The purpose of the pressure measurements is to obtain the measured grip force and pressure in each finger. The force resistors chosen can detect clear measurements of 20g-5kg of applied force, and only require a simple interface. A vital feature of the Ohmite FRSO4BE sensor is its small size, which allows it to be placed in any desired location. Eight sensors are positioned on the glove, one at the base of each finger and three in the palm area.

2.9 Interface to computer

This feature is vital for calibration purposes, as well as reviewing the performance data of the user. It allows the technician to make any necessary adjustments to the device to adjust to the

user and data reading. Connectivity of the device to a computer is achieved by the microcontroller code and software interface set into the device.

2.11 Minimum sample frequency

A minimum sample frequency is necessary to retrieve and respond to sensor data at a high enough rate. There is a required minimum standard of 1khz per sensor needed for sampling and processing within the microcontroller. The device uses a sensor with 2khz chosen to allow smoother detection of the rate of change in sampled data.

2.12 Minimum full sample frequency

This specification requires achieving a calculated frequency to encompass sensor input within the system of the device. Currently, the utilized 16MHz/13 Sensors at 2khz sampling presents a potential of approximately 615 times the necessary bandwidth. This allows a large number of the clock cycles to be devoted to calculation and data storage/transmission.

3. Constraints

Constraints in this context break down into two categories, limitations on the functioning of the device, and limits on what can be accomplished with available resources. The limitations on the device are generally centered around safety and avoiding stresses that may damage the device. The resource limitations include what can be accomplished in the allowed timeframe and budget.

The constraints for this project were derived from a combination of client interaction and research into standards (particularly safety) and methods for fulfilling the specifications. The engineering group designed a device that is being worn on the arm. The device extends from the tip of the fingers up to the mid-bicep with the upper portion being primarily for secure attachment. The device attaches to the fingers and uses servomotors to actuate them. The design helps with rehabilitation purposes as well as mobility improvement by adding a supporting force to the grip equal to at least 10% of the normalized standard. Some constraints for the design of the glove were associated with the actual fit and weight of the device. The device must be able to fit on the arm and be independently powered.

Other constraints include establishing a system of rehabilitation with the glove, meeting deadlines, and maintaining the initiated budget. A Project schedule is currently planned in Project libre. The project timeline has rigorous times for project delivery. The group members, working only part-time, makes delivering the final beta-tested prototype unlikely. A concept prototype that is not fully debugged or properly tested is possible with the constraints and timeline. A copy of the project libre schedule is found in Appendix D. The team initiated with a budget of $1,500; this set the budget for the project and prototype, meaning the team had to be extremely careful and knowledgeable of best, yet low-cost materials. The budget is limited and does not provide room for building and testing multiple models. This puts stress on material resources if materials are

lost, damaged, or are mismanaged. Also, there is a lack of high-quality equipment for testing and calibration. The technical constraints consist of the group's technical ability with components and inexperience with assembly and synchronizing components. Internal Constraints consist of members learning the fundamentals, theory, calculation, and real-world dynamics work together.

4. Standards

The following are standards with requirements that must be fulfilled to bring the final product to the market, especially in international markets. An advantage in this arena is that many of the standards are centered around material usage and the glove primarily contains materials and products that have already been approved.

Table III. List of International Standards for Medical Devices

Standard	Description
EN980A1	Graphical Symbols for use in the labeling of medical devices
EN1401	Information supplied by the manufacturer with medical devices
EN ISO 10993-1	Biological evaluation of medical devices – Part 1: Evaluation and Testing (ISO 10993-1:1997)
EN ISO 10993-9	Biological evaluation of medical devices – Part 9: Framework for identification and qualification of potential degradation products (ISO 10993-9:1999)
EN ISO 10993-10: 2002	Biological evaluation of medical devices – Part 10: Tests for irritation and sensitization (ISO 10993-10:2002)
EN ISO 10993-13	Biological evaluation of medical devices – Part 13: Identification and quantification of degradation products from polymeric medical devices (ISO 10993-12:1998)
EN ISO 10993-15	Biological evaluation of medical devices – Part 15: Identification and quantification of degradation products from metal and alloys (ISO 10993-15:2000)
EN ISO 10993-16	Biological evaluation of medical devices – Part 16: Toxicokinetic study design for degradation products leachable (ISO 10993-16:1997)
EN ISO 10993-17: 2002	Biological evaluation of medical devices – Part 17: Establishment of allowable limits for leach able substance (ISO 10993-117:2002)
BS 5736: Part 8	Evaluation of medical device for biological hazards: part 8: Method of test for skin irritation of solid medical devices
ISO 14155	Clinical investigation of medical devices
AS/NZS 3551	Technical management programs for medical devices
BS EN 868-1	Packaging materials and systems for medical devices which are to be sterilized- Part 1: General requirements and test methods
ISO 15225:2000	Nomenclature-Specification for a nomenclature system for medical devices for purposes of regulatory data exchange
IEC 60601-1-1-1:2000	Medical Device Equipment: Part 1 General Requirement For safety-Collateral standard: safety requirements for medical electrical systems
Directive 2011/65/EU	Restriction of Hazardous Substances

5. Design Detail

5.1 Mechanical Design

The mechanical design of the glove is based on the hand dimensions and biomechanics of a woman. Each material consideration meets the required specification given for this project by the sponsor. The motor system of the glove is placed near the elbow on the anterior side of the arm to create distance from the hand, distribute weight, and not interfere with the movement of the hand. On the posterior side of the glove are springs and a base to counteract the pull forces applied to each finger. The fingers connect to the motors through 3D-printed ring-shaped tendon sleeves, which also serve as a guide for the Kevlar string. Components such as the tendon sleeves, wrist sleeve, and the cover are printed from a flexible material to provide the user comfort and adjustability. Detailed mechanical drawings can be found in Appendix F.



Figure 1. Anterior side of prototype



Figure 2. Posterior side of prototype

5.2 Component Selection

The Tower Pro model MG996R are the servomotors chosen to actuate the fingers, their placement on the device are seen in Figure 1. These servomotors were chosen due to their low voltage, low current draw, light weight, and high efficiency. The motors are positioned in a circular array around the upper part of the forearm because of the limited surface area on the arm. Each motor weighs 55 grams and has a torque of 12 kg/cm at 7V. The speed of the motor is .17 seconds per 60 degrees and a total rotation time at maximum speed of 0.51 seconds at intermittent operation. These servomotors provide the required force correction.

A counteracting force to the motors in the form of extension springs is provided to assist it the user's fingers return to an unflexed position. These springs are lightweight, they have adequate size, and are durable. The dimensions for the springs are 5/16 x 1-18 x 0.023 in, and they have a safe workload of 0.33 lbs. The spring constant is 0.12 N/mm, and it has a max load of 10.6 lbf.

5.3 Design process of each component

The first step for designing was acquiring the measurements for the index finger. The thumb required a small adjustment of 0.13 mm to both the width and height, while the small finger required a decrease of 0.13 mm. Measurements were taken from a group member who will serve as a testing subject. Each phalanx was measured for height and width to create an accurate ellipse. The gathered measurements can be seen in Table IV. These measurements were then compared to an anthropologic hand measurement chart. After analyzing both the acquired measurements and the anthropologic measurements, it was determined that the subject's hand size was small. Measurements were also taken for the wrist and elbow, as well as the distance between them. The length between the wrist and elbow was 9.5 in, and the circumference measurements for the wrist and elbow can be seen in Table V. These measurements were integrated into the design dimensions of various components.

Table IV. Measurements of Index finger

Phalanx	Height (in)	Width (in)
Distal	0.4	0.527
Medial	0.527	0.656
Proximal	0.671	0.687

Table V. Measurements of wrist and elbow

Part	Circumference (in)
Wrist	2.032
Elbow	2.035

The next step was to outer glove components based on the 2D cad drawings seen in Appendix F. These drawings demonstrate the positioning of the spring plate, servo mounts, tendon sleeves on both the anterior and posterior sides of the right arm. The subassemblies and their

measurements are also represented in the drawings, as well as the placement of the different sensors. The cad drawings were rendered into a 3D format using Autodesk inventor. The manufacturing drawings for all the components can be seen in Appendix L.

5.3.1 Tendon Sleeves

The first component created using Autodesk inventor was the tendon sleeves. This glove requires a total of 14 tendon sleeves. The tendon sleeves are designed to guide the Kevlar string through the entire finger and pull the distal phalanx to provide a closed fist. Two different types of tendon sleeves are required, the distal tendon sleeve and a tendon sleeve for the other phalanxes. The distal tendon sleeve, designed for the top phalanx, has two 0.89 mm holes on the front and back for Kevlar string to attach. They are designed as a ring so they can be wrapped around the phalanx and fit most finger sizes. These tendon sleeves have guides in both the front and back for the Kevlar string. Sleeves having dimensions of 16.32 mm in length and a width of approximately 15.58 mm which is a standard size for adult women. Each sleeve was cut in half and tied together by elastic string to stretch and accommodate for different sizes. A diagram of the tendon sleeve is seen in Figure 3. The 3D rendered model of the tendon sleeve is shown in Figure 4.

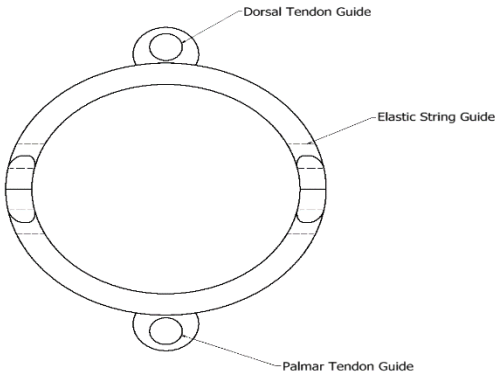


Figure 3. Diagram of Tendon Sleeve



Figure 4. Tendon Sleeve model

5.3.2 Spring Plate

The design of the plate which houses the springs is rendered from the original CAD drawings but slightly modified in size and holes for the fasteners. The purpose of the spring plate is to hold the springs in place as the fingers exert contrary force. The spring plate has an overall length of 60.23 mm, a width of 33.6 mm, and a height of 12.08 mm. There are 5 rectangular perforations on the top surface with dimensions of 6.5 x 6.5 mm to hold each fastener. This spring plate fits on the posterior side of the hand. There are two guides on the sides for Velcro straps that secure the spring plate to the glove. The spring plate diagram is seen in Figure 5, and the 3D rendered model in Figure 6.

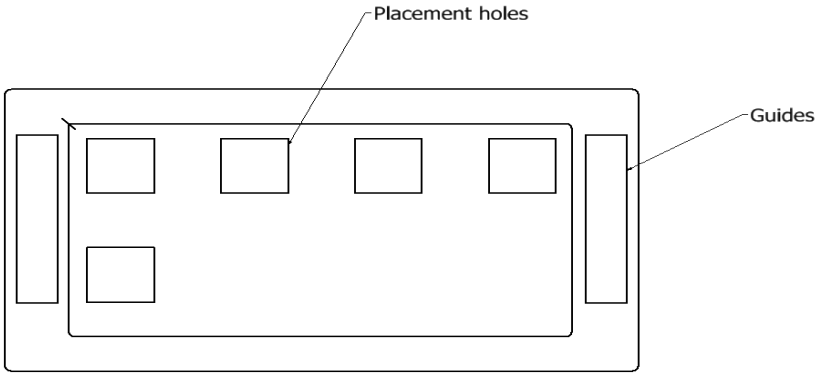


Figure 5. Diagram of Spring plate



Figure 6. Spring plate model

5.3.3 Servomotor Mounts

Servomotor mounts provide a solution to house five servomotors and allows the user to adjust to their comfort. Three distinct holders were made, two of the house two motors while the other only houses one. Each mount consists of a mounting frame for the motors and guides for Velcro straps. The framing mounts for components 1 and 2 have an offset to avoid interference from the Kevlar string, while the third mount only possesses one. The dimensions for servomotor mounts 1 and 2 are 136.4 mm x 73.32 mm x 33.5 mm, while mount 3 has dimensions of 136.4 mm x 49.32 mm x 33.5 mm. Servomotor snaps into the mounts retaining the motor in place, however

four #6 x ½” screws assist in detaining the motor in place. The three servomotor mounts connect via two Velcro straps, and the design diagram drawing is seen in Figure 7. Examples of the manufactured models are shown in Figure 8.

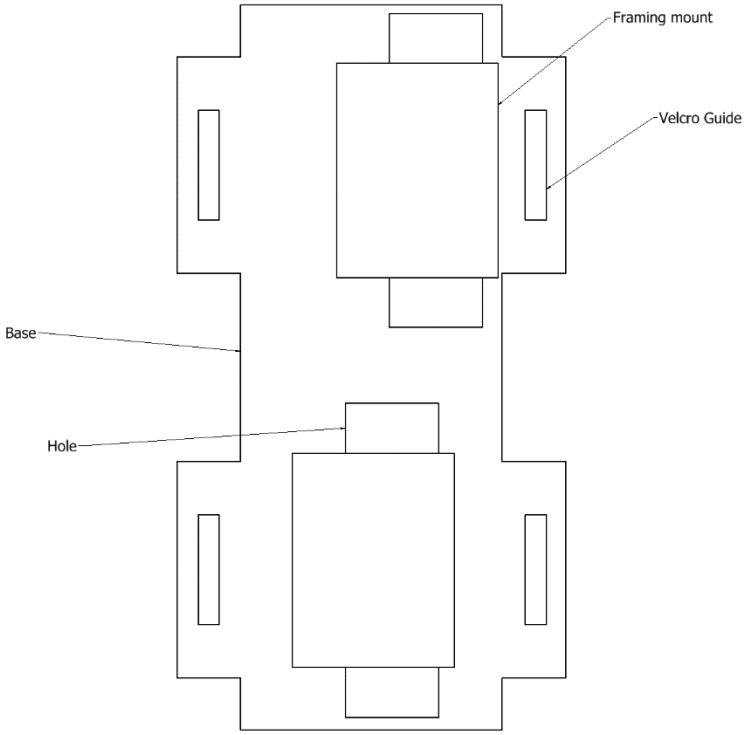


Figure 7. Diagram of Servomotor mount



Figure 8. Servomotor mount models

5.3.4 MyoWare™ Sensor Case

The purpose of the sensor case is to protect the MyoWare™ muscle sensor but not interfere with the connections to the EMGs. The case consists of two components that connect by snapping into place. The overall dimensions for the top of the case are 56.5 mm x 30 mm x 9 mm, and the bottom is 30 x 10 x 6 mm. MyoWare™ sensor case 1 has a clip of 4 mm x 5 mm x 1 mm and a catch of 3 x 3 mm. The second part of the case has a beam with dimensions of 5 mm x 2 mm x 4 mm and a hook with dimensions of 3.4 mm x 2.4 mm x 1 mm. The drawings for both MyoWare™ sensor case components are seen in Figure 9 and Figure 10.

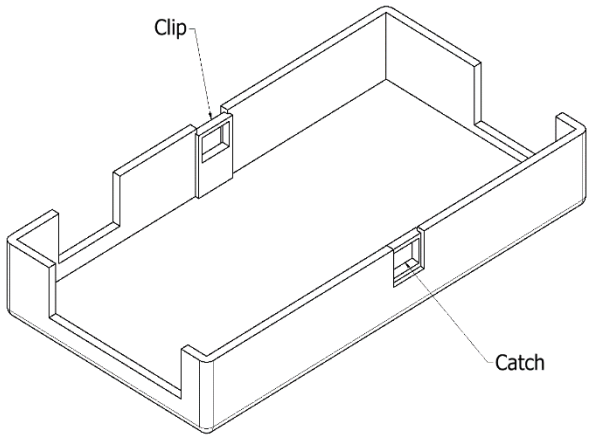


Figure 9. Diagram of *MyoWare*™ case 1

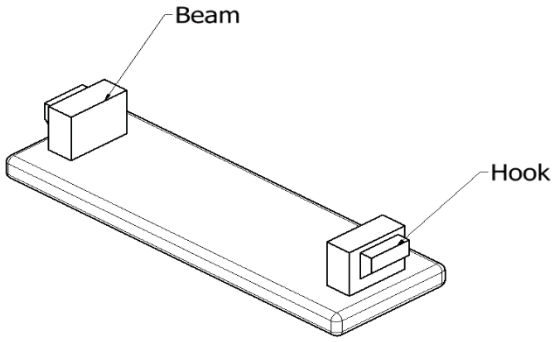


Figure 10. Diagram of MyoWare™ case 2

5.3.5 Wrist Sleeve

The purpose of the wrist sleeve is to serve as a tendon router and prevent cross-interference of the Kevlar line. The dimensions for the wrist sleeve are 76.2 mm x 92.2 mm x 9.5 mm, within the sleeve are eight pipe guides that are 8 mm x 8 mm x 1.5 mm. Each guide has an opening of 3.25 mm to house five pieces of 105 mm x 3 mm PTFE tubing. The wrist sleeve also has guides on the side for attachment of Velcro straps. Figure 8 provides a detailed diagram of the wrist sleeve.

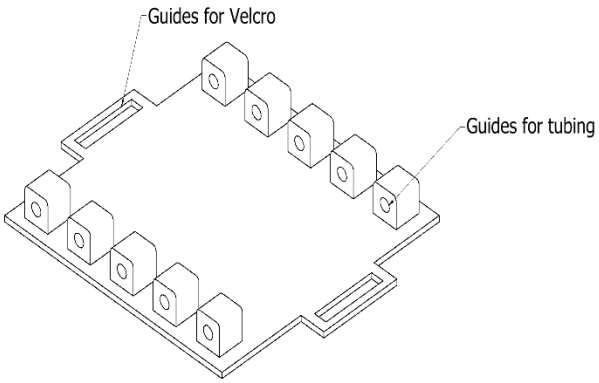


Figure 11. Diagram of Wrist Sleeve

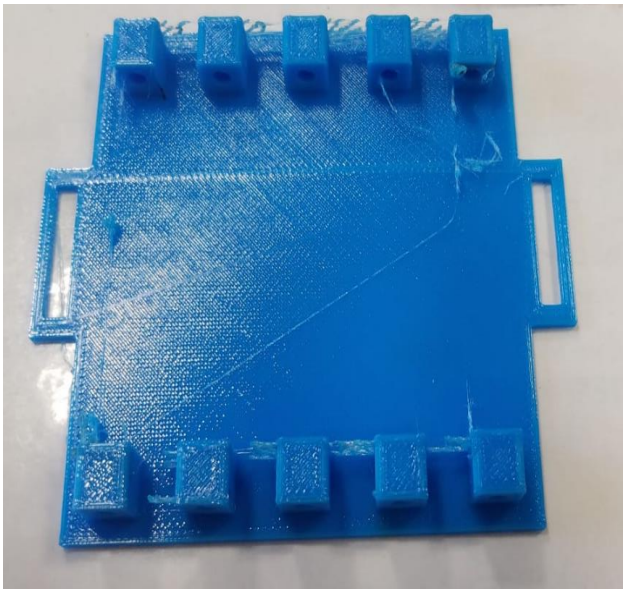


Figure 12. Wrist Sleeve model

5.3.6 Camshaft Attachment

The camshaft attachment creates the desired movement of the fingers and connects the motor to the tendon sleeves via the Kevlar string. There are three sections to the cam attachment, which are the entrance to the motor shaft, the guide for the Kevlar string, and the hole to tie off the string. The length of the servo arms of the cam, which is 0.62 in, allowed to maximize the distance that the Kevlar line pulled. The body of the cam is a 120-degree portion of a circle due to the

motors only rotating a fixed distance and this size providing the necessary arc distance for movement of the artificial tendons. A labeled diagram with the placement of these sections is seen in Figure 12.

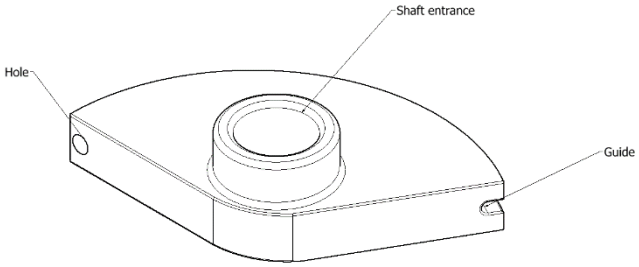


Figure 13. Diagram for Cam Attachment

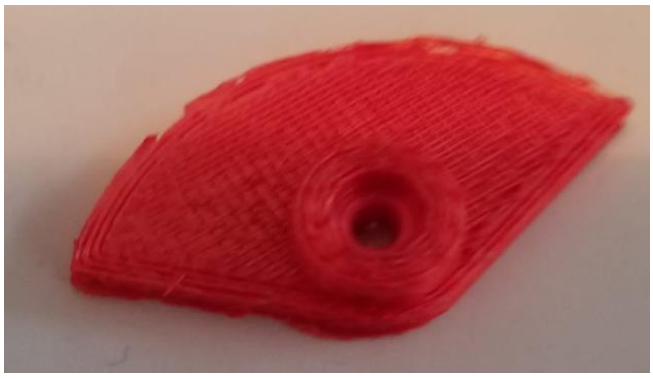


Figure 14. Cam attachment model

5.4 Fabrication details

CAD files were converted into STL files, which were then manipulated into code for the 3D printer. All components were manufactured using the Prusa i3 Mk3, as shown in Figure 15. Components were 3D printed from PLA and TPU-95A material. The outer skeleton of the glove is divided into two sections based on their placement, the glove assembly, and the arm sleeve assembly. The tendon sleeves and spring plate will be part in the glove assembly. While the servomotor holders, servomotor attachment and the microcontroller case are placed on the arm

sleeve. These components were then connected to the glove via fasteners, screws, and elastic string. Assembly drawings for each of the outer glove components are found in Appendix K.

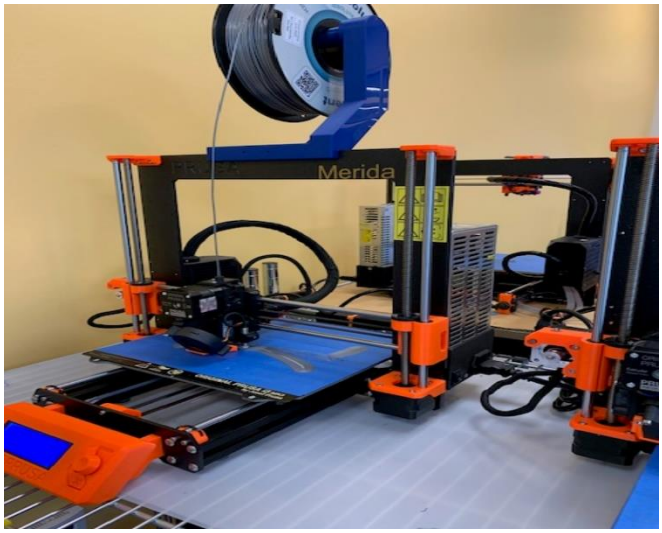


Figure 15. Prusa i3 Mk3

5.4.1 Tendon Sleeves

The tendon sleeves are made from TPU-95A material, which provides them the ability to flex. Figure 16 demonstrates a manufactured tendon sleeve and their exact placement on the glove. There were nine tendon sleeves fabricated, as well as five distal tendon sleeves for this project. The guide for assembly of the tendon sleeves are in Figure 94. Assembly requires having two 40 mm pieces of elastic string tied to the side openings of the tendon sleeves. The tendon sleeves are then placed on the medial and proximal phalanx of each finger, while the distal tendon sleeves are placed on top.



Figure 16. Assembled Tendon Sleeves

5.4.2 Spring Plate

The spring plate is fabricated from PLA material to provide endurance against counteracting forces. Components for the assembly of the spring plate entail fasteners, retainers, and compression springs. First, connect the nylon fasteners into each of the squared placement holes placed on the top of the spring plate. Then the nylon retainers are placed about ¾ into the holes provided in the nylon fasteners. The hook end of each spring is placed on the shaft of the retainer, and the retainer is fully pressed into the fastener. This is done to connect and secure the spring from the spring plate properly. A Velcro strip is then run through the guides on the sides of the spring plate to adjust to the user's comfort. The assembled spring plate is placed on the posterior side of the glove. Figure 17 provides a visual representation of the assembled spring plate. Figure 95 provides a visual guide of the component placement within the assembly.

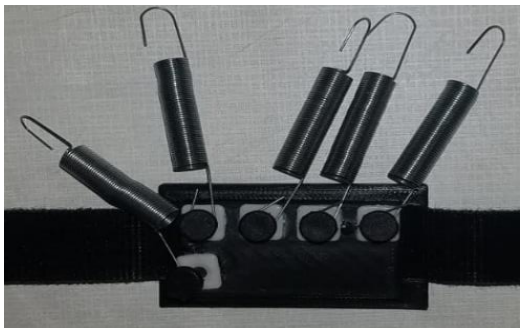


Figure 17. Assembled Spring Plate

5.4.3 Servomotor Holders

The three servomotor holders and the servomotor attachment tip are 3D printed from PLA material. Assembly of the servomotor holders consist of five different items: a servomotor, the servomotor tip attachment, the holder, eight 2.5 x 12 mm screw, and two 2.5 x 6 mm screw. First step was to connect the servomotor attachment tip to the shaft of the motor via a 2.5 x 6 mm Philips screw. Then the servomotor is mounted onto the holders and the motors' mounting flange lines up to the holes on the holder. A Phillips 2.6 x 12 connects the mounting flange of the motor and the holder. Two strips of Velcro run through the guides on all three of the holders to connect them. The visual representation of the assembled servomotor mounts is seen in Figure 18.

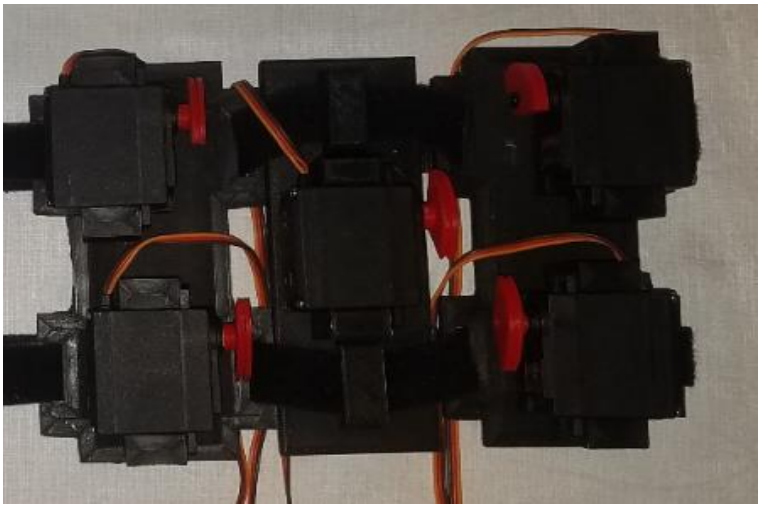


Figure 18. Assembled Servomotor Mounts

5.4.4 Wrist Sleeve

The components required to make the wrist sleeve assembly are five PTFE tubing pieces, the wrist sleeve, and a Velcro strap. The wrist sleeve is constructed from TPU-95A, which provides flexibility needed to wrap around the user's wrist. After printing the sleeve, excess t of material is removed from tubing guides to allow PTFE tubing to slide through each notch. The PTFE tubing is cut into five 10.5 cm pieces and passed through the tubing guides. A strip of hook and loop fastening material is then put through guides on the sleeve. An example of the wrist sleeve is seen in Figure 19.

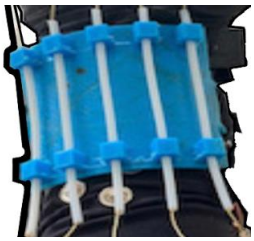


Figure 19. Assembled Wrist Sleeve

5.4.5 MyoWare™ Muscle Sensor Case

The MyoWare™ sensor case is made from PLA material to protect the sensors against any unwanted forces. The case consists of two parts that are assembled by snapping them together. A MyoWare™ muscle sensor is placed in between the case parts, and the larger pins connect with the openings placed in the front of the case. This case then connects to the snap fasteners on the compression sleeve. A total of six components are necessary for this assembly. Figure 88 shows the assembly for the MyoWare™ sensor case. Figure 20 demonstrates the assembled MyoWare™ sensor case.



Figure 20. Assembled MyoWare™ sensor case

6. System and Subsystem

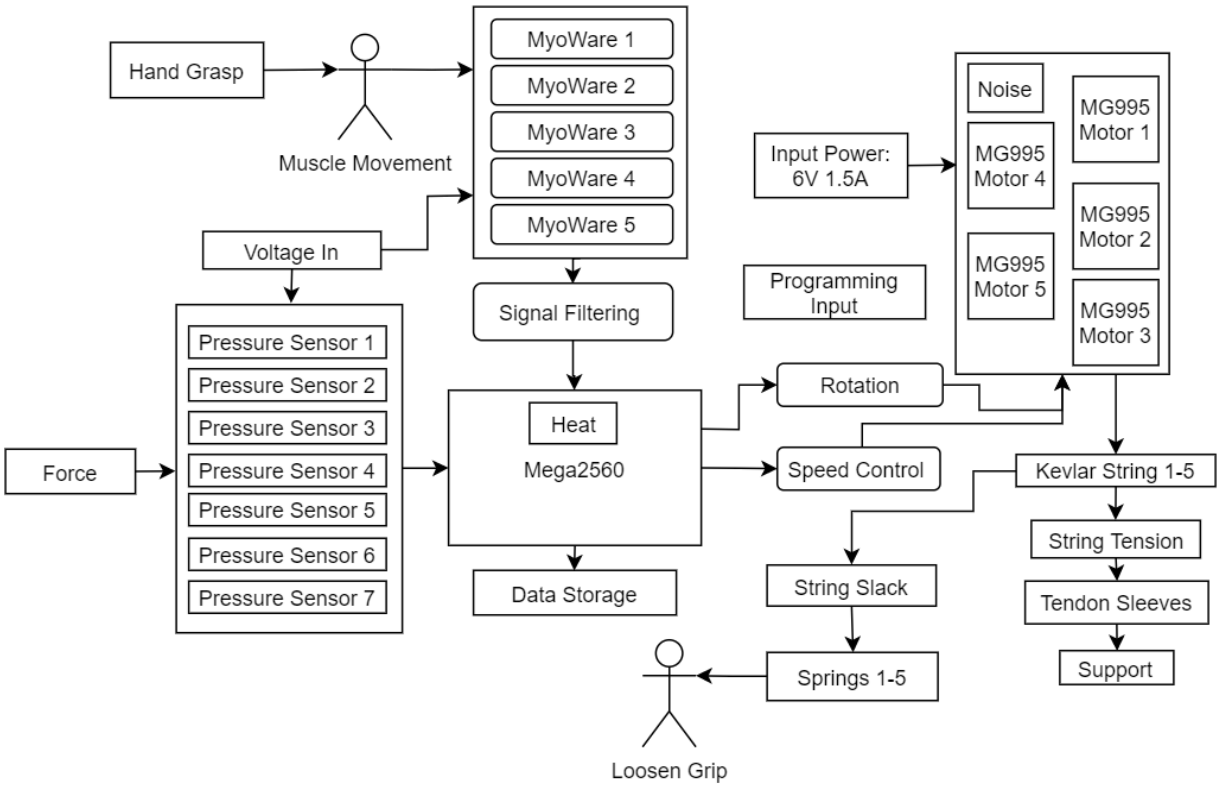


Figure 21. Glove White Box. This detailed figure expands to include the voltage, power, and other physical properties that are involved in the operation of the glove. The programming of the glove is processed through the circuit board Mega2560.

7. Calculations

The first step for acquiring the correct calculations for each finger was to understand the anatomy of the hand. A human hand is composed of five digits that include four fingers and one thumb each. The fingers and thumb account for twenty degrees of freedom, nineteen muscles, seventeen joints, and twenty bones [1]. Those four fingers are composed of three phalangeal bones, which are the distal phalanx (DP), the middle phalanx (MP), and the proximal phalanx (PP). The phalangeal bones are attached to one metacarpal bone located in the area of the palm. Between the phalangeal bones, there are three active joints known as interphalangeal joints, which contribute to the flexion and extension of the fingers. These active joints are the distal interphalangeal (DIP) joint, proximal interphalangeal (PIP) joint, and the metacarpophalangeal (MCP) joint. Unlike fingers, the thumb only has two phalangeal bones and two joints. The thumb consists of the distal phalanx (DP), the proximal phalanx (PP), the interphalangeal (IP) joint, and the metacarpophalangeal (MCP) joint.

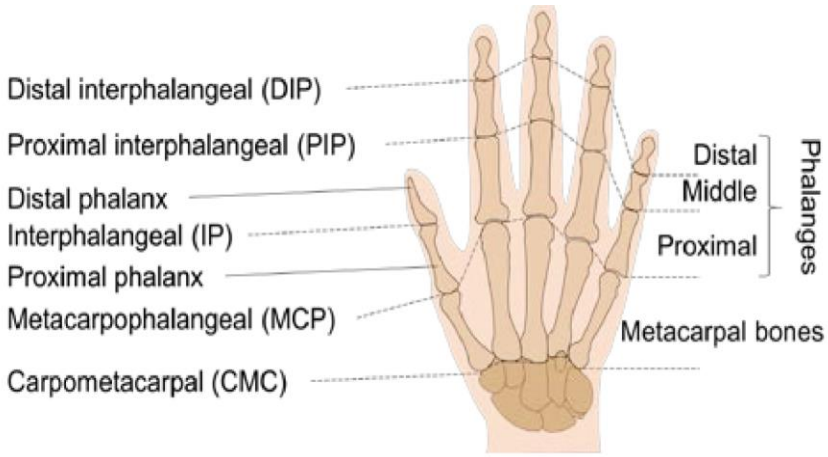


Figure 22. Schematic of hand skeleton *[2]*

For each calculation it is important to consider the actual length of the phalanx bones to provide accurate readings. Table VI provides the average lengths of phalanges and metacarpals for

both male and females of different age groups [3]. As a finger flexes or extends there is a change in the angles of each interphalangeal joint. Table VII provides a different range of degree angles for each joint during flexion position.

Table VI. Lengths of phalanges and metacarpals *[2]*

Finger	Distal Phalanx (mm)	Medial Phalanx (mm)	Proximal Phalanx (mm)	Metacarpal (mm)
Thumb	21.67 ± 1.60	-	31.57 ± 3.13	46.22 ± 3.94
Index	15.82 ± 2.26	22.38 ± 2.51	39.78 ± 4.94	68.12 ± 6.27
Middle	17.40 ± 1.85	26.33 ± 3	44.63 ± 3.81	64.6 ± 5.38
Ring	17.30 ± 2.22	25.65 ± 3.29	41.37 ± 3.87	58 ± 5.06
Small	15.96 ± 2.45	18.11 ± 2.54	32.74 ± 2.77	53.69 ± 4.36

Table VII. Change of degree angles based on finger flexion *[3]*

Finger	DIP	PIP	MP
Thumb	0-5	-	0-10
Index	10-20	30-45	45
Middle	10-20	30-45	45
Ring	10-20	30-45	45
Small	10-20	30-45	45

Kinematics analysis of the finger is performed to determine the desired movement for each finger and their calculations. This is important for finding the orientation and position of the fingertips as the hand changes into different positions. Figure 23 demonstrates the change of position of the finger during flexion. Phalangeal bones are represented in the figure as l_{DP}, l_{MP}, and l_{PP} . The change in joint angles are represented as θ_{MCP}, θ_{PIP}, and θ_{DIP}. The change of position of the fingertips is in Equation (1) and Equation (2), while Equation (3) shows the total change of angle.

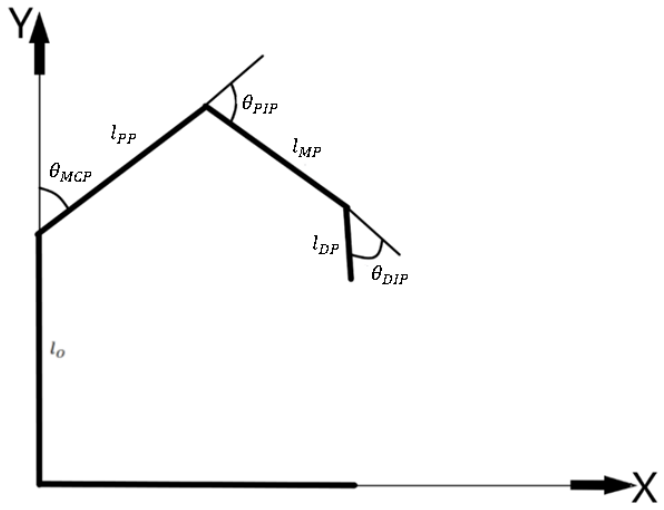


Figure 23. Finger Schematic

$$x = l_{PP}cos(\theta_{MCP}) + l_{MP}cos(\theta_{MCP} + \theta_{PIP}) + l_{DP}cos(\theta_{MCP} + \theta_{PIP} + \theta_{DIP}) \quad (1)$$

$$y = l_{PP}\,sin(\theta_{MCP}) + l_{MP}sin(\theta_{MCP} + \theta_{PIP}) + l_{DP}sin(\theta_{MCP} + \theta_{PIP} + \theta_{DIP}) \quad (2)$$

$$\phi = \theta_{MCP} + \theta_{PIP} + \theta_{DIP} \quad (3)$$

In order to determine the amount of force necessary in each phalanx it was important to find the momentum in each joint. Figure 24 and Figure 25 reveal the direction of the phalangeal and interphalangeal joints as the finger is in flexion. Each torque is identified by the force times the direction of the movement of the phalanx. The three interphalangeal joints are identified as t_{DIP} , t_{PIP} , and t_{MCP}. After solving for the torque of the joints the amount of force from each phalanx can be identified. The forces from each phalanx are labeled as F_{DP}, F_{MP}, F_{PP}. Each of the forces is then added together to determine the total amount of pulling force (F_T) needed to flex the finger.

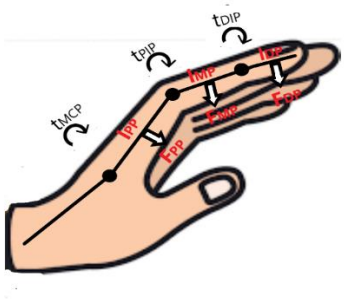


Figure 24. Side view of hand movement

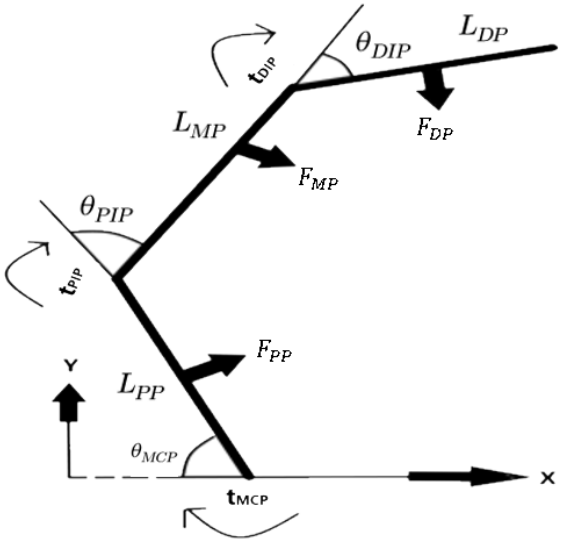


Figure 25. Finger schematic of applied torque and forces

$$\sum M_n = F_i D_i \qquad i = DP, MP, PP \qquad n = DIP, PIP, MCP \tag{4}$$

$$F_i = \frac{M_n}{D_i} \tag{5}$$

$$\sum F_T = F_{DP} + F_{MP} + F_{PP} \tag{6}$$

An artificial tendon-driven system recreates the function of tendon movement which produces a grasp and force within a hand. Kevlar wire is pulled to create a pulley system within

each of the mounts placed on the joints which provide movement to the finger into the desired position.

Much like a pulley, the force is subtracted by the counter acting force which is the wire tension. Tension on the wire (T_C) is measured by dividing the torque of the phalanx (t_n) by their length (l_n). In order to achieve the desired flexion of the finger it is necessary to find the maximum change of length in wire tendon represented by x_{max} in Equation (8). The change of length of the wire is determined by the radius of each joint (t_{MCP}, t_{PIP}, t_{DIP}) multiplied by the direction which is based on the change of angles.

$$T_C = \frac{t_n}{l_n} \tag{7}$$

$$x_{max} = \left(\left(\frac{t_{MCP}}{2} sin\left(\frac{\theta_{MCP}}{2}\right)\right) + \left(\frac{t_{PIP}}{2} sin\left(\frac{\theta_{PIP}}{2}\right)\right) + \left(\frac{t_{DIP}}{2} sin\left(\frac{\theta_{DIP}}{2}\right)\right)\right) \tag{8}$$

The counteracting force to the system is done by a spring that is attached to Kevlar wire located in the posterior part of the glove as seen in Figure 26 and Figure 27. As the finger flexes the spring provides a counterforce that regulates the pulling force. The total amount of the necessary pull force is demonstrated as F_{net}. The force of the spring (F_s) is obtained by using Hooke's law based on the maximum change of tendon length. The final force (F_f) is obtained by subtracting the pulling force by the spring force. An example of the worked-out calculations for a finger is found in Appendix C.

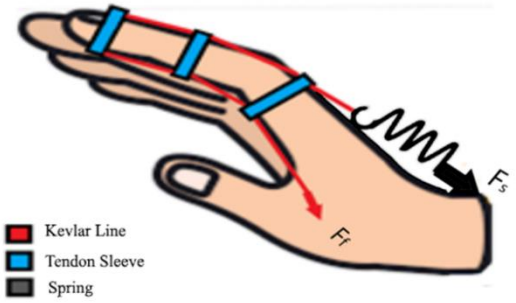


Figure 26. Spring placement

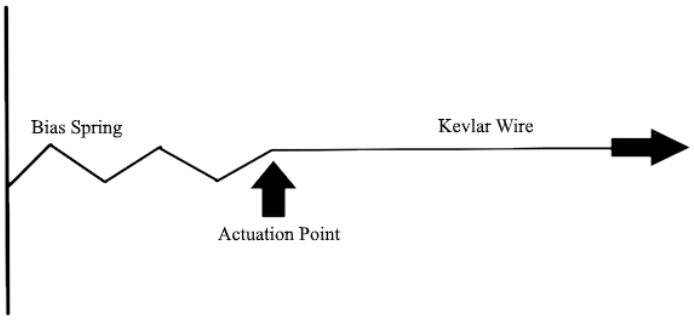


Figure 27. Spring schematic

$$F_s = k(x_{max}) \quad (9)$$

$$F_f = F_{net} - F_s \quad (10)$$

The final step for calculating the proper force necessary to pull a finger is the amount of torque in the servo motor. Equation [11] is used to calculate the essential servo motor load torque (T_s). This is obtained by multiplying the overall pull force (D_m) by the radius of the extended link placed on the shaft of the servo motor.

$$T_s = F_f * \frac{D_m}{2} \quad (11)$$

Each equation analyzed the total force of each finger, the tension of the wire, and the torque of the motors. An example of the detailed calculations can be seen in Appendix 27.2. The results are shown below in Table VIII.

Table VIII. Calculation Results

Finger	Total force of finger (N)	Torque of motor (J)	Tension of wire (N)
Thumb	6.373	0.094	2.469
Index	8.313	0.112	4.327
Middle	8.265	0.065	4.716
Ring	8.325	0.075	4.635
Small	8.045	0.109	3.482

8. Failure Mode and Effect Analysis

A failure mode and effect analysis (FMEA) was done in order to predict possible mechanical malfunctions and failures of the glove. The FMEA is divided into separate sections for the glove components for a more structured approach. This represents a unified model for safety and security cause-effect analysis. Table IX shows the ranking system used.

Table IX. Failure Mode Criteria

Component	Type of Failure	Cause	Effect	Risk Analysis	Recommended Action
Fingers	Spring	Size	Not enough force/too much force/no force	2	Place springs in spring holders when ready to begin rehabilitation process and remove after recommended time. To prevent discomfort, remove springs periodically
Fingers/wrist	Spring Holder	Placement	Spring holder must be placed closer to the wrist to allow more elasticity and resistance	1	Place spring holder just above the wrist for more comfort.
Fingers/Thumb	Breakdown	Overload	Finger breaks	5	Replace component. Use recommended load within parameter
Arm	Servomotor	Temperature	Overhearing	5	Regular maintenance and inspection. Avoid excess moisture and debris.

Hand	Glove	Tear and Wear	Glove's fabric may tear after prolonged usage	1	Use glove only for rehabilitation purposes. Avoid sharp objects and water.
Hand/Arm	Kevlar String	Size	Too long/too short	3	Measure user's length to avoid inaccurate results and/or discomfort

Table X. Ranking system

Rating	**Description**	**Criteria**
1	Very Low or None	Minor nuisance
2	Low or Minor	Product operable at reduced performance
3	Moderate or Significant	Gradual performance degradation
4	High	Loss of Function
5	Very High or Catastrophic	Safety-related catastrophic failures

The size of the springs is crucial to the glove. If the springs are too big, it may cause an uncomfortable sensation on the hand and may cause pain to the user after a certain amount of time. If the springs are too small, there is not enough force in the spring to cause the fingers to pull back to the desired position. If the spring is taken off completely, the fingers will not return to the original position. The size of the springs chosen were the best for the design. It is recommended for the user to use the same size springs and remove them after 30 minutes do prevent discomfort.

The spring holder may be placed in either below the knuckles or closer to the wrist. Based on the team's experiment, it was more comfortable to place the spring holder closer to the wrist than below the knuckles. This gives the springs more space to move.

The length of the Kevlar string must be measured and personalized per user. If the Kevlar is too long, it may cause the servomotor to delay the motion and cause inaccurate results. If the string is too small, then the finger will bend more aggressively and hurt the user.

Factor of Safety ($F.S_{Spring}$):

$$F.S._{spring} = \frac{F_{fail}}{F_{allow}} \tag{12}$$

$$F.S._{spring} = \frac{8.46lbs \times \frac{1lbs}{4.448N}}{6.653N}$$

$$F.S._{spring} = 5.656$$

9. Testing Results

This device consisted of four distinct testing procedures for the materials, components, and the functionality of the device. A tensile test was performed to observe the strength and durability of the material. The muscle sensors were tested for signal reading and interaction with the device. Electrical circuits were evaluated for feedback and interaction with the code. A grip strength test was necessary to analyze the capability of the glove for providing a minimum of 10% strength support.

9.1.1 Testing & Results for Kevlar String

Tension testing determines the reaction of the material as its subjected to a sequence of pulling forces. This method of testing is essential to determine the amount of stress a given material and shape can tolerate to judge the safety and quality of a product. With this test, there is confirmation of the material's tensile strength. This step is crucial as the string will act like a human tendon and will transfer force to the fingers to provide flexion and extension.

Procedures for testing Kevlar String:

The first step for testing is to take the measurements such as length, diameter, and cross-sectional area of the Kevlar sample. Table XI provides the measurements necessary to calculate the properties of the material. The original length and area of the string are useful to determine its elasticity and durability. The string is adequately secured to the Mecmesin MultiTest 50-I tensile and compression testing machine. Figure 88 shows the Kevlar prepared for testing. The machine applies capacity force measurements from 500N to 50kN to the material, and the testing comes to a complete halt as soon as the material fails. The data is collected and analyzed via Mecmesin Emperor software or Microsoft Excel. Materials are then collected, measured, and inspected for changes in their length. Using the acquired data, a stress-strain diagram is made to demonstrate

how much force the string can withstand before failure occurs. The stress-strain diagram is shown in Figure 93. The Kevlar can withstand all intended stress that the glove is designed to produce. Detailed results can be found in Appendix J.

Table XI. Measurements of Kevlar String

Measurements	Kevlar String
Length (mm)	152
Diameter (mm)	45
Area (mm^2)	141.4

Results for Kevlar String:

The results yielded 358,121 data points. The results were put in Excel® and sorted into 100 data points to graph. The functions used were CONCATENATE and INDIRECT with a set multiplier. The graphs and data point of the results can be found in Appendix J. Young Modulus was calculated using point 45 and 60 located in the elastic region.

Table XII. Material properties for Kevlar Line Braided .8mm

Properties	**Kevlar line**
Young Modulus (GPa)	44.642
Ultimate Strength (MPa)	1600
Yield Strength (MPa)	1150

9.1.2 Testing & Results PLA

Similarly, to the testing for the Kevlar string, the tensile compression test of the PLA is used to improve the quality of the components. Most of the housings used to attach the sensors and motors into the glove were made from PLA. This step will help determine if this material is the best way to go for the application that it will be used. This testing method was necessary since the outer structure of the device has components fabricated from PLA material. This testing method determines if these components are too sensitive to withstand any unwanted impacts.

Procedures for testing PLA:

The first step was to create an ASTMD638 sample structure made entirely out of PLA material. The measurements for this sample are shown in Table XII, and an example of the ASTMD638 are seen in Figure 89. In this project, the thickness of the sample was designed to replicate the base thickness of the servo holders. Each end of the ASTMD sample is clamped down in the Mecmesin MultiTest 50-I to commence the testing. Figure 87 shows the testing of the sample. The test ends as soon as the sample completely fractures. Data obtain from the test is then placed into a stress-strain diagram to analyze and calculate the permanent deformation or failure. Figure 91 shows the stress – strain diagram for the PLA material.

Table XIII. Measurements of PLA sample

Measurements	ASTMD638 PLA
Length (mm)	154
Width (mm)	19
Height (mm)	5
Area (mm^2)	95

Results for PLA:

The results yielded 73,845 data points. The results were put in Excel® and sorted into 100 data points to graph. The functions used were CONCATENATE and INDIRECT with a set multiplier. The data points of the results can be found in Appendix J. Young Modulus was calculated using point 34 and 51 located in the elastic region.

Table XIV. Material Properties for PLA

Properties	**PLA**
Young Modulus (MPa)	1717.2
Ultimate Strength (MPa)	34
Yield Strength (MPa)	25

9.1.3 Muscle Sensor Experiments

Properly operating myoelectric sensors form one of the core technologies for the operation of the glove. As a muscle contracts it releases an electrochemical cascade that, can be detected and translated into a measurable waveform. Several things can affect the ability to capture this signal including electrode placement, perspiration, humidity or improper contact. Proper electrode placement is likely the most important factor in determining success at signal capture. The majority of the other issues can be solved by being in a cool room and wiping the arm down with alcohol.

The commercially available MyoWare muscle sensors are the ones chosen for this project. They are accurate, inexpensive and readily available making part replacement easier if necessary. The initial work of capturing and analyzing the signal is handled in multiple fashions from simple to more complex. First the sensor is wired for power, placed on the center of a person's forearm, and monitored with a multimeter allowing visibility of a voltage change occurring in relation to muscle contractions. Second, the device is attached to an oscilloscope. This allowed the capture of a waveform set that that shows both the baseline when a muscle is not moving and the shifts that occur when muscle contract. The third Step is interfacing the sensors to a National Instruments data acquisition (NI-DAQ) board and monitoring the signals through LabView. Finally, a microcontroller was attached in the place of the data acquisition board and programmed to retrieve the signal and return information through a standard USB connection. The waves retrieved fall into a frequency range from 20 Hz to 1 kHz with a power range from 1mv to 100mv. Most useful waves exist in a narrower range from 100 Hz to 400 Hz and 20mv to 90 mv. Outside this range the signals are considered noise or an indication of

damage to the neuromuscular system. The device can still detect and record this outer range set, this is ignored for the purposes of motivating the actuators.

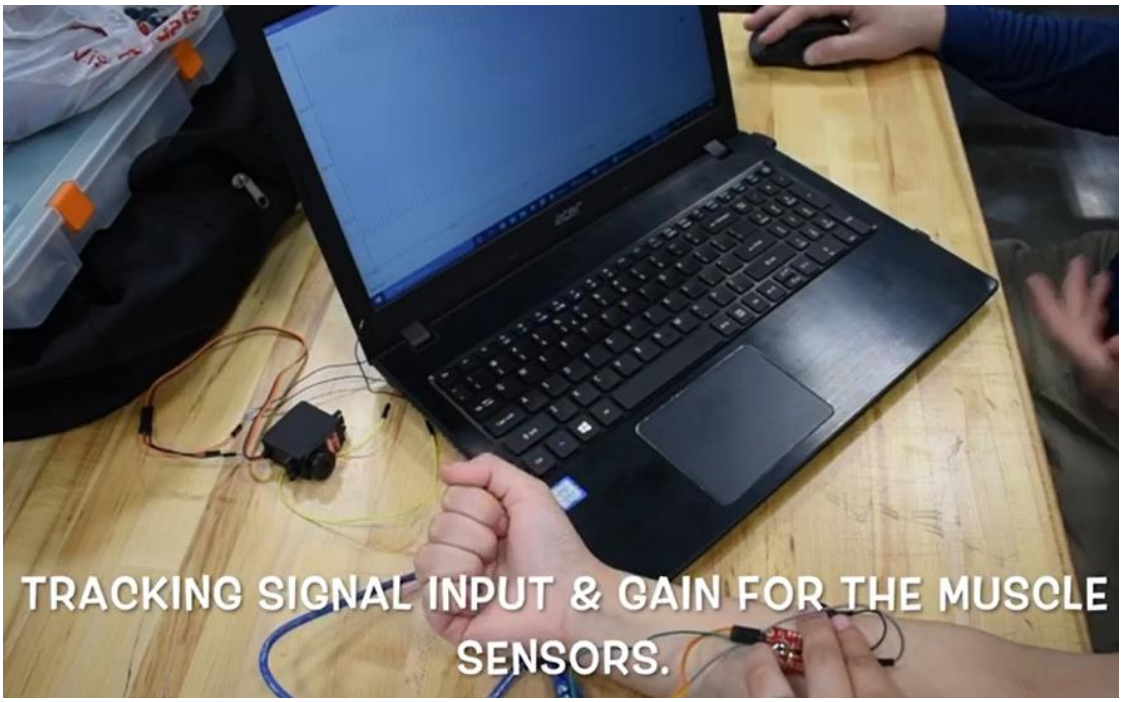


Figure 28. Tracking signal input and gain for the muscle sensors.

9.1.4 Electrical Circuit Testing:

The core needs dictating electrical circuit are safety of the user, the provision of power, and the prevention of circuit damage. Much of this testing is calculation, simulations and review of datasheets. The pressure sensors require a 10k resistor as a base offset and may need to be formed into voltage dividers to extend the range of the sensor, though this does compromise resolution. The muscle sensors needed gain adjustment to attain proper signal from the muscles and return the voltage detected at comparable levels between the sensors. The motors draw a maximum of 3 A at 15 W output and the rest of the system peaks at around 1 A using 5V. The configuration for the power feeding the motors is 7V with a maximum current draw of 2.15 A.

This being the case, the power supply for the system is the same base used for desktop computers. This allows the use of power conditioned to a level ideal for digital processing available at 5 V, 7 V and 12 V along with the surge and damage prevention built in.

9.1.5 Grip Strength Testing:

Grip strength testing is important to calculate the muscular strength of a person, or in this case the pulling force of the device. This test is fundamental since it is the foundation of the project and this information will provide data that will be incorporated with the rest of the project. The grip force determines the functionality of the device's motor system.

Procedures for testing grip:

Dynamometer was used to initially test the users grip strength without the glove. This device uses five different hand positions, progressing from a tight grip to a wider grip with the fingers and thumb spread farther apart.

To obtain the most accurate results, use the hand grip testing protocol. You will need a tester as well as a participant.

1. Have the participant sit in a chair with her elbow bent to 90 degrees.
2. The participant will then grasp the device with the gauge facing the tester, wrapping the fingers and thumb fully around the handle.
3. The tester will then instruct the participant to "squeeze, squeeze, squeeze," providing verbal cues to encourage maximum effort until the needle stops rising.
4. The tester will then read the result, and document it in pounds.
5. Turn the needle back to "zero."
6. Repeat this process on the other hand.
7. Perform three trials, and then calculate the average for each hand. [4]



Figure 29. Grip Strength test of index finger without glove showing 14.5Kg.



Figure 30. Grip Strength test of hand without glove showing 63.3Kg grip.



Figure 31. Grip Strength test hand with glove showing 69.3 kg.

Results of grip testing:

The device will generate force which surpasses the 10% minimal additive force desired in the specifications. Table XIV provides the measurements taken without the use of the device. These strength measurements are the average of three trials and serve as a comparative baseline. Table XIV demonstrates the average force for each finger with the assistance of the glove. Table XVI compares the grip force obtained with and without the glove. After testing the grip strength for each finger and the full hand, the analyzed results determined that the device exceeded the 10% additive strength force for each finger. The additional force is an extra benefit of the selected servomotors allowing closer to a 45% addition of force for the target market. The software and

controller board can be easily configured to reduce the amount of additional force provided as needed.

Table XV. Force measurements of fingers without gloves

Finger	Measurement (kg)
Thumb	13.2
Index	19.6
Middle	10.7
Ring	6.3
Small	7.1

Table XVI. Grip Force measurements

	Grip Force (kg)
Without glove	58.2
With glove	68.7

.

Table XVII. Without Glove only grip trial measurements.

Without Glove					
	Average kg	Trial 1	Trial 2	Trial 3	Standard Deviation
Thumb	13.2	13.7	12.9	12.9	0.46
Index	19.6	20.3	19.8	18.6	0.87
Middle	10.7	11.3	11	9.7	0.85
Ring	6.3	7	6	5.8	0.64
Pinky	7.1	7.7	7.6	5.9	1.01

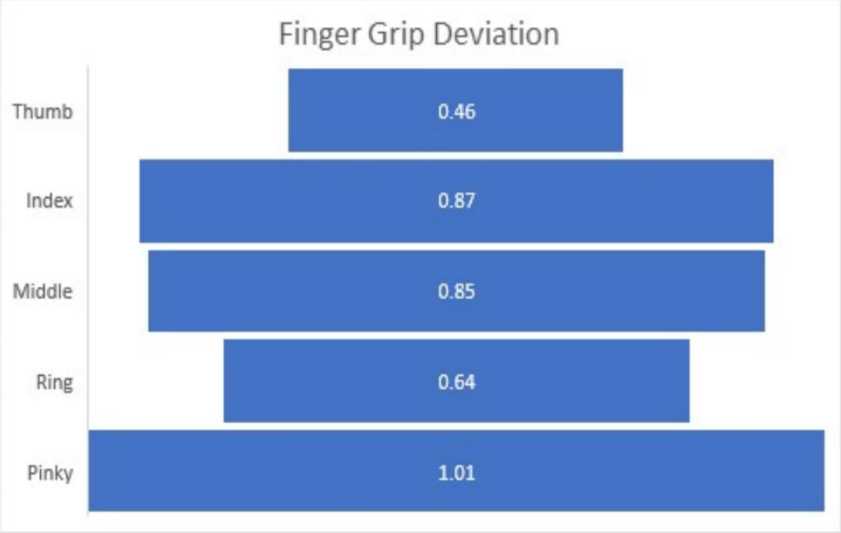


Figure 32. Finger grip without glove deviation.

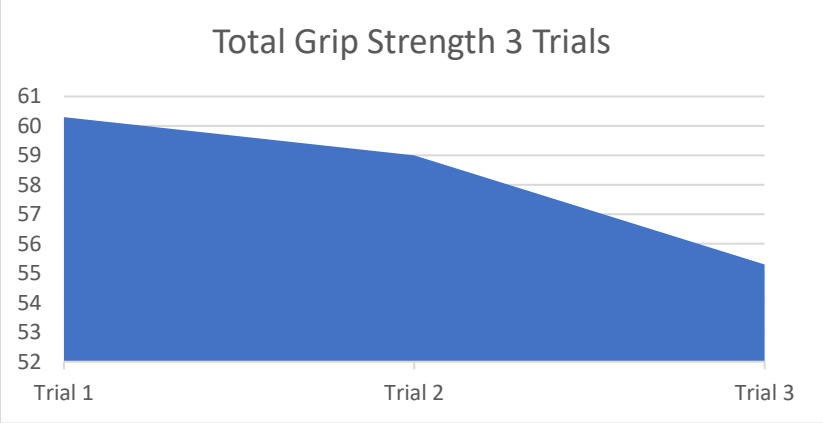


Figure 33. Total grip without glove strength from 3 Trails.

Table XVIII. Glove only grip trial measurements

With Glove					
	Average kg	Trial 1	Trial 2	Trial 3	Standard Deviation
Thumb	14.1	14.9	14.7	12.6	1.27
Index	22	23	22.4	20.5	1.31
Middle	13.2	14	13.2	12.4	0.80
Ring	8.4	8.6	8.5	8	0.32
Pinky	8.8	9.2	9.1	8.1	0.61
Grip	68.7	70.2	68.3	67.7	1.31



Figure 34. With glove finger deviation.

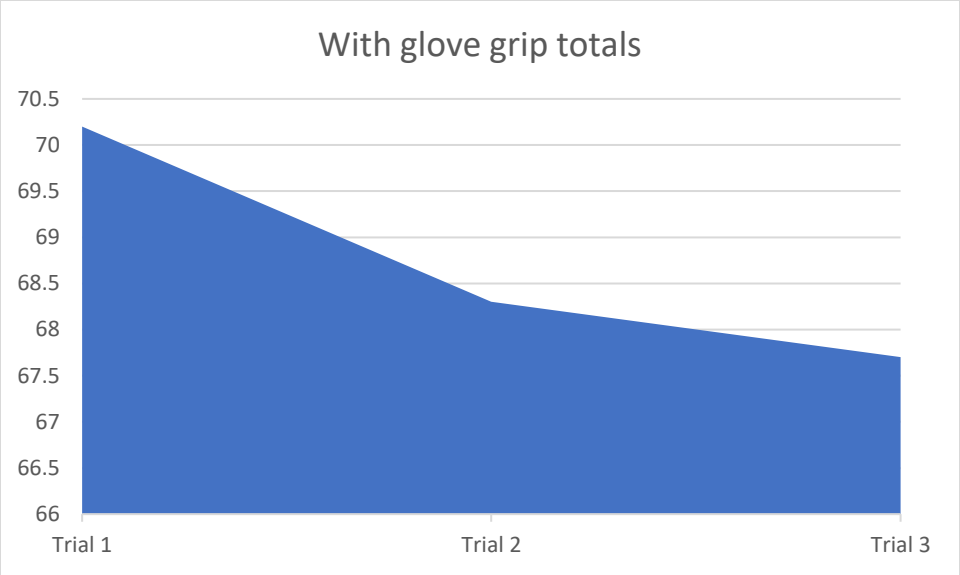


Figure 35. Total grip without glove strength from 3 Trails

10. Finite Element Analysis

10.1 Static Structural

Static structural analysis was performed to investigate the stresses generated on the spring plate and servomotor holders due to underlying forces. The 3D geometry of the spring plate and servomotors were imported from AutoDesk Inventor. The imported STP files of each component can be found in Appendix I-i. Step by step on how the team performed the analysis can be followed in the next paragraphs. Finally, the structures are analyzed for stress and deformation.

10.2 MATERIAL DETAILS

Property	Value	Unit
Material Field Variables	Table	
Isotropic Elasticity		
Derive from	Young's Modulu...	
Young's Modulus	3.01E+07	Pa
Poisson's Ratio	0.3	
Bulk Modulus	2.5083E+07	Pa
Shear Modulus	1.1577E+07	Pa

Figure 36. Details about the materials of spring plate and servomotor holders properties.

The material used is PLA. The components were printed using 100% filament, which was later discovered that 80% was better because it allows flexibility.

10.3 Meshing

When analyzing complex structures, it is important to divide the complex geometry of the structure into small parts, as the stress or the effect of force and load will not be the same on all parts of a huge and complex structure. Meshing allows you to divide the structure into a finite number of elements. Each element is analyzed for the effect of stress and deformation. The following table describes the number of nodes in the mesh and elements for each component. Appendix I-ii shows meshing images along with mesh details from the ANSYS report.

Table XIX. Nodes in mesh of each element

	Number of nodes	Elements
Spring Plate	12710	7633
Servomotor Holder 1	4124	2127
Servomotor Holder 2	4124	2119
Servomotor Holder 3	2670	1267

10.4 Boundary Conditions

Boundary conditions play an important role in the analysis. It decided the degrees of freedom of different parts of the components. The material also should be specified as rigid or flexible depending upon the type of parts. These areas are more prone to deformation and undergoes maximum stress. The following table explains locations of the two boundary conditions for each element. More details to be found in Appendix I-iii.

Table XX. Boundary condition of elements

	Fixed Support	Forces
Spring Plate	Located at the end of the spring plate where the Velcro connects.	Applied where the springs are attached and pulling back as they contract.
Servomotor Holder 1	Located at the end of the spring plate where the Velcro connects.	Applied where the servomotors are resting.
Servomotor Holder 2	Located at the end of the spring plate where the Velcro connects.	Applied where the servomotors are resting.
Servomotor Holder 3	Located at the end of the spring plate where the Velcro connects.	Applied where the servomotor is resting.

10.5 Equivalent Stress

The Von misses stress is obtained. This type of stress decided whether the structure is in a state of failure or not. It primarily defines a formula using which the stresses in different directions of the three-axis x, y and z are combined to give Von Misses stress. If the Von Misses stress is greater than the yield stress of the material, then the structure is in a condition to breakdown. Results obtained in ANSYS for equivalent stress can be found in Appendix I-iv. The maximum Von Misses stress obtained are as follow:

Table XXI. Maximum Von Misses stress of components

	Maximum Von Misses stress
Spring Plate	0.93 MPa
Servomotor Holder 1	9.509e-003 MPa
Servomotor Holder 2	9.8849e-003 MPa
Servomotor Holder 3	4.5569e-003 MPa

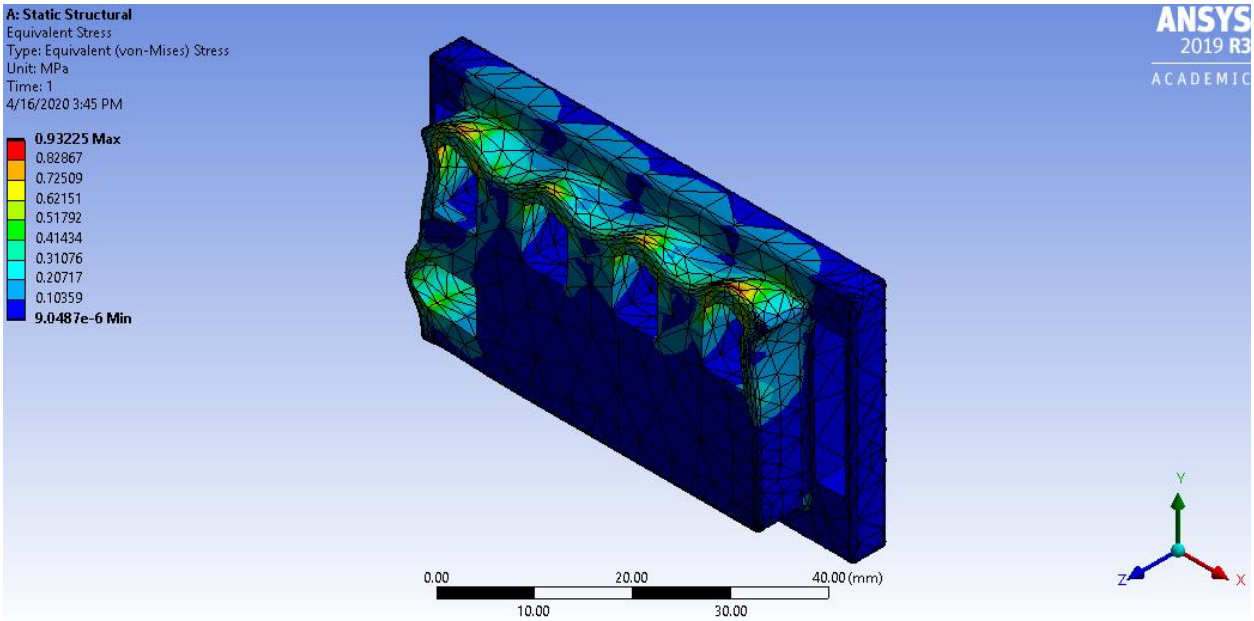


Figure 37. Simulation obtained for equivalent Von Misses Stress (spring plate)

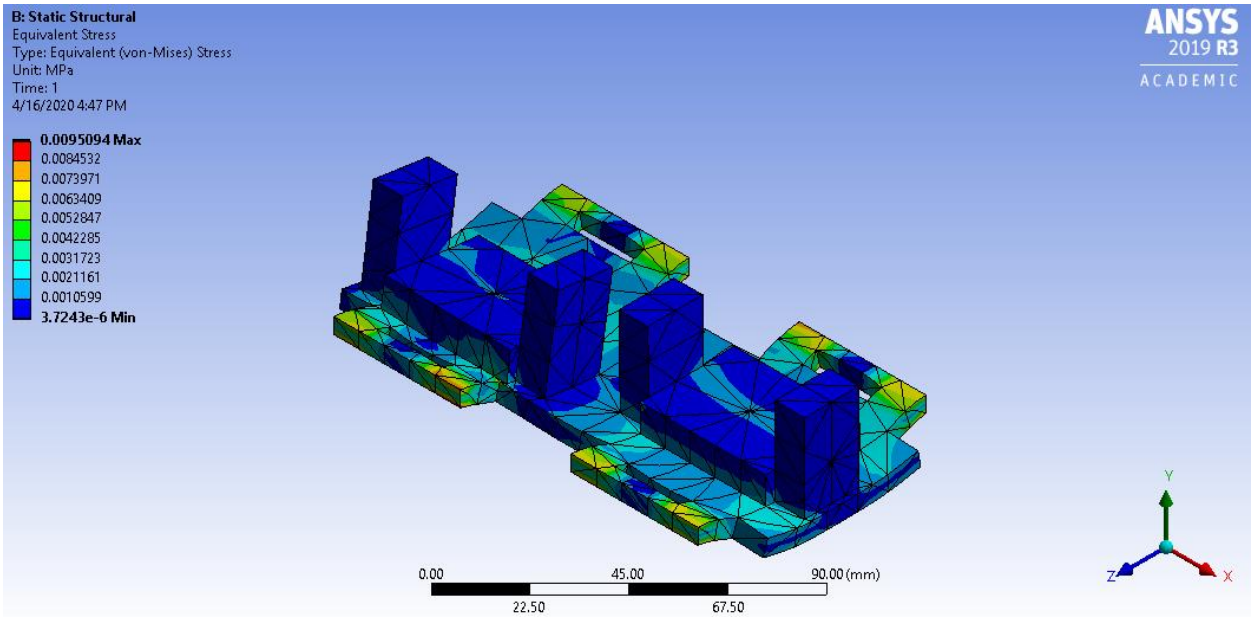


Figure 38. Simulation obtained for equivalent Von Misses Stress (servomotor holder 1)

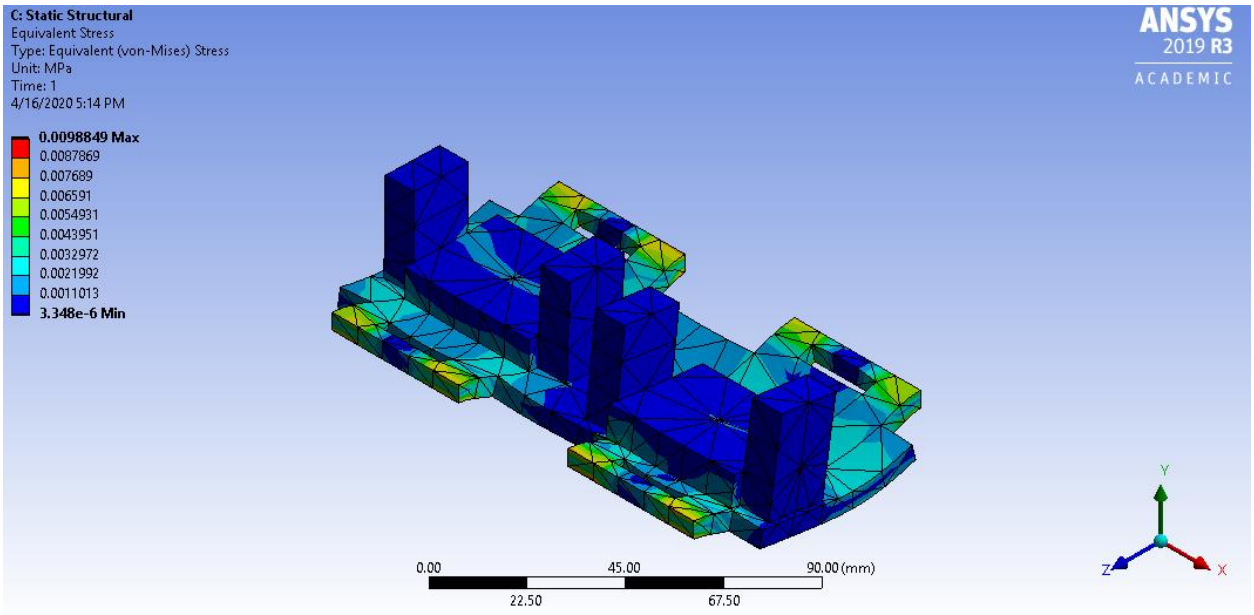


Figure 39. Simulation obtained for equivalent Von Misses Stress (servomotor holder 2)

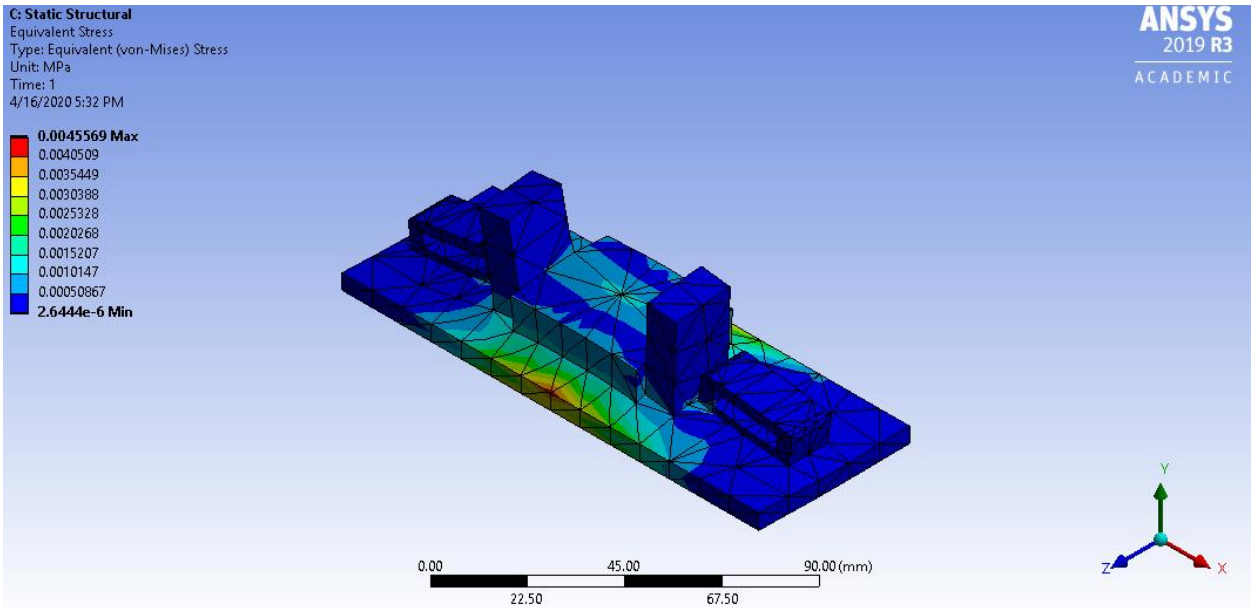


Figure 40. Simulation obtained for equivalent Von Misses Stress (servomotor holder 3)

10.6 Total Deformation

A maximum load is applied on each component and it is shown in Table XX. The elements being a hundred percent filled allows for the highest possible resistance value. Due to this, however, flexibility is very low causing plastic deformation and brittle behavior. After the maximum force is applied on the material, the element will fracture. This happens at 0.297 mm for the spring plate; 1.762e-002 mm for the servomotor holder 1; at 1.7826e-002 for the servomotor holder 2; and at 2.976e-003 mm for the servomotor holder 3.

The following formula can be used to calculate the Factor of Safety (F.S) of each component to better show the deformation. Results are shown in Table XX. A F.S. of 1 means that a structure or component will fail exactly when it reaches the design load and cannot support any additional load. Structures or components with F.S < 1 are not viable; basically, 1 is the minimum. With the equation below, a F.S. of 2 means that a component will fail at twice the design load, and so on.

$$Factor\ of\ safety = \frac{maximum\ deformation}{average\ deformation}$$

Table XXII. Results obtained after deformation analysis

	Maximum Total Deformation	Force applied	Factor of Safety
Spring Plate	0.297 mm	50 N	6.454
Servomotor Holder 1	1.762e-002 mm	0.5586 N	1.377
Servomotor Holder 2	1.7826e-002 mm	0.5586 N	1.501
Servomotor Holder 3	2.976e-003 mm	0.5586 N	2.148

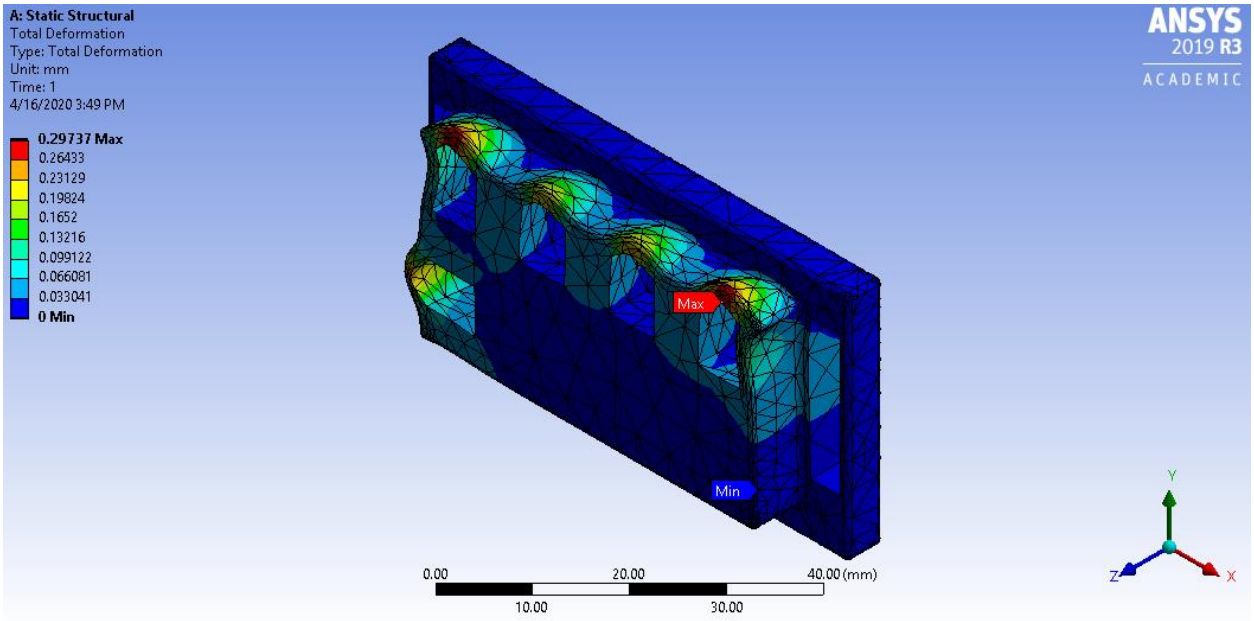


Figure 41. Simulation obtained for total deformation (spring plate)

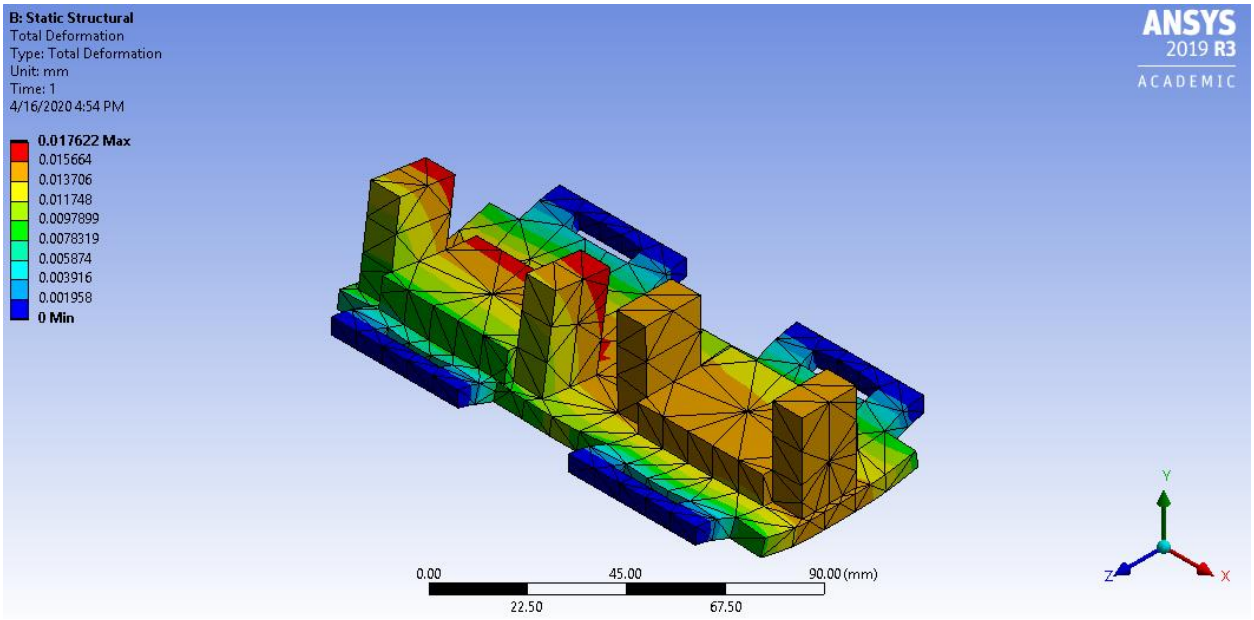


Figure 42. Simulation obtained for total deformation (servomotor holder 1)

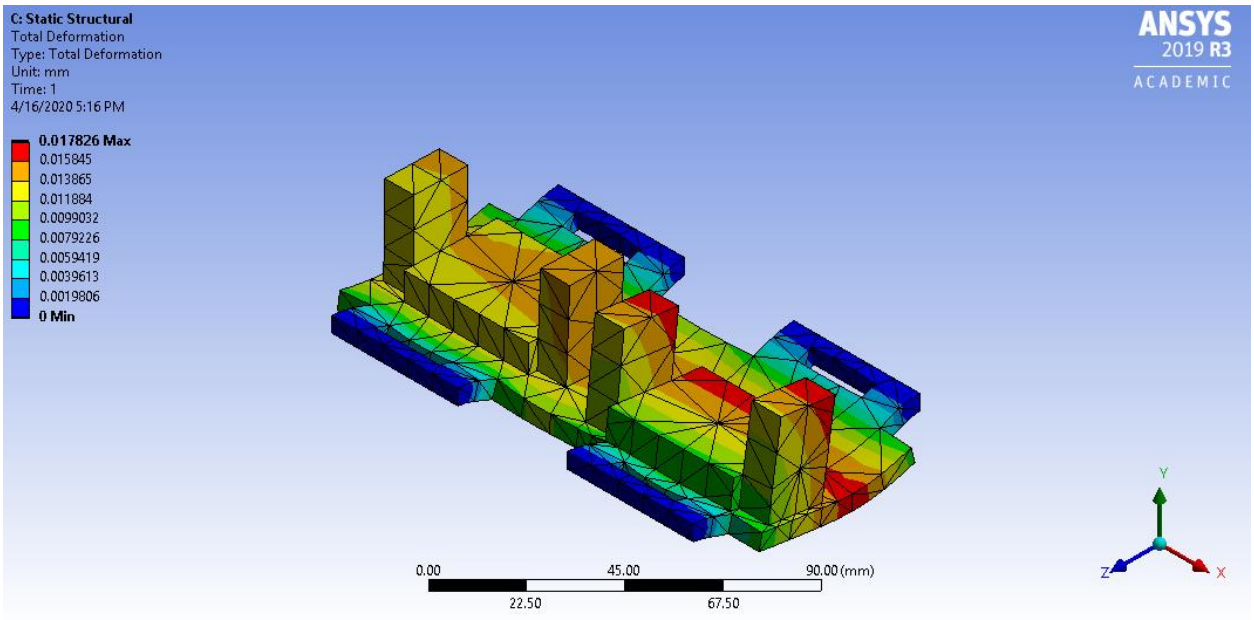


Figure 43. Simulation obtained for total deformation (servomotor holder 2)

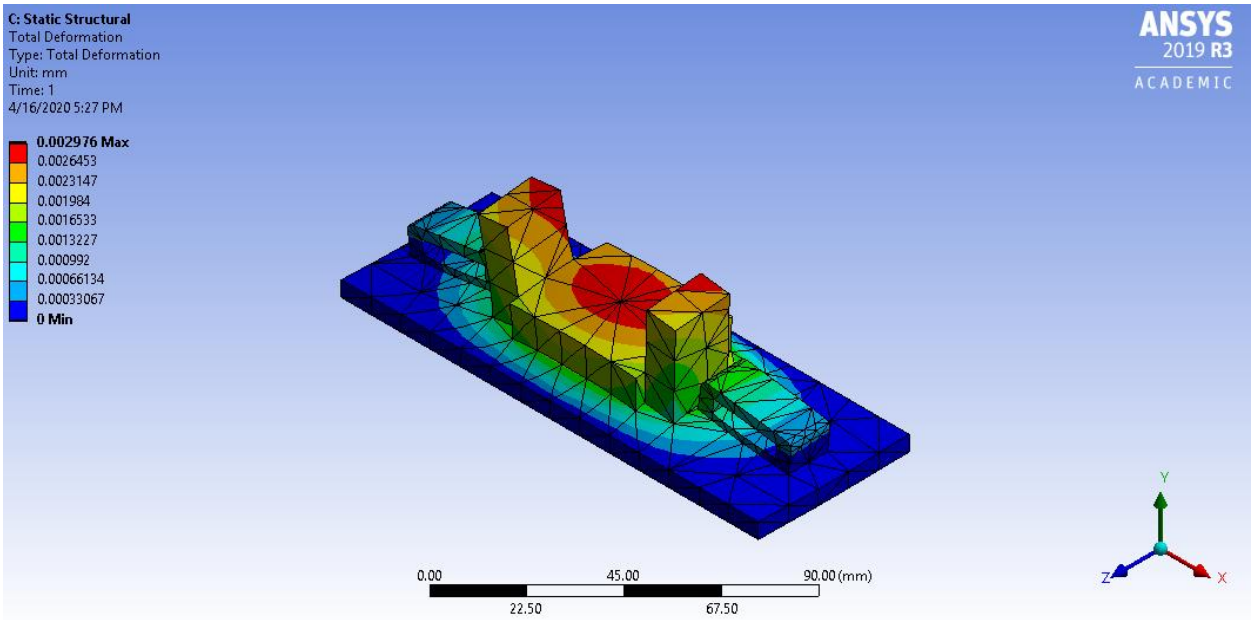


Figure 44. Simulation obtained for total deformation (servomotor holder 3)

11. Bill of Materials

Table XXIII. Display of materials required to construct the glove prototype. The materials are biocompatible and readily available in the marketplace. PLA and TPU were used for a modular fitting.

Item#	Component	Quantity	Price	Unit	Extended	Category
1	MyoWare™ Muscle Sensor	5	$37.99	unit	$189.95	ELE
2	Ohmite FSR04BE pressure sensor	7	$5.73	unit	$40.11	ELE
3	10K Resistors	7	$0.03	unit	$0.21	ELE
4	WYCTIN 60-40 Tin Lead Rosin Core Solder Wire 0.0236 inches(0.6mm)	25	$0.16	grams	$4.05	ELE
5	Gen Basic female to female jumper connectors	29	$0.08	unit	$2.18	ELE
6	ELEGOO MEGA 2560 R3 Board ATmega2560 ATMEGA16U2 + USB Cable Compatible with Arduino IDE	1	$16.98	unit	$16.98	ELE
7	28 AWG copper wire	50	$0.13	ft.	$6.73	ELE
8	McDavid Compression Arm Sleeve, Black, Medium	1	$12.64	unit	$12.64	MAT
9	PTFE Teflon tubing 10ft- 2mm ID X 4mm OD for 1.75 Filament Bowden 3D	25	$0.40	ft.	$9.99	MAT
10	"Copper Compression Full Finger Arthritis Gloves "	1	23.95	unit	$23.95	MAT
11	EZYKOO 465 Pcs Car Retainer Clips & Plastic Fasteners Kit- Bumper Fastener F3143	5	$0.20	unit	$1.00	MAT
12	Hillman 5/16 x 1-1/8 x 0.023" Extension Spring	5	$2.49	unit	$12.43	MAT
13	Hillman #6 x 1/2" Pan Phillips Metal Screw	1	$1.28	20 pcs	$1.28	MAT
14	Stretch Magic Jewelry Cord	2	$6.99	16ft	$13.98	MAT
15	Velcro 12 ft x 3/4" One-Wrap Roll	1	$1.04	ft.	$1.04	MAT
16	PLA Poly Lactic Acid	0.25	$16.99	kg	$4.25	MAT
17	TPU 95-A	0.0922	$27.99	kg	$2.58	MAT
18	Dritz 116-65 Snap Fasteners, Size 16 (7/16-Inch), Nickel	36	$0.49	unit	$17.60	MAT
19	100lb Braided 1000 ft. emma kites Kevlar Line Cord for Kite Tension Cable	25	$0.02	ft.	$0.60	MAT
20	MG996R Servo Motor	5	4.49	unit	$22.45	MEC
			Grand Total		$383.99	

12. Economic Feasibility

12.1 Cost of Materials for Prototype

The material cost to replicate the glove is approximately $389.99. A complete breakdown of the material costs for the glove is in the cost of the prototype table in the appendix. The costs were based on the unit or approximate measurement of material. This price does not include machines, tooling, or labor.

12.2 Commercialization of Prototype & Scalability

The prototype is scale is based on the ability to adjust glove parts and sizing to suit the customer. When manufacturing prototypes, it is important to consider the materials and process technology to use for each project. Looking at other manufacturers in the industry some prototypes, such as functional or engineering prototypes, must be made of the same material as the production part, other prototypes—such as those for concept or presentation—may be made of a lower-cost or faster-to-build material or process. [5] The glove uses functional materials and devices that are readily available and be produced in house to reduce overhead. The following information below will provide a brief method for commercialization and scalability for the force enhancing smart glove. Injection molding would be a sufficient substitution for the 3d printed parts once the designs and product categories have matured. 3d printing would continue to be essential for development. For the scalability, 3D printing will be calculated.

12.3 Machines

The machines involved to create many of the parts for the prototype are Ultimaker and Prusa model extrusion printers using polylactic acid (PLA) and thermoplastic polyurethane (TPU-95A). The Prusa model is more cost effective with the Prusa I3 MK3s 3d printer based at $749.

Oscilloscopes (avg price $495.00) are used for testing and conditioning the muscle sensors for testing and computers (avg. $1000) to program the circuit boards. Stress and strain test machines ($5500) are required for material development and quality control.

The standard electrical and shop tooling such as multimeters and other electrical tooling including soldering irons. Testing devices for quality control which include force gauges.

Table XXIV Display of machines required for manufacture and testing components of glove.

Machines	**Cost**	**1,000 units/month**	**10,000 units/month**
Prusa 3D Printers	$749.00	15	90
Oscilloscopes	$495.00	10	70
Stress and strain machines	$5,500.00	3	5
Computers	$1,000.00	70	300

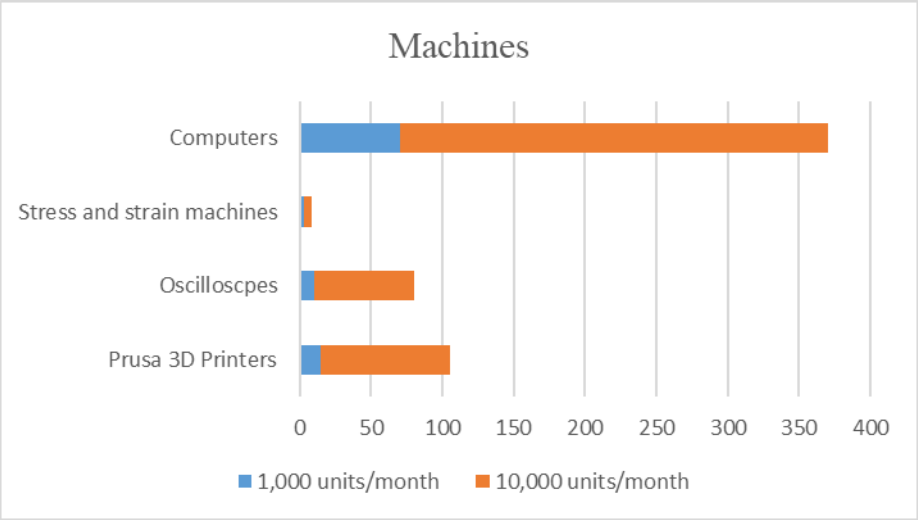


Figure 45. Display of machines required for manufacture and testing components of glove.

12.4 Materials

The materials involved are in the cost of the prototype table in appendix C. The key materials that are important to discuss scaling are the muscle sensor units, pressure sensors, motors, PLA, TPU 95-A, microfiber compression fabrics and circuit board.

Table XXV. Materials required to construct the glove prototype.

Item#	Component	Quantity	Unit
1	MyoWare™ Muscle Sensor	5	unit
2	Ohmite FSR04BE pressure sensor	7	unit
3	10K Resistors	7	unit
4	WYCTIN 60-40 Tin Lead Rosin Core Solder Wire 0.0236 inches(0.6mm)	25	grams
5	Gen Basic female to female jumper connectors	29	unit
6	ELEGOO MEGA 2560 R3 Board ATmega2560 ATMEGA16U2 + USB Cable Compatible with Arduino IDE	1	unit
7	28 AWG copper wire	50	ft.
8	McDavid Compression Arm Sleeve, Black, Medium	1	unit
9	PTFE Teflon tubing 10ft- 2mm ID X 4mm OD for 1.75 Filament Bowden 3D	25	ft.
10	Copper Compression Full Finger Arthritis Gloves	1	unit
11	EZYKOO 465 Pcs Car Retainer Clips & Plastic Fasteners Kit- Bumper Fastener F3143	5	unit
12	Hillman 5/16 x 1-1/8 x 0.023" Extension Spring	5	unit
13	Hillman #6 x 1/2" Pan Phillips Metal Screw	5	unit
14	Stretch Magic Jewelry Cord	2	16ft
15	Velcro 12 ft x 3/4" One-Wrap Roll	1	ft.
16	PLA Poly Lactic Acid	0.25	kg
17	TPU 95-A	0.0922	kg
18	Dritz 116-65 Snap Fasteners, Size 16 (7/16-Inch), Nickel	36	unit
19	100lb Braided 1000 ft. emma kites Kevlar Line Cord for Kite Tension Cable	25	ft.
20	MG996R Servo Motor	5	unit

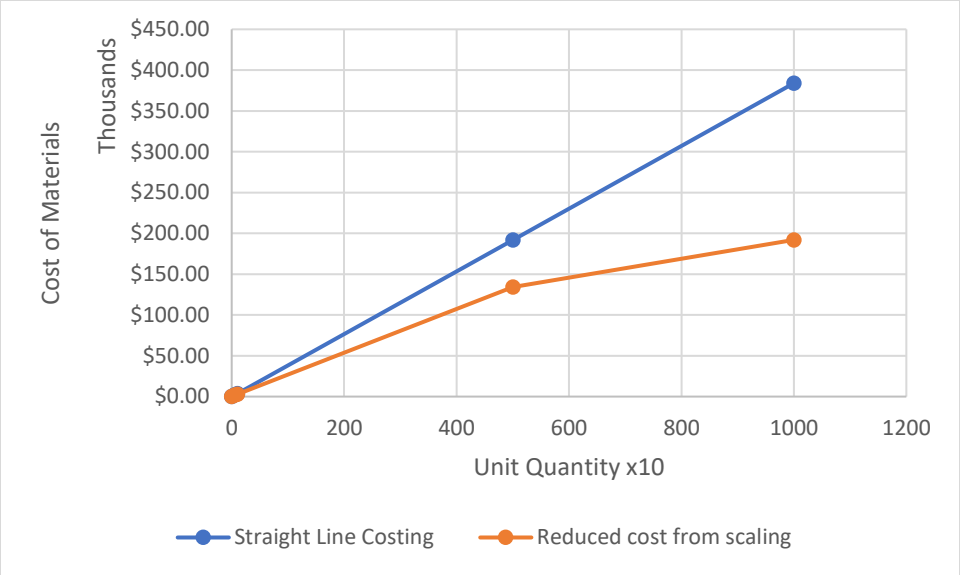


Figure 46. Line graph represents material costs when scaling. The cost of manufacture shows a reduction in cost with increase in quantity.

The increase in quantity displays a large decrease in the overall costs of production costs for materials. The table below is an extension of the Figure 2-line graph.

Table XXVI. Display of material cost when scaling. The price structure is based on standard price reduction with a 50% reduction at 10,000 units.

Quantity	Straight Line Costing	Reduced cost from scaling
1	$383.99	$383.99
5	$1,919.93	$1,727.94
10	$3,839.86	$3,071.89
500	$191,992.96	$134,395.07
1000	$383,985.93	$191,992.96

12.5 Labor

Standard labor pricing for technicians are on average $19.50 an hour and assemblers are on average $13.00 an hour and design engineers are on average $37.00 an hour and office staff average $22.

Table XXVII. Manufacture process time for a single glove.

Task	Time (hr)
Inner glove material cutting/sewing with sensor pockets	3
3d printing parts	24
Testing components	4
Electrical assembly	3
Mechanical assembly	3
Total	37

Table XXVIII. Average wages for manufacturing related workers.

Position	Wage (hr)
Office Staff	$22.00
Engineer	$37.00
Assembler	$13.00
Technicians	$19.50

Table XXIX. Production and manufacturing staff count based on 1000 units a month and 10,000.

Position	1000 units/month	10,000 units/month
Technicians	20	100
Design Engineers	10	25
Assemblers	50	250
Office	20	100

12.6 Facilities

The production and office building need to have standard power and conventional production and office areas. The production area must comply with safety regulations and quality testing area also need special paperwork and documentation.

12.7 Technical Feasibility

In technical feasibility the following issues are taken into consideration.

- *Whether the required technology is available or not*
- *Whether the required resources are available -*

  - Manpower- programmers, testers & debuggers

  - Software and hardware

The following skills and components are required for teams in order to complete this glove project.

Knowledge Base(s):

Mechanical: Force, Torque, Stress/Strain, Angle calculations, AutoCAD and inventor design and other mechanical abilities and requirements that undergraduate mechanical engineering students can complete. Mechanical calculations derived from Mathcad for the glove are in appendix, which show that glove mechanical properties are feasible with selected components.

Electrical: coding, electrical assembly, and fundamental circuit elements and microprocessor knowledge that undergraduate electrical engineers on team can complete.

Material: biological compatible materials and components that require students to process medical grade materials. Rheological analysis and safety requirements including thermal, force and electrostatic discharge properties.

12.8 Industry Specific Feasibility

For any system if the expected benefits equal or exceed the expected costs, the system can be judged to be economically feasible. In economic feasibility, cost benefit analysis is done in which expected costs and benefits are evaluated. Economic analysis is used for evaluating the effectiveness of the proposed system.

In economic feasibility, the most important is cost-benefit analysis. As the name suggests, it is an analysis of the costs to be incurred in the system and benefits derivable out of the system.

The glove provides strength due to fatigue, age, and nerve damage. Decreased alertness from worker fatigue has been a contributing factor in: [6]

- Industrial disasters such as the 2005 Texas City BP oil refinery explosion, the 2009 Colgan Air Crash, the explosion of the space shuttle Challenger and the nuclear accidents at Chernobyl and Three Mile Island.
- Increased sleep problems and risk for injury [7] among full-time employees in relation to the number of hours worked per week.
- Errors in patient care, increased needlesticks and exposure to blood and other body fluids and increased occupational injuries among healthcare workers.
- Direct or indirect links to increased costs [8] from lost productivity, increased injury and illness costs, increased time off the job due to illness and increased workers' compensation costs.
- An estimated annual cost of $136.4 billion from fatigue-related, health-related lost productive work time to employers. [9]

The glove has potential to aid and assist physical therapy. The current market shows that the glove can have a profitable segment in the rehabilitation industry. Physical therapy accounts for an estimated $26.6 billion, or approximately 90%, of all outpatient rehabilitation spending [6]. Expanding patient population that provides favorable tailwinds for products like the glove:

- Aging U.S. population
- Unhealthy youth lifestyle trends

- Growth in employment
- Increasing penetration of physical therapy services

New government regulations (e.g., the PPACA) increasing patient access to physical therapy

Outpatient rehabilitation is significantly less costly than surgery or hospitalization, but with similar clinical effectiveness

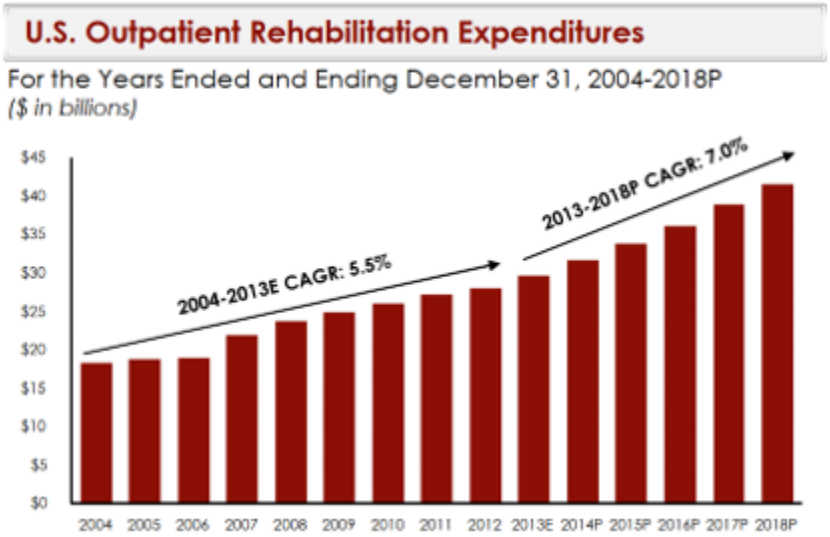


Figure 47. U.S outpatient Rehabilitation Chart *[10]*

Material cost for the rough prototype are current $1500 for materials, not including software, labor, and other development costs. Evaluation of scalability and mass production will depend on results from completed prototype.

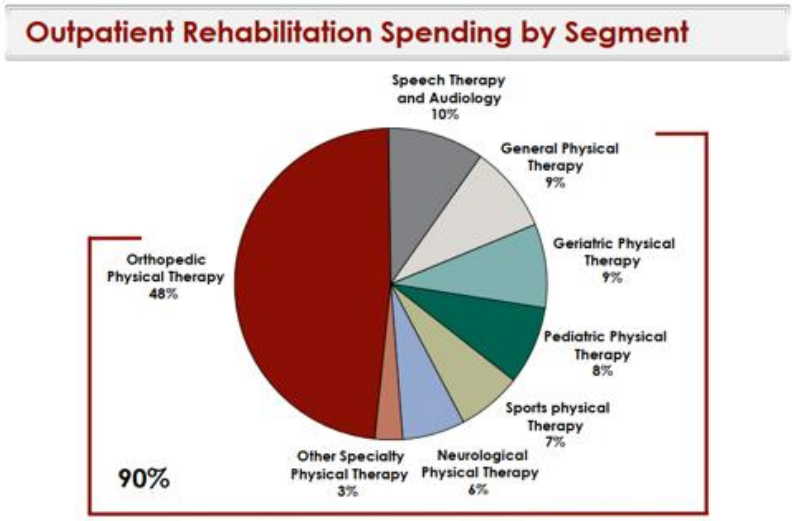


Figure 48. Industry segments for therapy *[10]*

The overall benefit of the glove will enable a personal tool that helps user's complete tasks with endurance. The customization and programming for future versions are appealing for industrial, military and sports applications.

More Benefit(s) in this market are:

- Outlook for reimbursement
    - Due to the cost saving and effectiveness of outpatient rehabilitation
    - Medicare/Medicaid reimbursement is governed by the Medicare Physician Fee Schedule.
        - This enables users to quickly access and acquire medicine and assisting devices.

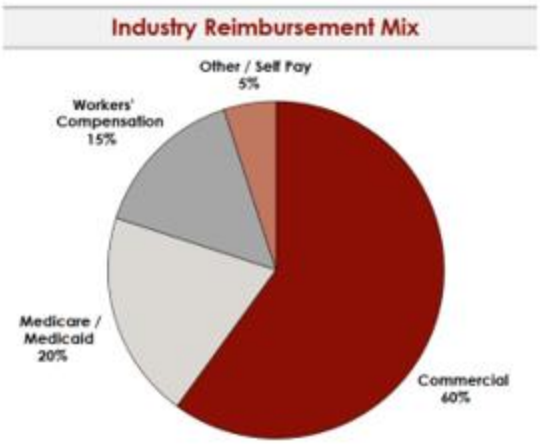


Figure 49. Industry Reimbursement Mix *[10]*

13. Flow Charts of Operation

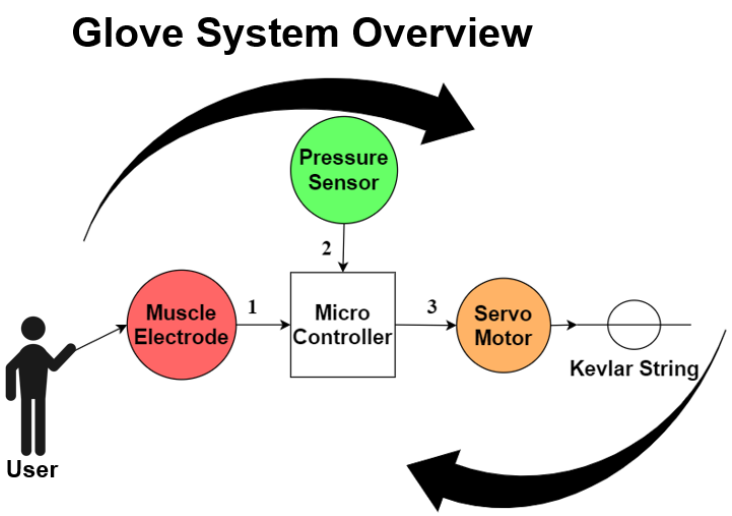


Figure 50. Glove system overview. The user muscle cells stimulate the muscle electrode. The microcontroller processes that muscle signal data while getting active data from the pressure sensors to actuate a servo motor with Kevlar string.

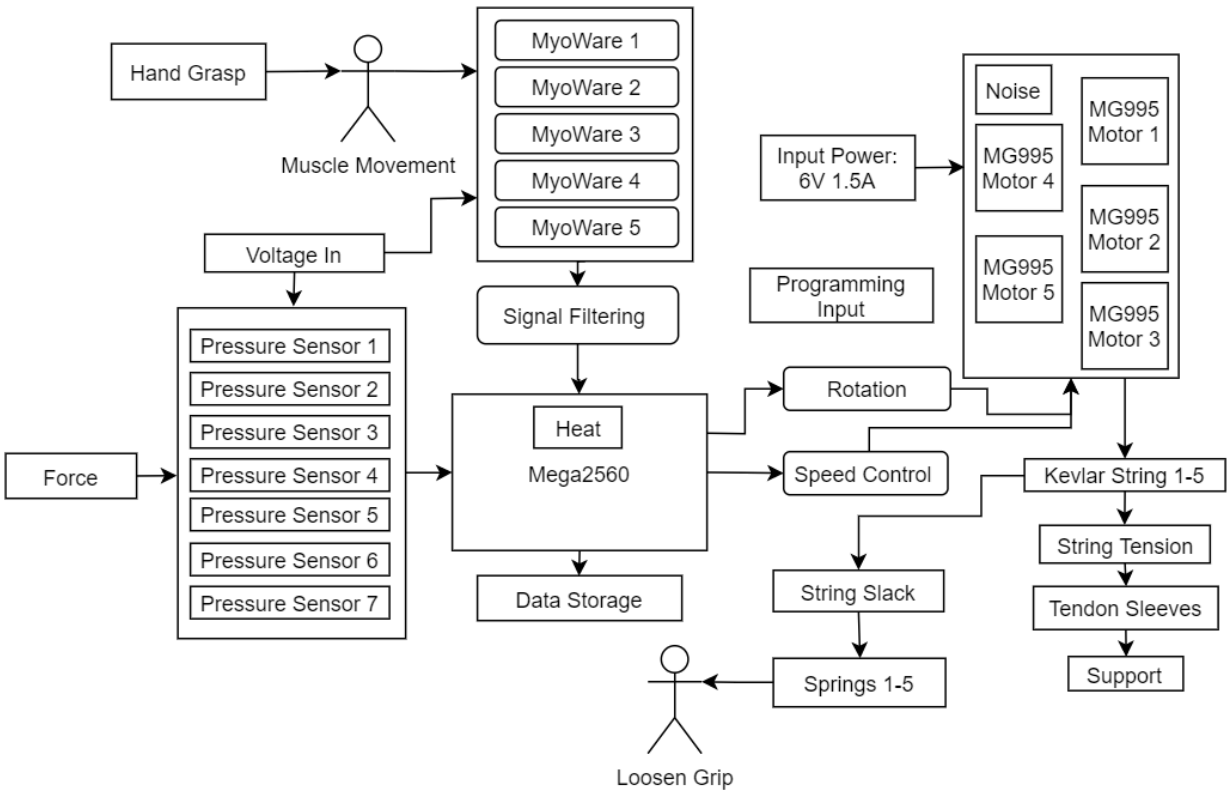


Figure 51 . Glove White Box. This detailed figure expands to include the voltage, power, and other physical properties that are involved in the operation of the glove. The programming in processed through the Mega2560 node square.

14. Final Acceptance Criteria

Table XXX. Acceptance Criteria

Specification	Testing Method
Sizing	Measurement Against Standard Chart
Force Correction Percentage	Load Cell Measurement
Force Correction Minimum (10% Of Prime Standard Female Norm)	Load Cell Measurement
Number of Joints	By Inspection
Degrees of Freedom	By Inspection
Weight: Glove	Manufacturer Material Specifications
Contact Temperature	Thermometers (Probe and Infra-Red)
Materials Biocompatible (Not-Toxic, Hypoallergenic Etc.)	Manufacturer Material Specifications
Mains Powered	Tested Default by Use of Functionality
Pressure Measurement	Test with Weight Standards and Gripping Cylinder
Interface to Computer for Adjustments and Data Reading	Attempt to Connect and Control
Minimum Sample Frequency	View Recording Data and Oscilloscope
Minimum Full Sample Frequency Minimum	View Recording Data and Oscilloscope

Final acceptance will be centered around general usage. Maximum force measurements will be taken before and after for cylindrical, pinch and lateral pinch grips (2+fingers to thumb). In addition to the above table of requirements the device will need to show that it will add the required 1.3 lbs. of force to each finger.

15. Recommendations

The material cost to replicate the glove is approximately $389.99. A complete breakdown of the material costs for the glove is located in the cost of prototype table in the appendix C. The costs were based on the unit or approximate measurement of material. This price does not include the machines, tooling, or labor. The prototype is scale is based on the ability to adjust glove parts and sizing to suit the customer. When manufacturing prototypes, it is important to consider the materials and process technology to use for each project. The glove uses functional materials and devices that are readily available and have the ability to be produced in house to reduce overhead. The following information below will provide a brief method for commercialization and scalability for the force enhancing smart glove. Injection molding would be a sufficient substitution for the 3d printed parts once the designs and product categories have matured. 3d printing would continue to be essential for development. For the purpose of the scalability 3d printing will be calculated.

Several potential improvements can be applied to the motor system to improve functionality and weight. Since linear actuators can generate more torque and are more efficient, a lesser amount would be required for the device which in turn drastically impacts the weight of the device. Switching to linear actuators would greatly change the design and size of the servo mount components to a smaller size.

16. Conclusion

The purpose of this project was to create a device that can assist the user with additive strength by reading muscle signals. By using a tendon drive pulley system, the cybernetic force enhancing smart glove enables more than 10% of standard functional improvement at roughly 4 times the increase in strength for the user. The biocompatible materials that were used enabled the skin to breath and offered very favorable support. Future development in biocompatible materials similar to Lycra [11] that better incorporate circuitry and microelectronics would enable a more lightweight and durable glove.

After running the analysis, it was discovered that 80% filament is preferred for the 3D printed parts of the materials used. This is because 80% filament allows flexibility on the material and helps decrease the total deformation and reduces the stress on the components. The use of PLA, and TPU enabled the team to quickly and precisely create and modify the designs for the tendon sleeves, motor mounts and other essential additively manufactured materials. The infill density was a critical feature to for each additively manufactured part to reduce weight and also satisfy the stress and strain put on the glove.

17. References

[1] E. Matheson and D. G. Brooker, "Assistive Rehabilitation Robotic Glove," Proceedings of Australasian Conference on Robotics and Automation, Monash University, Melbourne Australia, 2011.

[2] C. Yao, A. Argubi-Wollesen, R. Weidner and L. P. Wulfsherg, "Highly Biomimetic Design of a Muscle Glove," IEEE Robotics, Germany, 2016.

[3] B. Alexander and K. Viktor, "Proportions of Hand Segments," *Int. J. Morphol,* vol. 28, no. 3, pp. 755-758, 2010.

[4] A. Bailey, "Hand Grip Strength Test," 2019. [Online]. Available: https://www.livestrong.com/article/468905-hand-grip-strength-test/.

[5] I. Maw, "Key Considerations for Custom Prototype Manufacturing: Materials, Process, and Development," 2019. [Online]. Available: https://www.engineering.com/AdvancedManufacturing/ArticleID/19767/Key-Considerations-for-Custom-Prototype-Manufacturing-Materials-Process-and-Development.aspx.

[6] Occupational Safety and Health Administration, "Long Work Hours, Extended or Irregular Shifts, and Worker Fatigue," [Online]. Available: https://www.osha.gov/SLTC/workerfatigue/hazards.html.

[7] C. S. Smith, D. Folkard, P. Tucker and M. Evans, "Work schedules, health, and safety," *Handbook of occupational health psychology 2nd ed.,* pp. 185-204, 2011.

[8] S. Vegso, L. Cantley and M. Slade, "Extended work hours and risk of acute occupational injury: A case crossover study of workers in manufacturing," *Am J Ind Med,* vol. 50, no. 8, pp. 597-603, 205.

[9] J. Ricci, E. Chee, A. Lorandeau and J. Berger, "Fatigue in the U.S. workforce: Prevalence and implications for lost productive work time," *Occup Environ MEd,* vol. 49, no. 1, pp. 1-10, 2007.

[10] Harris Williams and Co., "Physical Therapy Market Overview," 2014. [Online]. Available: https://www.harriswilliams.com/system/files/industry_update/2014.2.17_physical_therapy_overview.pdf.

[11] G. M. &. V. K. &. J. T. Raghavendra, "Biomaterials: Design, Development and Biomedical Applications.," in *Nanotechnology Applications for Tissue Engineering*, Elsevier, 2015, pp. 26-42.

[12] Y. Hasegawa, "Improvement of Grasping Stability of Tendon Driven Hand with Mechanical Compliance," pp. 901-903, September 2006.

[13] A. Hadi, K. Alipour, S. Kazeminasab and M. Elahinia, "ASR glove: A wearable glove for hand assistance and rehabilitation using shape memory alloys," *Journal of Intelligent Material Systems and Structures,* vol. 29, no. 8, pp. 1577-79, 2018.

[1 S. J. Abbass and F. M. Rudah Masoud, "Biomechanical Concept Design of Artificial Human Hand," *Al-*
4] *Khwarizmi Engineering Journal,* vol. 7, no. 1, pp. 1-12, 2011.

[1 F. Chen Chen, A. Favetto, E. P. Ambrosio, S. Appendino, A. Battezano, D. Manfredi, F. Pescarmona
5] and B. Bona, "Human Hand: Kinematics, Statics and Dynamics," *International Conference on Environmental Systems,* 17-21 July 2011.

[1 A. C. Looker, Ph.D and C.-Y. Wang, Ph.D, "Prevalence of Reduced Muscle Strength in Older U.S.
6] Adults," *NCHS Data Brief,* no. 179, January 2015.

[1 C. C. Norkin and P. K. Levangie, Joint Structure and Function, Philadelphia: F.A. Davis, 1992, p. 296.
7]

[1 Ringer Gloves, "Hand injury statistics," Houston, Tx, 2017.
8]

[1 M. J. Mosley, C. Mavroidis and C. Pfeiffer, "DESIGN AND DYNAMICS OF A SHAPE MEMORY ALLOY
9] WIRE BUNDLE ACTUATOR," New Jersey.

[2 A. Dembe, J. Ericson, R. Delbos and S. Banks, "The impact of overtime and long work hours on
0] occupational injuries and illnesses: New evidence from the United States," *Occupational Environment Medicine,* no. 62, pp. 588-597, 2005.

[2 T. R. Control, "5 Steps for Production Liability Risk Management," [Online]. Available:
1] https://www.travelers.com/resources/product-service-liability/5-steps-for-product-liability-risk-management.

[2 Intertek, "Bringing Medical Devices to Market in the U.S," 2016. [Online]. Available:
2] https://www.intertek.com/blog/2016-09-27-med-device/.

[2 MatWeb, LLC, "Overview of materials for Polyactic Acid (PLA) Biopolymer," [Online]. Available:
3] http://www.matweb.com/search/DataSheet.aspx?MatGUID=ab96a4c0655c4018a8785ac4031b9278&ckck=1.

[2 Dupont, "Kevlar Aramid Fiber: Technical Guide," [Online]. Available:
4] https://www.dupont.com/content/dam/dupont/amer/us/en/safety/public/documents/en/Kevlar_Technical_Guide_0319.pdf.

18. Appendix A: Poster

The University of Texas at TYLER

HEC 4: Team Kracan

Electrical & Mechanical Engineering

Cybernetic Force Enhancing Smart Glove

Team Members: Alejandro Candelaria Silos, Ronald Freeman, Nicolas Pineda, Carolina Ramirez-Robledo, Kevin Scholtes, Alan Velazquez
Sponsor: Texas Tech University Health Services Center Surgical Staff
Advisor: Dr. Hussain Rizvi

Abstract

The purpose of this project is to determine and build an external assistive device in the form of a cybernetic glove; which improves a user's ability to grasp, hold, and manipulate. The initial target market is female users that have lost strength from nerve or muscle damage due to age, injury, or disease. Uses for this glove extends to medical, sport, commercial, and industrial applications.

Background

Nerve and muscle damage due to aging diseases and injuries can severely inhibit a person's ability to complete everyday activities. Currently medical, sports and commercial industries are seeking a system that will give people the strength to reduce recovery time.

Hand Force Calculations

$\tau_f = F_f l$ Where τ = torque of finger, F_f = force of finger, l = length

$F_s = kx$ k = spring constant, x = spring stretch

$\tau_m = F_f r_c$ F_s = *Spring Force* τ_m = Torque of motor, r_c = radius of cam

Force Sense Resistor



- Conductive polymer senses the force applied to enable the proper function of the glove.
- The resistance change is inversely proportional to the applied force, in which the FRS04BE sensor can detect clear measurements from 20 grams to 5 kilograms.

Springs

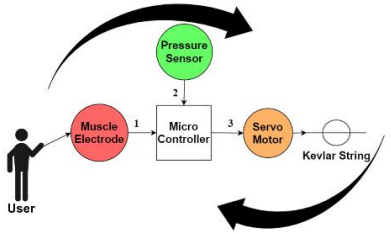
When the hand is on the release position, the springs will contract, and it will assist the opening of the hand.

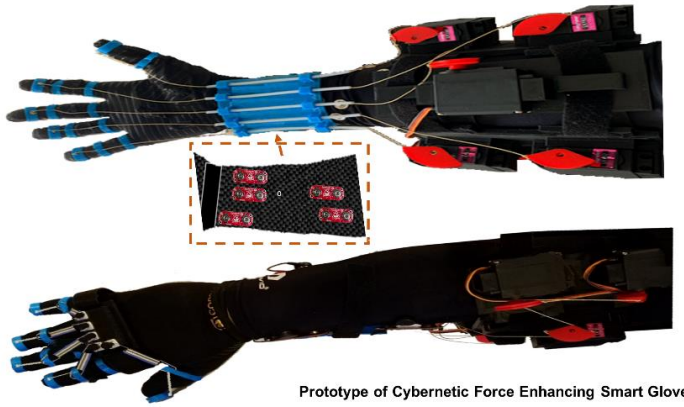
- Spring constant, k=0.109 N/mm
- Max. Load, F=10.6 lbf
- Displacement, x=20 mm



Fig. Custom spring plate to ensure sufficient action with motor movement.

Glove System Overview



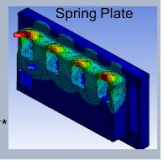


Prototype of Cybernetic Force Enhancing Smart Glove

Finite Element Analysis

- Material: PLA
- Mesh Size: 7.5 mm
- Boundary Conditions: Fixed support and forces*; Temperature and convection**
- Solution: Total deformation, equivalent stress, equivalent elastic strain*; Minimum and Maximum temperature, total heat flux, and directional heat flux**

* Static Structural ** Steady-State Thermal



Servo Motor

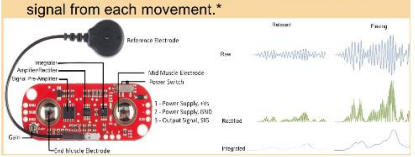
Metal geared servo motors (5)* actuate the red PLA cam at the top left where the kevlar string attached. The cam design enables a rotation of 120°. Each motor has a max pull of 12 kg/cm (7V).



Motor Model: MG996R

Muscle Sensor

- Converts and conditions the electrical signals generated by muscle action.
- When relaxed the signal will be at minimum, when flexed the signal will fluctuate in amplitude and frequency.
- The sensor acts as the initiation stage to control which motor actuates to the target position at the desired rate.
- Sensors (5)* are attached to the wrist sleeve in scientifically determined positions to read the clearest signal from each movement.*



Inner Glove Materials

- 3D printed TPU-95A tendon sleeves for the fingers (14)*
- Size 6 steel snap fasteners to hold the muscle sensor (15)*
- 45 cm Kevlar braid running from fingertips to servomotors, allows for adjustment (5)*QWEE234
- Premium compression glove that is breathable and is self fitting. (1)*

*The number in parenthesis () indicates total materials used.

Outer Glove Materials

- **Servomotor mounts:** Designed in inventor and extruded in PLA which houses and reinforces the servomotors.
- **Spring plate:** Located in the posterior side of hand designed in inventor and printed in PLA, it acts as a counterbalance for the servomotor actuation.
- **Wrist sleeve:** Serves as a guide for the kevlar braid as they connect from the glove to the arm sleeve. Printed in TPU so it can flex around the wrist for self-fitting.

Summary

- The Kracan glove enables a 10% of standard functional improvement in strength for the user. Made from safe biocompatible materials and controlled with muscle signals the glove focuses on the flexion and extension of the fingers, providing a strong grip force.
- For the design aspect, the team went through many versions looking for materials to reduce the weight and bulk of the glove components, finally deciding on the use of Lycra, PLA, and TPU.

Acknowledgements

This project was conducted at The University of Texas at Tyler | Houston Engineering Center. Advising and support by Dr. Hussain Rizvi. Sponsored by Dr. Daniel Nguyen M.D. Texas Tech University Health Services Center Surgical Staff. Support from Houston Community college for access to their maker space and guidance from staff and faculty.

19. Appendix B: Sign-Off Sheet

The University of Texas at TYLER
COLLEGE OF ENGINEERING

Department of Mechanical Engineering
Phone: +1.903.566.7003
Fax: +1.903.566.7148
Uttyler.edu/engineering

SENIOR DESIGN II – FINAL STATUS SHEET

TEAM: HEC4 /Team Kracan **Date:** 04/24/2020

Project final status:
COMPLETED: X
NOT COMPLETED: _____
ESTIMATED % Completion ____ %

Location on OneDrive where team project folder can be downloaded - See instructions after this table:
https://livepatriotsuttyler.sharepoint.com/:f:/s/HECGroup4/EsK7MH4EX7BChrH_U2ux5XQB-VHC2fN23JmHTZE_SMWVqA?e=rL0rl7

PENDING ITEMS:

OUTSTANDING ITEMS ORDERED (BUT NOT RECEIVED)

OUTSTANDING ITEMS NOT ORDERED

FINAL COMMENTS:

SIGNATURE:

1.- Name: Kevin Scholtes **Signature:**
2.- Name: Carolina Ramirez-Robledo **Signature:**
3.- Name: Alan Velazquez **Signature:**
4.- Name: Alejandro Candelaria Silos **Signature:**
5.- Name: Ronald Freeman **Signature:**
6.- Name: Nick Pineda **Signature:**
7.- Name: **Signature:**

Page 1 of 2

20. Appendix C: Economic Feasibility

Table XXXI. Cost of Prototype

Item#	Component	Quantity	Price	Unit	Entended	Category
1	MyoWare Muscle Sensor	5	$37.99	unit	$189.95	ELE
2	Ohmite FSR04BE pressure sensor	7	$5.73	unit	$40.11	ELE
3	10K Resistors	7	$0.03	unit	$0.21	ELE
4	WYCTIN 60-40 Tin Lead Rosin Core Solder Wire 0.0236 inches(0.6mm)	25	$0.16	grams	$4.05	ELE
5	Gen Basic female to female jumper connectors	29	$0.08	unit	$2.18	ELE
6	ELEGOO MEGA 2560 R3 Board ATmega2560 ATMEGA16U2 + USB Cable Compatible with Arduino IDE	1	$16.98	unit	$16.98	ELE
7	28 AWG copper wire	50	$0.13	ft.	$6.73	ELE
8	McDavid Compression Arm Sleeve, Black, Medium	1	$12.64	unit	$12.64	MAT
9	PTFE Teflon tubing 10ft- 2mm ID X 4mm OD for 1.75 Filament Bowden 3D	25	$0.40	ft.	$9.99	MAT
10	Copper Compression Full Finger Arthritis Gloves	1	23.95	unit	$23.95	MAT
11	EZYKOO 465 Pcs Car Retainer Clips & Plastic Fasteners Kit- Bumper Fastener F3143	5	$0.20	unit	$1.00	MAT
12	Hillman 5/16 x 1-1/8 x 0.023" Extension Spring	5	$2.49	unit	$12.43	MAT
13	Hillman #6 x 1/2" Pan Phillips Metal Screw	1	$1.28	20 pcs	$1.28	MAT
14	Stretch Magic Jewelry Cord	2	$6.99	16ft	$13.98	MAT
15	Velcro 12 ft x 3/4" One-Wrap Roll	1	$1.04	ft.	$1.04	MAT
16	PLA Poly Lactic Acid	0.25	$16.99	kg	$4.25	MAT
17	TPU 95-A	0.0922	$27.99	kg	$2.58	MAT
18	Dritz 116-65 Snap Fasteners, Size 16 (7/16-Inch), Nickel	36	$0.49	unit	$17.60	MAT
19	100lb Braided 1000 ft. emma kites Kevlar Line Cord for Kite Tension Cable	25	$0.02	ft.	$0.60	MAT
20	MG996R Servo Motor	5	4.49	unit	$22.45	MEC
			Grand Total		$383.99	

Legal Feasibility

It includes study concerning contracts, liability, violations, and legal other traps frequently unknown to the technical staff.

The glove will require legal paperwork for meeting standards here in the United States and plans for international production and distribution once the prototype stage is complete. Paperwork can be completed with help of a personal attorney that can incorporate or at minimum set up an LLC for Team Kracan. Incorporation along with setting up provisional patients (if any) for the glove can be completed. A provisional patient can be established if the team finds innovation in a part of the project. It is also advisable to set up insurance coverage that backs up incorporated or LLC status. Additional insurance will be useful especially for a product such as this glove. Backup files and data storage for the business should also be completed to ensure that the above items can be upheld and executed.

The user data and associated information should have protection and secured from unauthorized parties[8]. Legal requirements for products used in direct human contact and use must be processed through the local government. Key areas that the glove must consider and complete before bringing product to market are:

- Classifying Device
- Identify the correct premarket submission
- Prepare the premarket submission
- Submit to FDA
- Establish registration and device listing

Based on the initial outlook for the device we are currently finding areas for innovation to patient. The team is building safety into design in order to prepare it for the bullet points above. Legal counsel can be brought (consulted) in as soon as final design review and associated parameters are finalized.

Operational Feasibility

Operational feasibility is mainly concerned with issues like whether the system will be used if it is developed and implemented. Whether there will be resistance from users that will affect the possible application benefits? The essential questions that help in testing the operational feasibility of a system are following.

- *Does management support the project?*
- *Are the users not happy with current business practices? Will it reduce the time (operation) considerably? If yes, then they will welcome the change and the new system.*
- *Have the users been involved in the planning and development of the project? Early involvement reduces the probability of resistance towards the new system.*
- *Will the proposed system really benefit the organization? Does the overall response increase? Will accessibility of information be lost? Will the system effect the customers in considerable way?*

The team HEC4 under the guidance of the faculty and the sponsor of the project enables the organization to complete the project. Access to an electrical lab with tools for soldering with microelectronics is required. Access to force gauges for mechanical testing is needed in order to calibrate the glove with the microcontroller.

The plan is to use the labs at UT Tyler HEC and the WHI maker space. Items that are not able to be completed at these locations will be outsourced by a third party.

Sponsor feedback was initiated during the early phases of the project and are strong at this point in the project.

The glove may enable future group to continue, expand or use this project as a template for future work for the UT Tyler senior design program. Main concept drawing and bill of materials will be open to faculty involved in the project.

Scheduling Feasibility

> ***Schedule Feasibility*** *is defined as the probability of a project to be completed within its scheduled time limits, by a planned due date. If a project has a high probability to be completed on-time, then its schedule feasibility is appraised as high. In many cases a project will be unsuccessful if it takes longer than it was estimated: some external environmental conditions may change; hence a project can lose its benefits, expediency and profitability. If a work to be accomplished at a project does not fit the timeframes demanded by its customers, then a schedule is unfeasible (amount of work should be reduced, or other schedule compression methods applied).*

Project schedule is currently planned in Project libre and task modeling flow charts. The project timeline has very strict times for project delivery. A concept prototype that is not fully debugged or properly tested is possible with the constraints and timeline. A copy of the project libre schedule is found in appendix. The project constraints are listed below.

- Technical Constraints
    - Technical ability with components and inexperience with assembly and synchronizing components.
- Internal Constraints
    - Group members still learning the fundamentals and realizing how theory, calculation and real-world dynamics work together.
    - Lack of full time focus on project from members from being full time students with jobs and family.

- Financial Budget
    - Budget is limited and does not provide room for building and testing multiple model.
    - Puts stress on material resources if materials are lost, damaged or are mismanaged.
- Equipment
    - Lack of high-quality equipment for testing and calibration.
- External Constraints
    - Medical Regulations
    - Legal Liability

21. Appendix D: Timelines

Table XXXII. Project Timeline

	Task	Due Date
X	Problem Statement	9/10/2019
X	Question for Sponsor	9/20/2019
X	Met with Sponsor	9/25/2019
X	Specification sign-off	10/03/2019
X	Concept Selection	10/04/2019
X	Detail Design	11/01/2019
X	Sponsor Detail Design	12/04/2019
X	Build sign-off	4/01/2020
	*X indicates task has been completed	

Table XXXIII. Project Schedule

Task #	Task Description	Lead Engineer	Start Date	End Date	Total Days
1	Inner glove material set up	Carolina Ramirez-Robledo	2/14/2020	2/18/2020	5
2	Sewing glove together	Carolina Ramirez-Robledo	2/19/2020	2/23/2020	5
3	Map inner glove sensor overlay	Carolina Ramirez-Robledo	2/23/2020	2/23/2020	1
4	Sew in sensor pockets	Carolina Ramirez-Robledo	2/24/2020	2/26/2020	3
5	Inlay sensors into glove	Carolina Ramirez-Robledo	2/27/2020	2/29/2020	3
6	Test Sensors	Ronald Freeman	3/1/2020	3/2/2020	2
7	Stress Analysis	Carolina Ramirez-Robledo	2/18/2020	2/26/2020	9
9	Verification of glove calculations	Alejandro Candelaria-Silos	2/25/2020	3/2/2020	7
10	Signal processing algorithm	Ronald Freeman	1/28/2020	2/3/2020	7
11	Code response algorithm	Ronald Freeman	2/4/2020	2/10/2020	7
12	Code calibration algorithm	Ronald Freeman	2/11/2020	2/17/2020	7
13	Code data storage algorithm	Ronald Freeman	2/18/2020	2/24/2020	7
14	Code system level utilities	Ronald Freeman	2/25/2020	3/2/2020	7
15	Gather testing standards	Alan Velazquez	2/11/2020	2/15/2020	5
16	Test component safety and durability	Alan Velazquez	2/18/2020	2/23/2020	6
17	Safety Report	Alan Velazquez	2/25/2020	3/27/2020	3
18	Board Selection	Kevin Scholtes	2/9/2020	2/15/2020	5
19	Identify and select connected peripherals	Kevin Scholtes	2/9/2020	2/19/2020	10
20	Map physical i/o connections	Kevin Scholtes	2/19/2020	2/29/2020	10
21	Verify motor control design	Kevin Scholtes	2/19/2020	3/5/2020	5
22	Power control design and testing	Kevin Scholtes	2/19/2020	3/10/2020	5
23	Map outer skeleton for outer glove	Nicolas Pineda	2/8/2020	2/25/2020	18
24	Assemble outer skeleton for outer glove	Alejandro Candelaria-Silos	2/26/2020	3/2/2020	7
25	install convers for springs and servo motors	Alejandro Candelaria-Silos	3/2/2020	3/4/2020	2
26	Servo motor installation and reinforcement	Alejandro Candelaria-Silos	3/4/2020	3/6/2020	2
27	Spring installation	Alejandro Candelaria-Silos	3/6/2020	3/7/2020	1

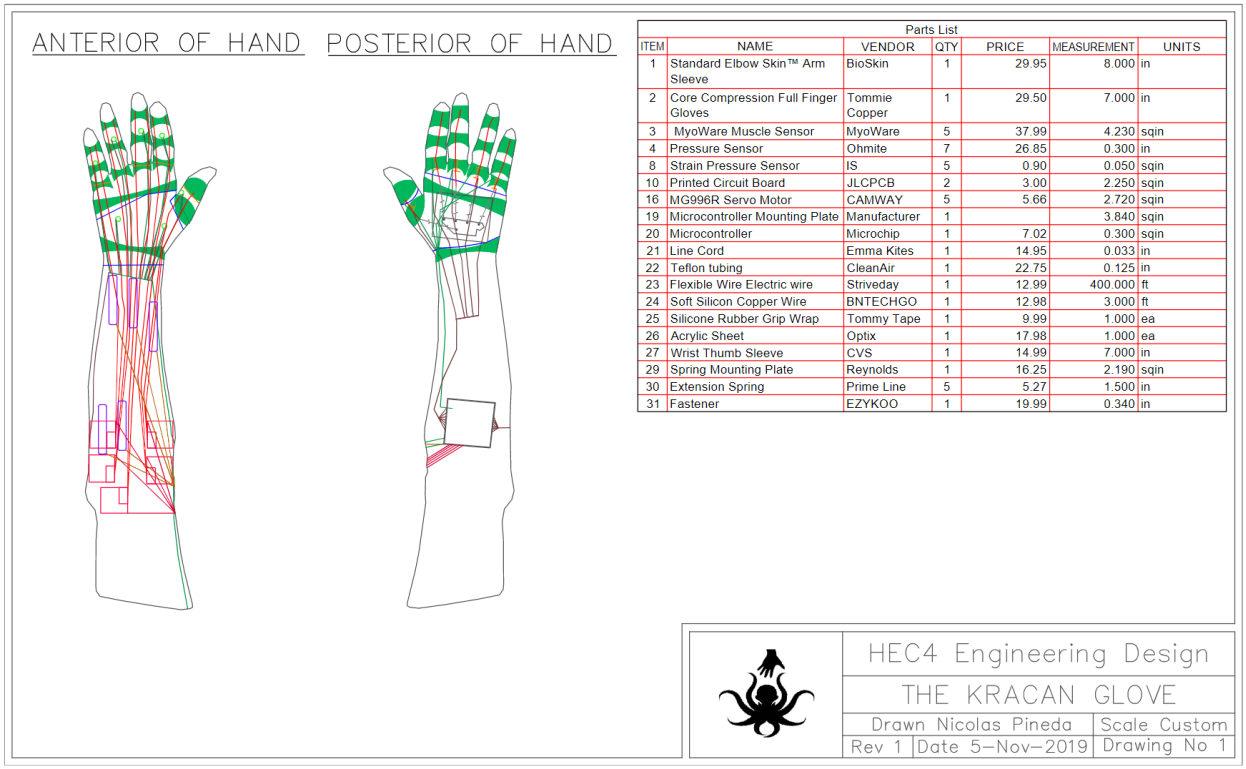
28	Measure, cut and set up Kevlar line and Teflon tubes	Carolina Ramirez-Robledo	2/28/2020	3/2/2020	4
29	Hand bio-mechanical testing	Nicolas Pineda	2/18/2020	3/2/2020	14
30	Final construction for testing	Ronald Freeman	3/16/2020	3/20/2020	4
31	Internal acceptance testing	Alan Velazquez	3/16/2020	3/20/2020	5
32	Client acceptance testing and client sign off	Nicolas Pineda	3/23/2020	4/01/2020	9

22. Appendix E: ARCI

Table XXXIV. Accountability, Responsibility, Consulted, Informed

Number	Responsible Party	Verifier	Task
1	Carolina	Ronald	Aesthetics/Comfort
2	Carolina	Nicolas	Finite Element Analysis
3	Alejandro	Carolina	Calculations
4	Alejandro	Nicolas	AutoCAD Drawings
5	Carolina	Ronald	Comfort Testing
6	Ronald	Kevin	Coding
7	Nicolas	Alan	Durability
8	Kevin	Ronald	Electrical Design
9	Ronald	Kevin	Electrical Testing
10	Alan	Alejandro	Hard Structure
11	Carolina	Kevin	Materials
12	Alan	Nicolas	Physical Fabrication
13	Kevin	Ronald	Purchasing
14	Alejandro	Nicolas	Mechanical Testing

23. Appendix F: Mechanical Drawings



Parts List

ITEM	NAME	VENDOR	QTY	PRICE	MEASUREMENT	UNITS
1	Standard Elbow Skin™ Arm Sleeve	BioSkin	1	29.95	8.000	in
2	Core Compression Full Finger Gloves	Tommie Copper	1	29.50	7.000	in
3	MyoWare Muscle Sensor	MyoWare	5	37.99	4.230	sqin
4	Pressure Sensor	Ohmite	7	26.85	0.300	in
8	Strain Pressure Sensor	IS	5	0.90	0.050	sqin
10	Printed Circuit Board	JLCPCB	2	3.00	2.250	sqin
16	MG996R Servo Motor	CAMWAY	5	5.66	2.720	sqin
19	Microcontroller Mounting Plate	Manufacturer	1		3.840	sqin
20	Microcontroller	Microchip	1	7.02	0.300	sqin
21	Line Cord	Emma Kites	1	14.95	0.033	in
22	Teflon tubing	CleanAir	1	22.75	0.125	in
23	Flexible Wire Electric wire	Striveday	1	12.99	400.000	ft
24	Soft Silicon Copper Wire	BNTECHGO	1	12.98	3.000	ft
25	Silicone Rubber Grip Wrap	Tommy Tape	1	9.99	1.000	ea
26	Acrylic Sheet	Optix	1	17.98	1.000	ea
27	Wrist Thumb Sleeve	CVS	1	14.99	7.000	in
29	Spring Mounting Plate	Reynolds	1	16.25	2.190	sqin
30	Extension Spring	Prime Line	5	5.27	1.500	in
31	Fastener	EZYKOO	1	19.99	0.340	in

Figure 52: Drawing No. 1: Anterior of Hand and Posterior of Hand

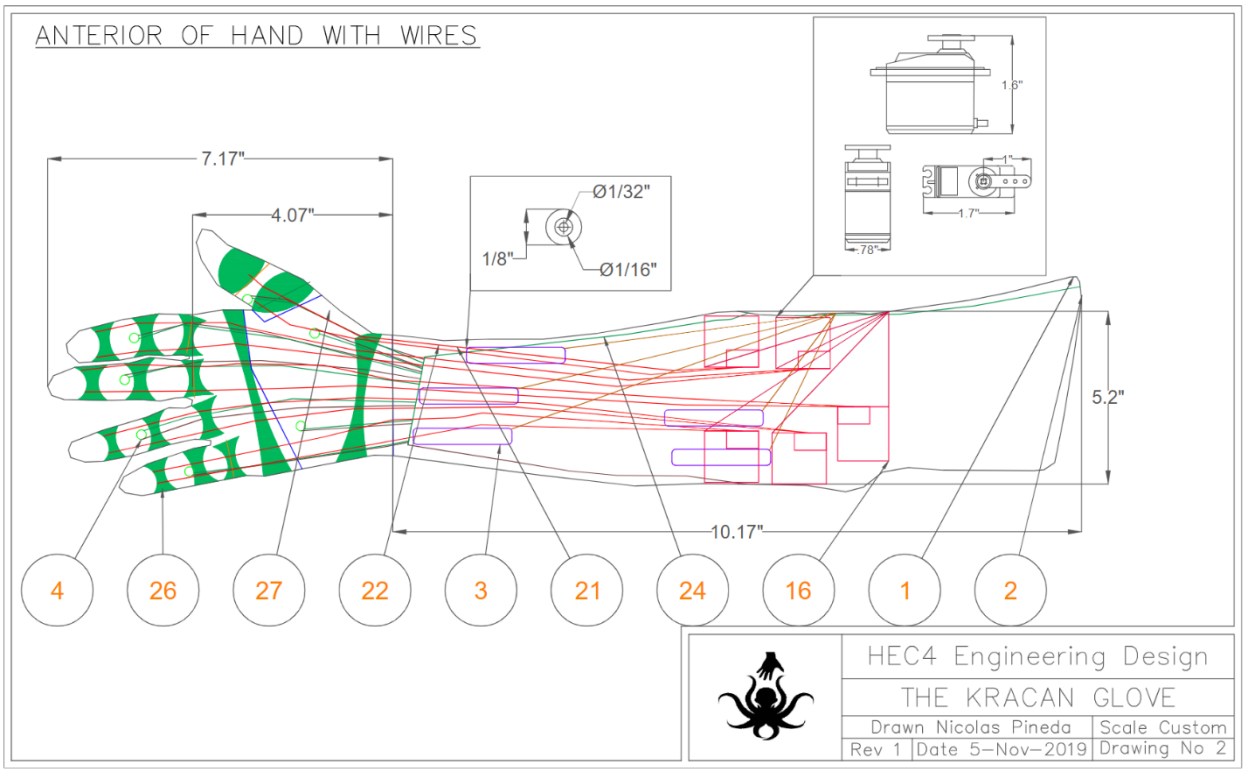


Figure 53: Drawing No. 2: Anterior of Hand with Wires

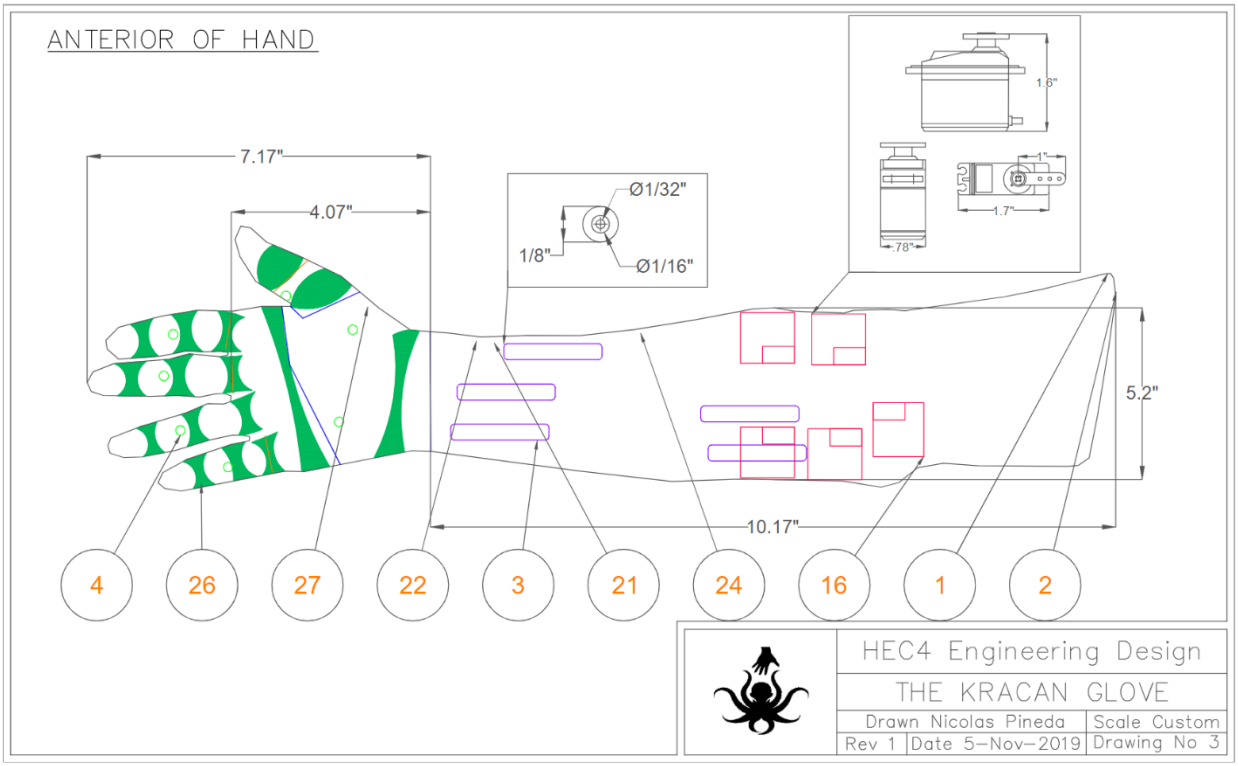


Figure 54: Drawing No. 3, Anterior of Hand

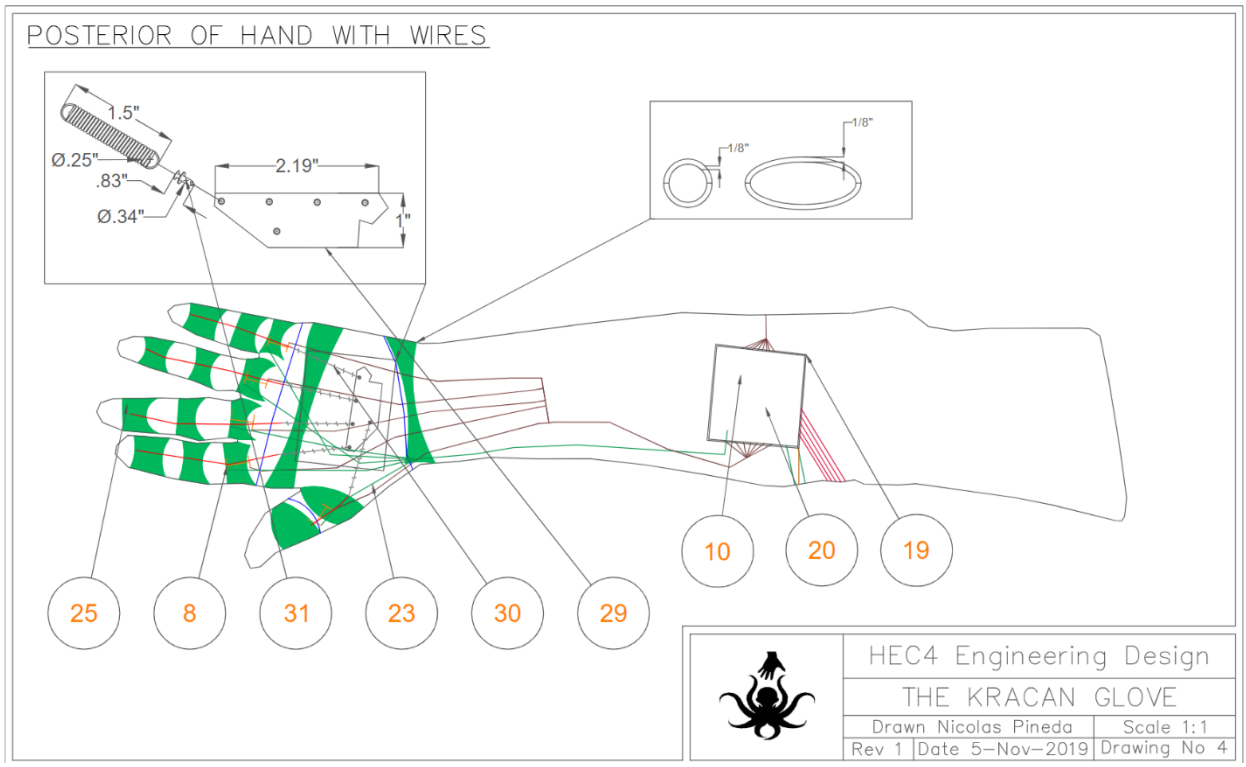


Figure 55: Drawing No. 4, Posterior of Hand with Wires

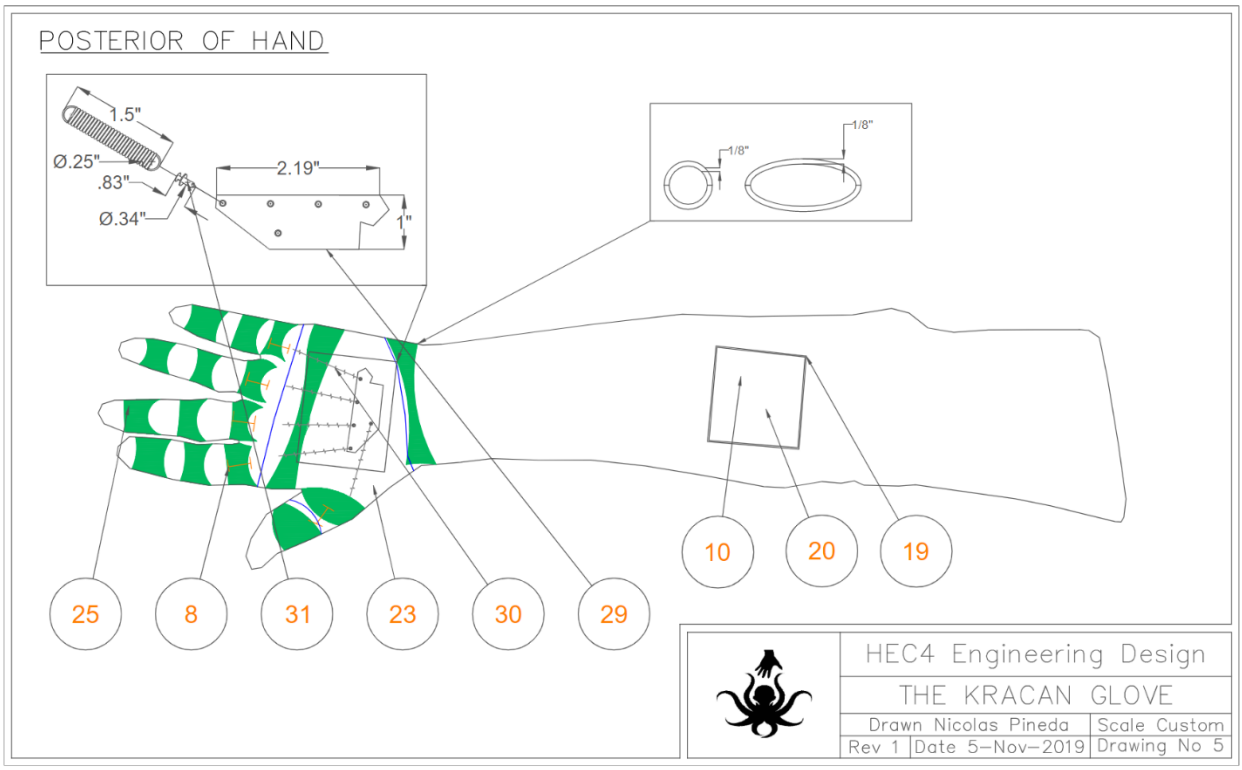


Figure 56: Drawing No. 5, Posterior of Hand

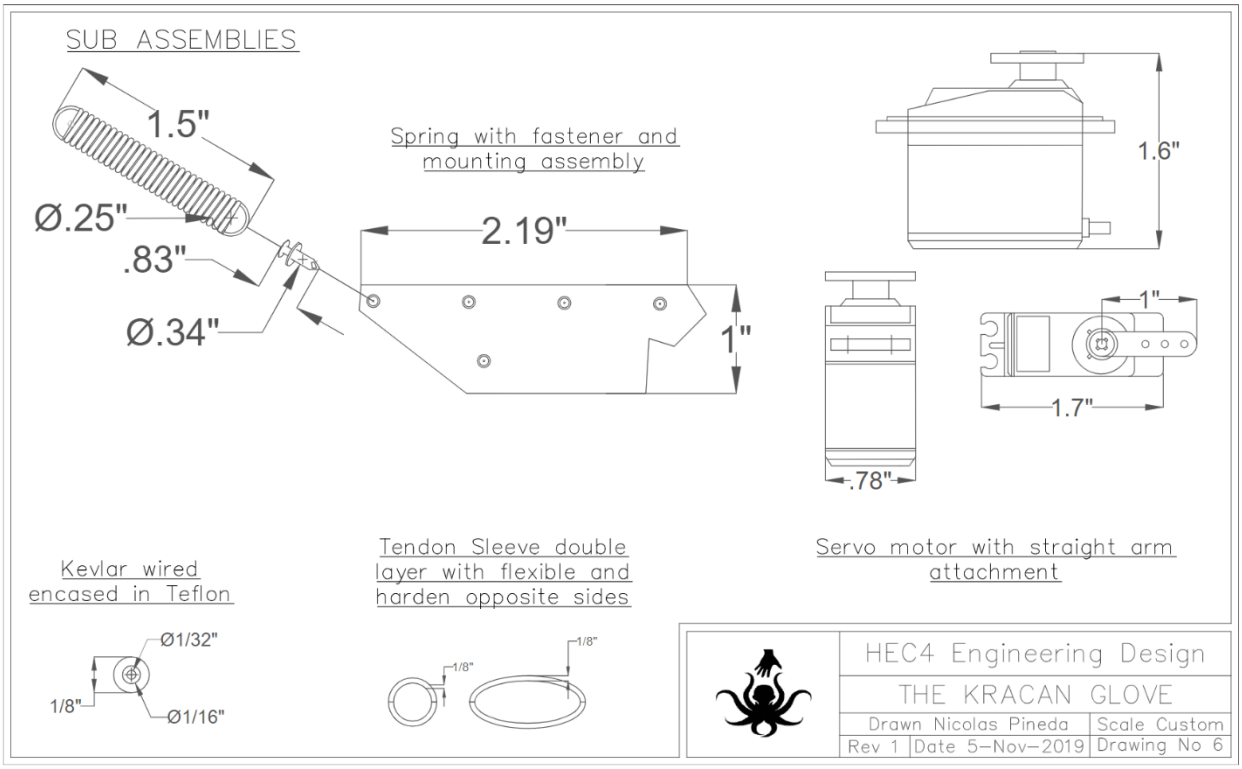
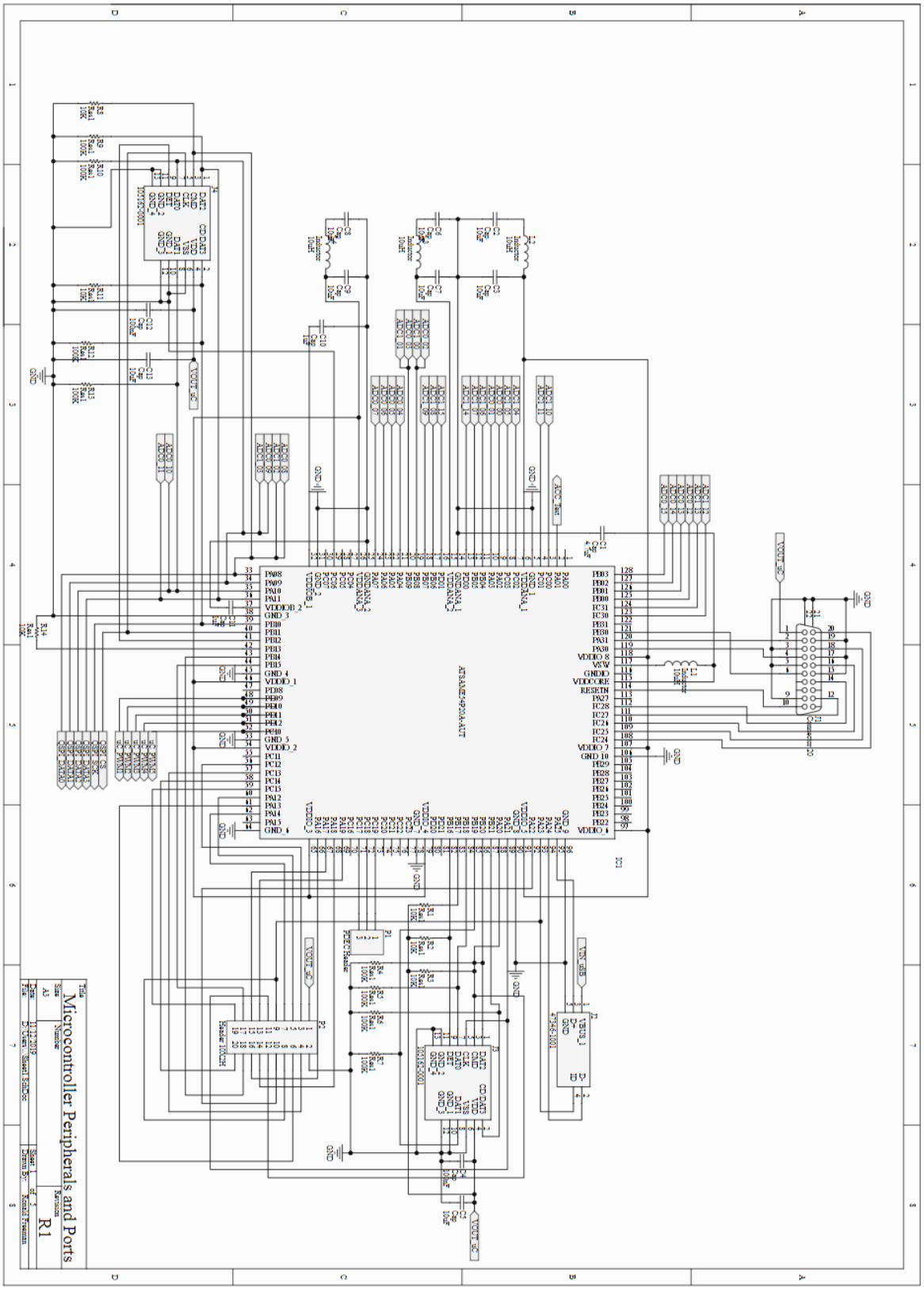
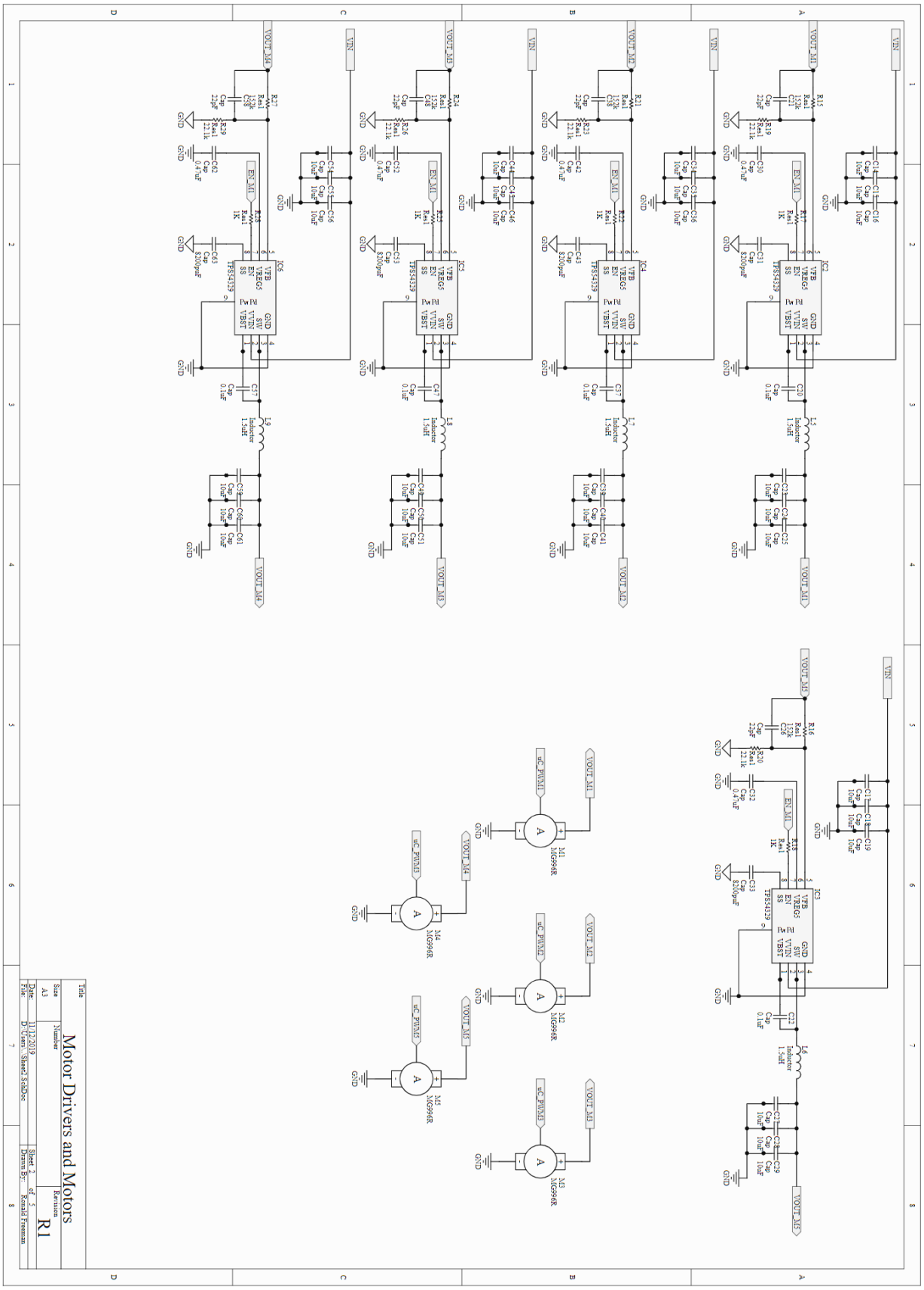
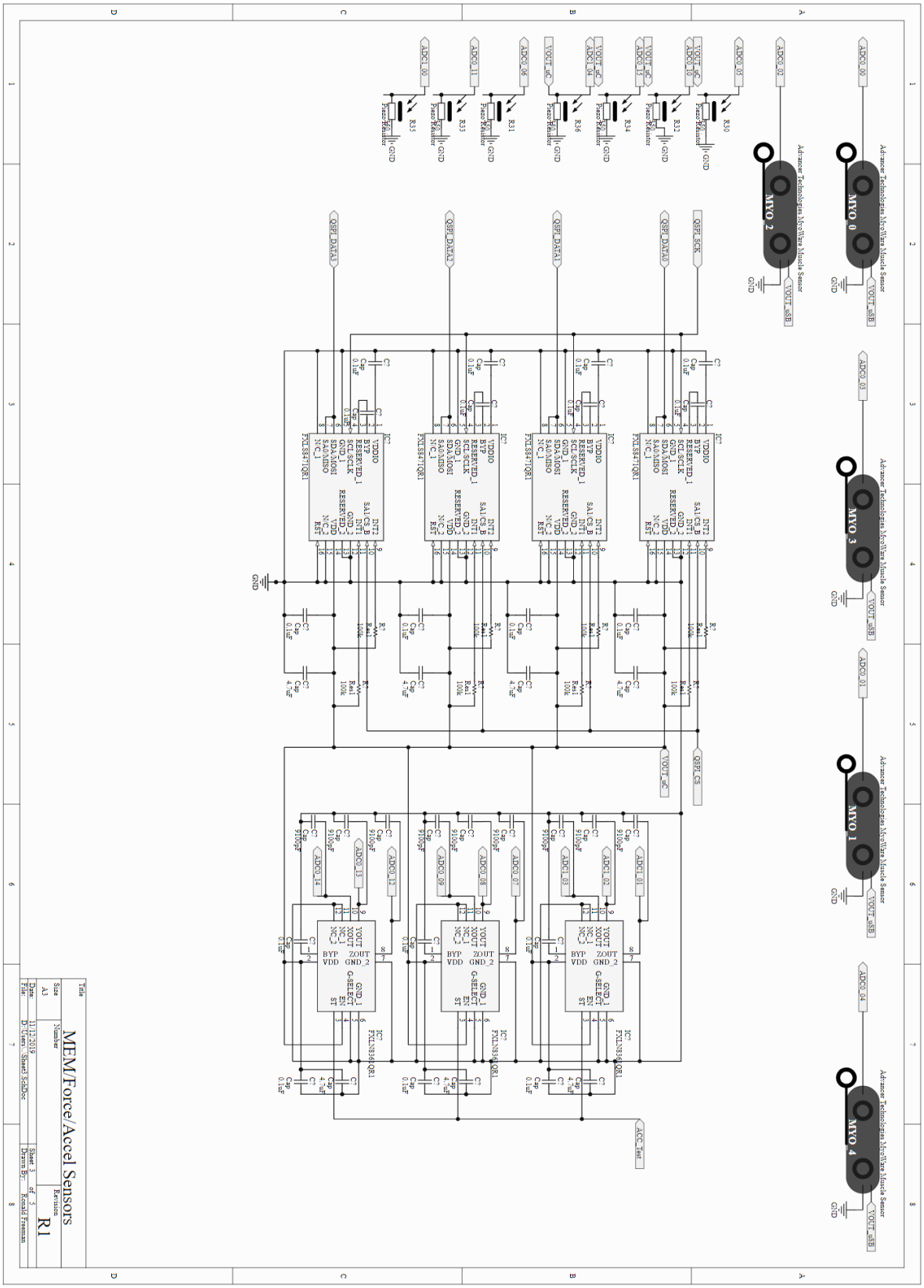


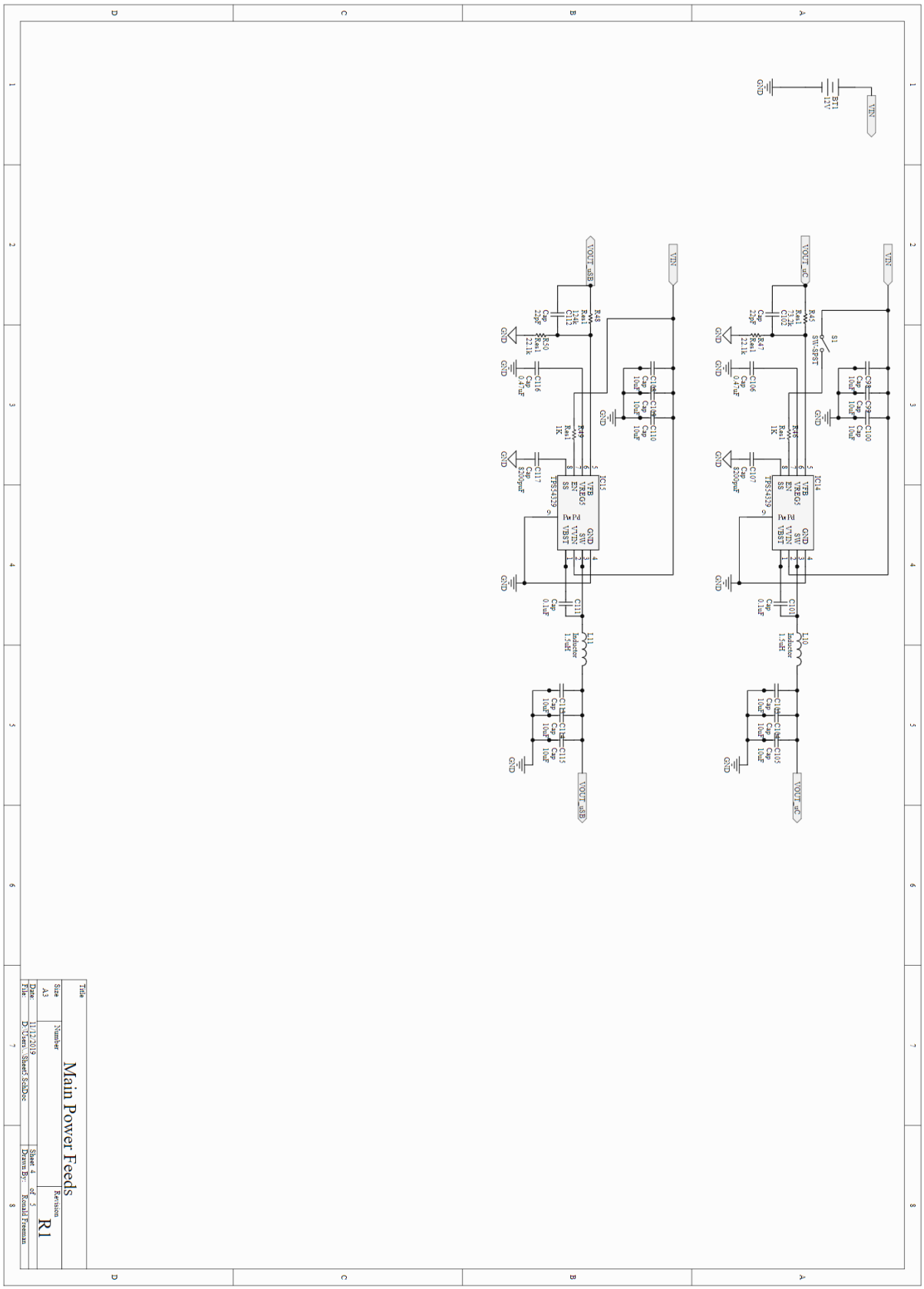
Figure 57: Drawing No. 6, Sub-Assemblies

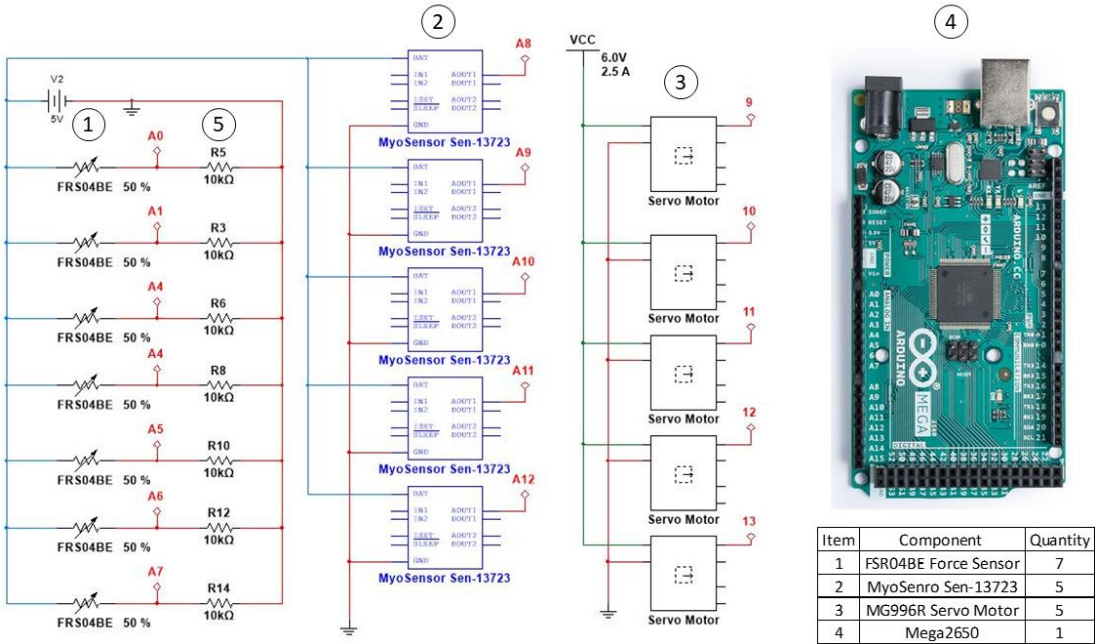
24. Appendix G: Electric circuit diagrams




Motor Drivers and Motors
R1
Number
Revision
A3
11/12/2019
D:\Users\...\Sheet3.SchDoc
Sheet 2 of 5
Drawn By: Ronald Freeman
VIN
VOUT_M1
VOUT_M2
VOUT_M3
VOUT_M4
VOUT_M5
EN_M1
GND
TPS54339
Inductor
1.5uH
aC_PWM1
aC_PWM2
aC_PWM3
aC_PWM4
aC_PWM5
M1
M2
M3
M4
M5
MG996R


MEM/Force/Accel Sensors
R1
Advancer Technologies MyoWare Muscle Sensor
MYO_0
MYO_1
MYO_2
MYO_3
MYO_4
FXLN8356QR1
FXLS8471QR1


Main Power Feeds
R1
Ronald Freeman
11/12/2019
Sheet 4
of 5
D:\Users\...\Sheet4.SchDoc
A3
Number
Revision
Title
Size
Date
File
Drawn By:
VIN
VOUT_adC
VOUT_adSB
BT1
12V
S1
SW-SPST
IC14
IC15
TPS54335
L10
L11
4.7uH
0.1uF
0.47uF
3300pF
10uF
22pF
221k
1K



Item	Component	Quantity
1	FSR04BE Force Sensor	7
2	MyoSenro Sen-13723	5
3	MG996R Servo Motor	5
4	Mega2650	1
5	10k resistors	7

Figure 58. Prototype circuit diagram for presented glove.

25. Appendix H: Code

```
//*************************************************************************************************************************

//Kracan Smart Glove System Controls

//*************************************************************************************************************************

#include <Servo.h>

#include <EEPROM.h>


Servo servo[5];                                 // create servo object to control a servo

int currentPos[5] = {0,0,0,0,0};                // variable to store the current servo position

int targetPos[5] = {180,180,180,180,180};       // variable to store the target servo position


int myoVal[5]={0,0,0,0,0};                      // last muscle sensor readings

int myoValMinThreshold[5]={0,0,0,0,0};          // muscle sensor minimum triggering values

int myoValMaxThreshold[5]={1023,1023,1023,1023,1023};   // muscle sensor maximum limit return values

int myoValMultiplier[5]={1,1,1,1,1};            // muscle sensor gain multiplier values

int myoValWorking[5]={0,0,0,0,0};               // isolated set for mathematical work before setting muscle sensor values

int myoValDelta[5]={0,0,0,0,0};                 // last muscle delta calculated

int myoValStored[5][10];                        // previous 10 muscle sensor readings

int myoValDeltaStored[5][10];                   // previous 10 muscle delta calculations


int pressVal[8]={0,0,0,0,0,0,0,0};              // last pressure sensor readings
```

```
int pressValMinThreshold[8]={0,0,0,0,0,0,0,0};                    // pressure sensor minimum
triggering values

int pressValMaxThreshold[8]={1023,1023,1023,1023,1023,1023,1023,1023};  // pressure sensor
maximum limit return values

int pressValMultiplier[8]={1,1,1,1,1,1,1,1};                      // pressure sensor gain multiplier
values

int pressValWorking[8]={0,0,0,0,0,0,0,0};                         // isolated set for mathematical
work before setting pressure sensor values

int pressValDelta[8]={0,0,0,0,0,0,0,0};                           // last pressure delta calculated

int pressValStored[8][10];                                        // previous 10 pressure sensor readings

int pressValDeltaStored[8][10];                                   // previous 10 pressure delta
calculations


//int currentStoredIndex=0;


bool verbose=true;                                                // true= return verbose logging information
by serial port


int positionServo=0;                                              // increment value for which servo/sensor
combination is currently being manipulated


bool serialConnected = false;                                     // Is the controller connected to USB
serial communication


void inline setPosition(int pos, int serv){

  //Calculate movement rate


  targetPos[serv]=map(pos, 0, 1023, 0, 180);                      // set Target position after mapping
myoelectric scale to use it with the servo (value between 0 and 180)


  if(targetPos[serv]>180){                                        // if the values passed is too high, set it to
the upper limit
```

```
   targetPos[serv]=180;
  }


  if(targetPos[serv]<0){                                  // if the valus passed is too low, set it to the
lower limit
   targetPos[serv]=0;
  }


  if(serv<4){
     targetPos[serv]-=180;
  }



  if(currentPos[serv]<targetPos[serv]){
   for (pos = currentPos[serv]; pos < targetPos[serv]; pos += 1) {     // goes from 0 degrees to 180
degrees
     servo[serv].write(pos);                                  // tell servo to go to position in variable
'pos' increasing in increments of 1 degree
     delay(3);                                              // waits 3ms for the servo to commit the position
    }
  }


  if(currentPos[serv]>targetPos[serv]){
   for (pos = currentPos[serv]; pos < targetPos[serv] ; pos -= 1) {     // goes from 180 degrees to 0
degrees
     servo[serv].write(pos);                                   // tell servo to go to position in variable
'pos' decreasing in increments of 1 degree
     delay(3);                                               // waits 3ms for the servo to commit the
position
    }
```

```
  }


    myoValDelta[serv]=targetPos[serv]-currentPos[serv];

    currentPos[serv]=targetPos[serv];                    // set the new stored position value to
the incoming one once completed

}



void inline shiftMatrixValues() {

/*

* This function shifts the most recent values for the operating parameters to a lower spot in the
array and eventually out of the array completely.

* This short running history is maintained  to detect the rate of change for the signals and help
regulate the acceleration motor position and acceleration

*/



      myoValStored[0][0]=myoValStored[0][1];
myoValStored[0][1]=myoValStored[0][2];          myoValStored[0][2]=myoValStored[0][3];
myoValStored[0][3]=myoValStored[0][4];          myoValStored[0][4]=myoValStored[0][5];
myoValStored[0][5]=myoValStored[0][6];          myoValStored[0][6]=myoValStored[0][7];
myoValStored[0][7]=myoValStored[0][8];          myoValStored[0][8]=myoValStored[0][9];
myoValStored[0][9]=myoVal[0];

      myoValStored[1][0]=myoValStored[1][1];
myoValStored[1][1]=myoValStored[1][2];          myoValStored[1][2]=myoValStored[1][3];
myoValStored[1][3]=myoValStored[1][4];          myoValStored[1][4]=myoValStored[1][5];
myoValStored[1][5]=myoValStored[1][6];          myoValStored[1][6]=myoValStored[1][7];
myoValStored[1][7]=myoValStored[1][8];          myoValStored[1][8]=myoValStored[1][9];
myoValStored[1][9]=myoVal[1];

      myoValStored[2][0]=myoValStored[2][1];
myoValStored[2][1]=myoValStored[2][2];          myoValStored[2][2]=myoValStored[2][3];
myoValStored[2][3]=myoValStored[2][4];          myoValStored[2][4]=myoValStored[2][5];
myoValStored[2][5]=myoValStored[2][6];          myoValStored[2][6]=myoValStored[2][7];
```

```
myoValStored[2][7]=myoValStored[2][8];          myoValStored[2][8]=myoValStored[2][9];
myoValStored[2][9]=myoVal[2];

    myoValStored[3][0]=myoValStored[3][1];
myoValStored[3][1]=myoValStored[3][2];          myoValStored[3][2]=myoValStored[3][3];
myoValStored[3][3]=myoValStored[3][4];          myoValStored[3][4]=myoValStored[3][5];
myoValStored[3][5]=myoValStored[3][6];          myoValStored[3][6]=myoValStored[3][7];
myoValStored[3][7]=myoValStored[3][8];          myoValStored[3][8]=myoValStored[3][9];
myoValStored[3][9]=myoVal[3];

    myoValStored[4][0]=myoValStored[4][1];
myoValStored[4][1]=myoValStored[4][2];          myoValStored[4][2]=myoValStored[4][3];
myoValStored[4][3]=myoValStored[4][4];          myoValStored[4][4]=myoValStored[4][5];
myoValStored[4][5]=myoValStored[4][6];          myoValStored[4][6]=myoValStored[4][7];
myoValStored[4][7]=myoValStored[4][8];          myoValStored[4][8]=myoValStored[4][9];
myoValStored[4][9]=myoVal[4];

    myoValDeltaStored[0][0]=myoValDeltaStored[0][1];
myoValDeltaStored[0][1]=myoValDeltaStored[0][2];
myoValDeltaStored[0][2]=myoValDeltaStored[0][3];
myoValDeltaStored[0][3]=myoValDeltaStored[0][4];
myoValDeltaStored[0][4]=myoValDeltaStored[0][5];
myoValDeltaStored[0][5]=myoValDeltaStored[0][6];
myoValDeltaStored[0][6]=myoValDeltaStored[0][7];
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myoValDeltaStored[0][8]=myoValDeltaStored[0][9];
myoValDeltaStored[0][9]=myoValDelta[0];

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myoValDeltaStored[1][2]=myoValDeltaStored[1][3];
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myoValDeltaStored[1][7]=myoValDeltaStored[1][8];
myoValDeltaStored[1][8]=myoValDeltaStored[1][9];
myoValDeltaStored[1][9]=myoValDelta[1];

    myoValDeltaStored[2][0]=myoValDeltaStored[2][1];
myoValDeltaStored[2][1]=myoValDeltaStored[2][2];
myoValDeltaStored[2][2]=myoValDeltaStored[2][3];
myoValDeltaStored[2][3]=myoValDeltaStored[2][4];
myoValDeltaStored[2][4]=myoValDeltaStored[2][5];
myoValDeltaStored[2][5]=myoValDeltaStored[2][6];
```

```
myoValDeltaStored[2][6]=myoValDeltaStored[2][7];
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myoValDeltaStored[2][8]=myoValDeltaStored[2][9];
myoValDeltaStored[2][9]=myoValDelta[2];

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myoValDeltaStored[3][1]=myoValDeltaStored[3][2];
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pressValStored[0][3]=pressValStored[0][4];      pressValStored[0][4]=pressValStored[0][5];
pressValStored[0][5]=pressValStored[0][6];      pressValStored[0][6]=pressValStored[0][7];
pressValStored[0][7]=pressValStored[0][8];      pressValStored[0][8]=pressValStored[0][9];
pressValStored[0][9]=pressVal[0];

    pressValStored[1][0]=pressValStored[1][1];
pressValStored[1][1]=pressValStored[1][2];      pressValStored[1][2]=pressValStored[1][3];
pressValStored[1][3]=pressValStored[1][4];      pressValStored[1][4]=pressValStored[1][5];
pressValStored[1][5]=pressValStored[1][6];      pressValStored[1][6]=pressValStored[1][7];
pressValStored[1][7]=pressValStored[1][8];      pressValStored[1][8]=pressValStored[1][9];
pressValStored[1][9]=pressVal[1];

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pressValStored[2][1]=pressValStored[2][2];      pressValStored[2][2]=pressValStored[2][3];
pressValStored[2][3]=pressValStored[2][4];      pressValStored[2][4]=pressValStored[2][5];
pressValStored[2][5]=pressValStored[2][6];      pressValStored[2][6]=pressValStored[2][7];
```

```
pressValStored[2][7]=pressValStored[2][8];      pressValStored[2][8]=pressValStored[2][9];
pressValStored[2][9]=pressVal[2];

    pressValStored[3][0]=pressValStored[3][1];
pressValStored[3][1]=pressValStored[3][2];      pressValStored[3][2]=pressValStored[3][3];
pressValStored[3][3]=pressValStored[3][4];      pressValStored[3][4]=pressValStored[3][5];
pressValStored[3][5]=pressValStored[3][6];      pressValStored[3][6]=pressValStored[3][7];
pressValStored[3][7]=pressValStored[3][8];      pressValStored[3][8]=pressValStored[3][9];
pressValStored[3][9]=pressVal[3];

    pressValStored[4][0]=pressValStored[4][1];
pressValStored[4][1]=pressValStored[4][2];      pressValStored[4][2]=pressValStored[4][3];
pressValStored[4][3]=pressValStored[4][4];      pressValStored[4][4]=pressValStored[4][5];
pressValStored[4][5]=pressValStored[4][6];      pressValStored[4][6]=pressValStored[4][7];
pressValStored[4][7]=pressValStored[4][8];      pressValStored[4][8]=pressValStored[4][9];
pressValStored[4][9]=pressVal[4];

    pressValStored[5][0]=pressValStored[5][1];
pressValStored[5][1]=pressValStored[5][2];      pressValStored[5][2]=pressValStored[5][3];
pressValStored[5][3]=pressValStored[5][4];      pressValStored[5][4]=pressValStored[5][5];
pressValStored[5][5]=pressValStored[5][6];      pressValStored[5][6]=pressValStored[5][7];
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pressValStored[5][9]=pressVal[5];

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pressValStored[6][1]=pressValStored[6][2];      pressValStored[6][2]=pressValStored[6][3];
pressValStored[6][3]=pressValStored[6][4];      pressValStored[6][4]=pressValStored[6][5];
pressValStored[6][5]=pressValStored[6][6];      pressValStored[6][6]=pressValStored[6][7];
pressValStored[6][7]=pressValStored[6][8];      pressValStored[6][8]=pressValStored[6][9];
pressValStored[6][9]=pressVal[6];

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pressValStored[7][1]=pressValStored[7][2];      pressValStored[7][2]=pressValStored[7][3];
pressValStored[7][3]=pressValStored[7][4];      pressValStored[7][4]=pressValStored[7][5];
pressValStored[7][5]=pressValStored[7][6];      pressValStored[7][6]=pressValStored[7][7];
pressValStored[7][7]=pressValStored[7][8];      pressValStored[7][8]=pressValStored[7][9];
pressValStored[7][9]=pressVal[7];

    pressValDeltaStored[0][0]=pressValDeltaStored[0][1];
pressValDeltaStored[0][1]=pressValDeltaStored[0][2];
pressValDeltaStored[0][2]=pressValDeltaStored[0][3];
pressValDeltaStored[0][3]=pressValDeltaStored[0][4];
pressValDeltaStored[0][4]=pressValDeltaStored[0][5];
pressValDeltaStored[0][5]=pressValDeltaStored[0][6];
pressValDeltaStored[0][6]=pressValDeltaStored[0][7];
pressValDeltaStored[0][7]=pressValDeltaStored[0][8];
```

```
pressValDeltaStored[0][8]=pressValDeltaStored[0][9];
pressValDeltaStored[0][9]=pressValDelta[0];

    pressValDeltaStored[1][0]=pressValDeltaStored[1][1];
pressValDeltaStored[1][1]=pressValDeltaStored[1][2];
pressValDeltaStored[1][2]=pressValDeltaStored[1][3];
pressValDeltaStored[1][3]=pressValDeltaStored[1][4];
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pressValDeltaStored[1][7]=pressValDeltaStored[1][8];
pressValDeltaStored[1][8]=pressValDeltaStored[1][9];
pressValDeltaStored[1][9]=pressValDelta[1];

    pressValDeltaStored[2][0]=pressValDeltaStored[2][1];
pressValDeltaStored[2][1]=pressValDeltaStored[2][2];
pressValDeltaStored[2][2]=pressValDeltaStored[2][3];
pressValDeltaStored[2][3]=pressValDeltaStored[2][4];
pressValDeltaStored[2][4]=pressValDeltaStored[2][5];
pressValDeltaStored[2][5]=pressValDeltaStored[2][6];
pressValDeltaStored[2][6]=pressValDeltaStored[2][7];
pressValDeltaStored[2][7]=pressValDeltaStored[2][8];
pressValDeltaStored[2][8]=pressValDeltaStored[2][9];
pressValDeltaStored[2][9]=pressValDelta[2];

    pressValDeltaStored[3][0]=pressValDeltaStored[3][1];
pressValDeltaStored[3][1]=pressValDeltaStored[3][2];
pressValDeltaStored[3][2]=pressValDeltaStored[3][3];
pressValDeltaStored[3][3]=pressValDeltaStored[3][4];
pressValDeltaStored[3][4]=pressValDeltaStored[3][5];
pressValDeltaStored[3][5]=pressValDeltaStored[3][6];
pressValDeltaStored[3][6]=pressValDeltaStored[3][7];
pressValDeltaStored[3][7]=pressValDeltaStored[3][8];
pressValDeltaStored[3][8]=pressValDeltaStored[3][9];
pressValDeltaStored[3][9]=pressValDelta[3];

    pressValDeltaStored[4][0]=pressValDeltaStored[4][1];
pressValDeltaStored[4][1]=pressValDeltaStored[4][2];
pressValDeltaStored[4][2]=pressValDeltaStored[4][3];
pressValDeltaStored[4][3]=pressValDeltaStored[4][4];
pressValDeltaStored[4][4]=pressValDeltaStored[4][5];
pressValDeltaStored[4][5]=pressValDeltaStored[4][6];
pressValDeltaStored[4][6]=pressValDeltaStored[4][7];
pressValDeltaStored[4][7]=pressValDeltaStored[4][8];
```

```
pressValDeltaStored[4][8]=pressValDeltaStored[4][9];
pressValDeltaStored[4][9]=pressValDelta[4];

    pressValDeltaStored[5][0]=pressValDeltaStored[5][1];
pressValDeltaStored[5][1]=pressValDeltaStored[5][2];
pressValDeltaStored[5][2]=pressValDeltaStored[5][3];
pressValDeltaStored[5][3]=pressValDeltaStored[5][4];
pressValDeltaStored[5][4]=pressValDeltaStored[5][5];
pressValDeltaStored[5][5]=pressValDeltaStored[5][6];
pressValDeltaStored[5][6]=pressValDeltaStored[5][7];
pressValDeltaStored[5][7]=pressValDeltaStored[5][8];
pressValDeltaStored[5][8]=pressValDeltaStored[5][9];
pressValDeltaStored[5][9]=pressValDelta[5];

    pressValDeltaStored[6][0]=pressValDeltaStored[6][1];
pressValDeltaStored[6][1]=pressValDeltaStored[6][2];
pressValDeltaStored[6][2]=pressValDeltaStored[6][3];
pressValDeltaStored[6][3]=pressValDeltaStored[6][4];
pressValDeltaStored[6][4]=pressValDeltaStored[6][5];
pressValDeltaStored[6][5]=pressValDeltaStored[6][6];
pressValDeltaStored[6][6]=pressValDeltaStored[6][7];
pressValDeltaStored[6][7]=pressValDeltaStored[6][8];
pressValDeltaStored[6][8]=pressValDeltaStored[6][9];
pressValDeltaStored[6][9]=pressValDelta[6];

    pressValDeltaStored[7][0]=pressValDeltaStored[7][1];
pressValDeltaStored[7][1]=pressValDeltaStored[7][2];
pressValDeltaStored[7][2]=pressValDeltaStored[7][3];
pressValDeltaStored[7][3]=pressValDeltaStored[7][4];
pressValDeltaStored[7][4]=pressValDeltaStored[7][5];
pressValDeltaStored[7][5]=pressValDeltaStored[7][6];
pressValDeltaStored[7][6]=pressValDeltaStored[7][7];
pressValDeltaStored[7][7]=pressValDeltaStored[7][8];
pressValDeltaStored[7][8]=pressValDeltaStored[7][9];
pressValDeltaStored[7][9]=pressValDelta[7];

}



void inline averagedSensorRead(){

  for(int sr=0;sr<=10;sr++)

  {
```

```
                                /*read muscle sensors*/
    myoValWorking[0] += analogRead(A0);       //Read thumb
    myoValWorking[1] += analogRead(A1);       //Read index
    myoValWorking[2] += analogRead(A2);       //Read middle
    myoValWorking[3] += analogRead(A3);       //Read ring
    myoValWorking[4] += analogRead(A4);       //Read pinky


                                /*read pressure sensors*/
    pressValWorking[0] += analogRead(A5);       //Read thumb
    pressValWorking[1] += analogRead(A6);       //Read index
    pressValWorking[2] += analogRead(A7);       //Read middle
    pressValWorking[3] += analogRead(A8);       //Read ring
    pressValWorking[4] += analogRead(A9);       //Read pinky
    pressValWorking[5] += analogRead(A10);      //Read Outside Lateral Palm
    pressValWorking[6] += analogRead(A11);      //Read Medial Palm
    pressValWorking[7] += analogRead(A12);      //Read Inside Lateral Palm
  }
                                //After sum of 10 high speed reads for each sensor, set value to
average of those
    myoVal[0] = myoValWorking[0]/10;          //This is done to reduce the affects of any noise or
random value spikes
    myoVal[1] = myoValWorking[1]/10;
    myoVal[2] = myoValWorking[2]/10;
    myoVal[3] = myoValWorking[3]/10;
    myoVal[4] = myoValWorking[4]/10;


    pressVal[0] = pressValWorking[0]/10;
    pressVal[1] = pressValWorking[1]/10;
```

```
    pressVal[2] = pressValWorking[2]/10;
    pressVal[3] = pressValWorking[3]/10;
    pressVal[4] = pressValWorking[4]/10;
    pressVal[5] = pressValWorking[5]/10;
    pressVal[6] = pressValWorking[6]/10;
    pressVal[7] = pressValWorking[7]/10;




}

void inline sendCurrentVals(){
/*
* Transmit values of all monitored parameters to a listening serial connected device
* Most likely this will be rhe interface written for the device which provides
* monitoring and calibration.
*/

    /*Send myo sensors*/
    Serial.print("DAT:|m[0]=");
    Serial.print(myoVal[0]);

    Serial.print("|m[1]=");
    Serial.print(myoVal[1]);

    Serial.print("|m[2]=");
    Serial.print(myoVal[2]);
```

```
Serial.print("|m[3]=");
Serial.print(myoVal[3]);

Serial.print("|m[4]=");
Serial.print(myoVal[4]);


/*Send presure sensors*/
Serial.print("|p[0]=");
Serial.print(pressVal[0]);

Serial.print("|p[1]=");
Serial.print(pressVal[1]);

Serial.print("|p[2]=");
Serial.print(pressVal[2]);

Serial.print("|p[3]=");
Serial.print(pressVal[3]);

Serial.print("|p[4]=");
Serial.print(pressVal[4]);

Serial.print("|p[5]=");
Serial.print(pressVal[5]);

Serial.print("|p[6]=");
```

```
Serial.print(pressVal[6]);

Serial.print("|p[7]=");
Serial.print(pressVal[7]);

Serial.print("|p[8]=");
Serial.print(pressVal[8]);

/*Send motor positions*/
Serial.print("|c[0]=");
Serial.print(currentPos[0]);

Serial.print("|c[1]=");
Serial.print(currentPos[1]);

Serial.print("|c[2]=");
Serial.print(currentPos[2]);

Serial.print("|c[3]=");
Serial.print(currentPos[3]);

Serial.print("|c[4]=");
Serial.print(currentPos[4]);

/*
Serial.print(" t[0]=");
Serial.print(targetPos[0]);
```

```
    Serial.print(" t[1]=");
    Serial.print(targetPos[1]);

    Serial.print(" t[2]=");
    Serial.print(targetPos[2]);

    Serial.print(" t[3]=");
    Serial.print(targetPos[3]);

    Serial.print(" t[4]=");
    Serial.print(targetPos[4]);
    */

    Serial.print("\n");
}

int inline decodeOp(char opCodeChar[]){
  if(strcmp(opCodeChar,"HEL")==0) {return 7966;}
  if(strcmp(opCodeChar,"RST")==0) {return 9114;}
  if(strcmp(opCodeChar,"CAL")==0) {return 7426;}
  if(strcmp(opCodeChar,"RSV")==0) {return 9116;}
  if(strcmp(opCodeChar,"RSA")==0) {return 9095;}
  if(strcmp(opCodeChar,"RMP")==0) {return 9050;}
  if(strcmp(opCodeChar,"PMD")==0) {return 8838;}
  if(strcmp(opCodeChar,"CMS")==0) {return 7553;}
  if(strcmp(opCodeChar,"UCA")==0) {return 9235;}
  if(strcmp(opCodeChar,"SOP")==0) {return 9170;}
  if(strcmp(opCodeChar,"000")==0) {return 5328;}
```

```
  if(strcmp(opCodeChar,"000")==0) {return 9768;}

  return 0;
}


void inline runReceivedCommands(char commandLine[]){
/*
*   If the glove is connected to a device by a serial cable commands can be issued to the glove
*   by the device. This function parses and calls routines to execure the provided commands.
*/

    int code=0;

    code = decodeOp(commandLine);

    switch (code){
      case 7966:    //HEL
          //Return Help Text

        break;

      case 9114:    //RST
          //Reset board as if powered off and back on

        break;

      case 7426:    //CAL
```

```
        //Enter calibration mode

        break;

    case 9116:    //RSV
        //Reads value from designated sensor

        break;

    case 9095:    //RSA
        //Reads value from designated sensor returning an average of a number of values sent as a parameter after sensor selectiion

        break;

    case 9050:    //RMP
        //Reads current setting for motor position

        break;

    case 8838:    //PMD
        //Position motor to given value of degrees

        break;

    case 7553:    //CMS
        //Cycle motors

        break;
```

```
  case 9235:    //UCA
     //User Calibration

    break;

  case 9170:    //SOP
     //Standard Operation
    break;

  case 5328:    //000
     //Pause code except for monitoring line for XXX command

    break;

  case 9768:    //XXX
     //Ends Pause Condition
     return;
    break;

  default:

  break;
}


return;
```

```
}


int inline  decodeOpParameter(char opCodeParam[]){
   return 0;
}


void loadCalibrationData(){
/*
* Reads the stored calibration data from longterm EEPROM storage to set the initial parameters input by the professional for their client
*/
  int addr=0;
  byte l;
  byte h;
  int bc=0;

  for(bc=0;bc<5;bc++){
    l=EEPROM.read(addr);
    addr++;
    h=EEPROM.read(addr);
    myoValMinThreshold[bc]=word(h,l);
    addr++;
  }

   for(bc=0;bc<5;bc++){
    l=EEPROM.read(addr);
    addr++;
```

```
  h=EEPROM.read(addr);
  myoValMaxThreshold[bc]=word(h,l);
  addr++;
}

for(bc=0;bc<5;bc++){
  l=EEPROM.read(addr);
  addr++;
  h=EEPROM.read(addr);
  myoValMultiplier[bc]=word(h,l);
  addr++;
}

for(bc=0;bc<8;bc++){
  l=EEPROM.read(addr);
  addr++;
  h=EEPROM.read(addr);
  pressValMinThreshold[bc]=word(h,l);
  addr++;
}

 for(bc=0;bc<8;bc++){
  l=EEPROM.read(addr);
  addr++;
  h=EEPROM.read(addr);
  pressValMaxThreshold[bc]=word(h,l);
  addr++;
}
```

```
  for(bc=0;bc<8;bc++){
    l=EEPROM.read(addr);
    addr++;
    h=EEPROM.read(addr);
    pressValMultiplier[bc]=word(h,l);
    addr++;
  }
}


void saveCalibrationData(){  //stores calibration level settings for user stores currently 78 bytes total
/*
* Persists calibration data sent through the serial port to long-term storage (EEPROM)
*/

  int addr=0;
  byte l;
  byte h;
  int bc=0;

  for(bc=0;bc<5;bc++){
    l=lowByte(myoValMinThreshold[bc]);
    h=highByte(myoValMinThreshold[bc]);
    EEPROM.write(addr, l);
    addr++;
    EEPROM.write(addr, h);
    addr++;
```

```
}

 for(bc=0;bc<5;bc++){
  l=lowByte(myoValMaxThreshold[bc]);
  h=highByte(myoValMaxThreshold[bc]);
  EEPROM.write(addr, l);
  addr++;
  EEPROM.write(addr, h);
  addr++;
}

for(bc=0;bc<5;bc++){
  l=lowByte(myoValMultiplier[bc]);
  h=highByte(myoValMultiplier[bc]);
  EEPROM.write(addr, l);
  addr++;
  EEPROM.write(addr, h);
  addr++;
}

for(bc=0;bc<8;bc++){
  l=lowByte(pressValMinThreshold[bc]);
  h=highByte(pressValMinThreshold[bc]);
  EEPROM.write(addr, l);
  addr++;
  EEPROM.write(addr, h);
  addr++;
}
```

```
  for(bc=0;bc<8;bc++){
   l=lowByte(pressValMaxThreshold[bc]);
   h=highByte(pressValMaxThreshold[bc]);
   EEPROM.write(addr, l);
   addr++;
   EEPROM.write(addr, h);
   addr++;
  }

  for(bc=0;bc<8;bc++){
   l=lowByte(pressValMultiplier[bc]);
   h=highByte(pressValMultiplier[bc]);
   EEPROM.write(addr, l);
   addr++;
   EEPROM.write(addr, h);
   addr++;
  }

}

void setup() {
// Initalize global arrays
  for(int svo=0;svo<10;svo++)
  {
    for(int svi=0;svi<5;svi++)
    {
      myoValStored[svi][svo]=0;
```

```
    myoValDeltaStored[svi][svo]=0;
   }

   for(int svi2=0;svi2<8;svi2++)
   {
    pressValStored[svi2][svo]=0;
    pressValDeltaStored[svi2][svo]=0;
   }
  }

//Retrieve long term stored calibration data
  loadCalibrationData();

                        /*Myosensor Pins*/
  pinMode(A0, INPUT);       /*Thumb*/
  pinMode(A1, INPUT);       /*Index*/
  pinMode(A2, INPUT);       /*Middle*/
  pinMode(A3, INPUT);       /*Ring*/
  pinMode(A4, INPUT);       /*Pinky*/

  /*Pressure senspor pins*/
  pinMode(A5, INPUT);
  pinMode(A6, INPUT);
  pinMode(A7, INPUT);
  pinMode(A8, INPUT);
  pinMode(A9, INPUT);
  pinMode(A10, INPUT);
  pinMode(A11, INPUT);
```

```
  pinMode(A12, INPUT);

  /*Motor movement pins*/
  pinMode(8, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(10, OUTPUT);
  pinMode(11, OUTPUT);
  pinMode(12, OUTPUT);

// attaches the servos on pins 8-12 to the servo objects
  servo[0].attach(8);
  servo[1].attach(9);
  servo[2].attach(10);
  servo[3].attach(11);
  servo[4].attach(12);

  Serial.begin(115200);          //  setup serial
  positionServo=0;
  for(positionServo=0;positionServo<5;positionServo+=1){
    setPosition(0,positionServo);
  }
  positionServo=0;
  for(positionServo=0;positionServo<5;positionServo+=1){
    setPosition(180,positionServo);
    currentPos[positionServo] = 0;
    targetPos[positionServo] = 180;
  }
```

```
  if (Serial) {
    Serial.println("----------------------");
    Serial.println("Connection established");
    Serial.println("----------------------");
    Serial.println();
    serialConnected = true;
  }
}
void loop() {
  if(Serial.available()>0){
    runReceivedCommands();
  }

  if(Serial.available()<1){

    averagedSensorRead();
    positionServo=0;
    for(positionServo=0;positionServo<5;positionServo+=1){
      if((pressVal[positionServo]>pressValMinThreshold[positionServo]) &&
(pressVal[positionServo]<pressValMaxThreshold[positionServo])}{     //Check if pressure
readings are within limits
        setPosition(myoVal[positionServo],positionServo);
//If within limits, move motor
        delay(15);
        shiftMatrixValues();
      }
    }
    if(verbose){
      sendCurrentVals();
```

```
    }
  }
}
```

26. Appendix I: FEA/Calculations

26.1 FEA

i. GEOMETRY

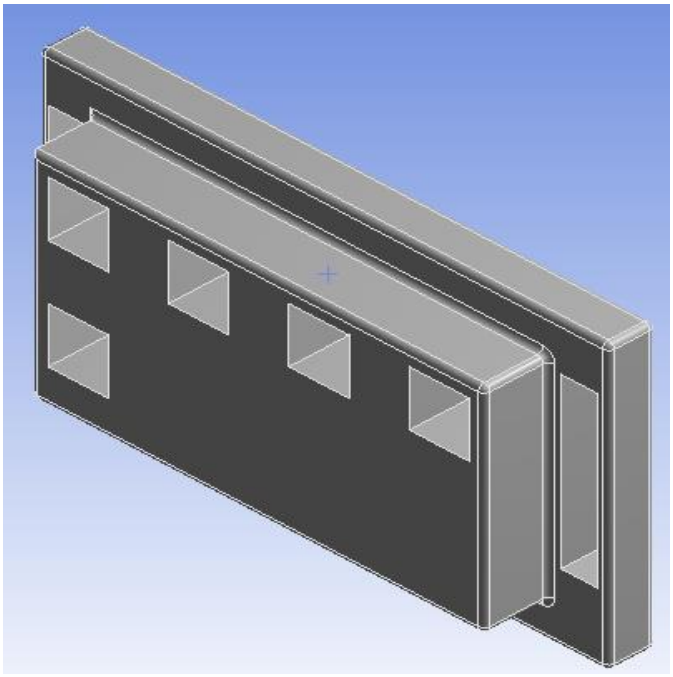


Figure 59. 3D model of spring plate

Bounding Box	
Length X	61.5 mm
Length Y	33.6 mm
Length Z	12.08 mm
Properties	
Volume	16011 mm^3
Mass	0. kg
Centroid X	33.864 mm
Centroid Y	20.195 mm
Centroid Z	5.2248 mm
Moment of Inertia ...	0. $kg \cdot mm^2$
Moment of Inertia ...	0. $kg \cdot mm^2$
Moment of Inertia ...	0. $kg \cdot mm^2$
Statistics	
Nodes	9210
Elements	5042
Mesh Metric	None

Figure 60. Chart for spring plate model geometry information from ANSYS report

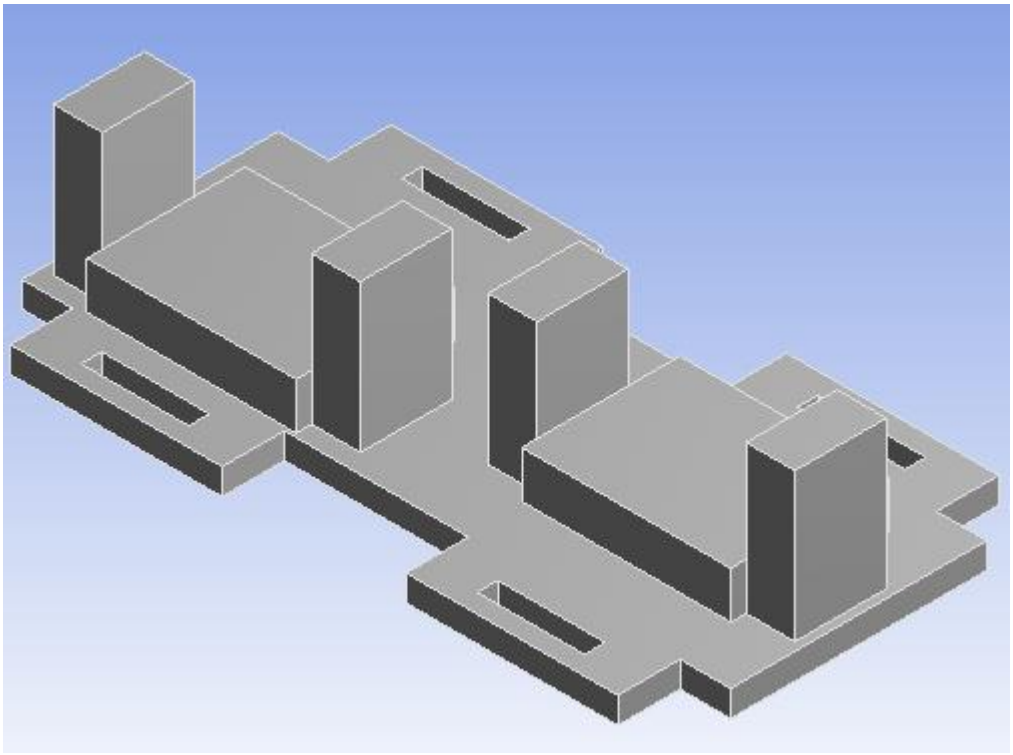


Figure 61. 3D model of servomotor holder 1

Material	
Assignment	PLA
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Properties	
Volume	4.9791 in^3
Mass	0. lbm
Centroid X	2.692 in
Centroid Y	0.31378 in
Centroid Z	-1.345 in
Moment of Inertia Ip1	0. $lbm \cdot in^2$
Moment of Inertia Ip2	0. $lbm \cdot in^2$
Moment of Inertia Ip3	0. $lbm \cdot in^2$

Figure 62. Chart for servomotor holder 1 model geometry information from ANSYS report

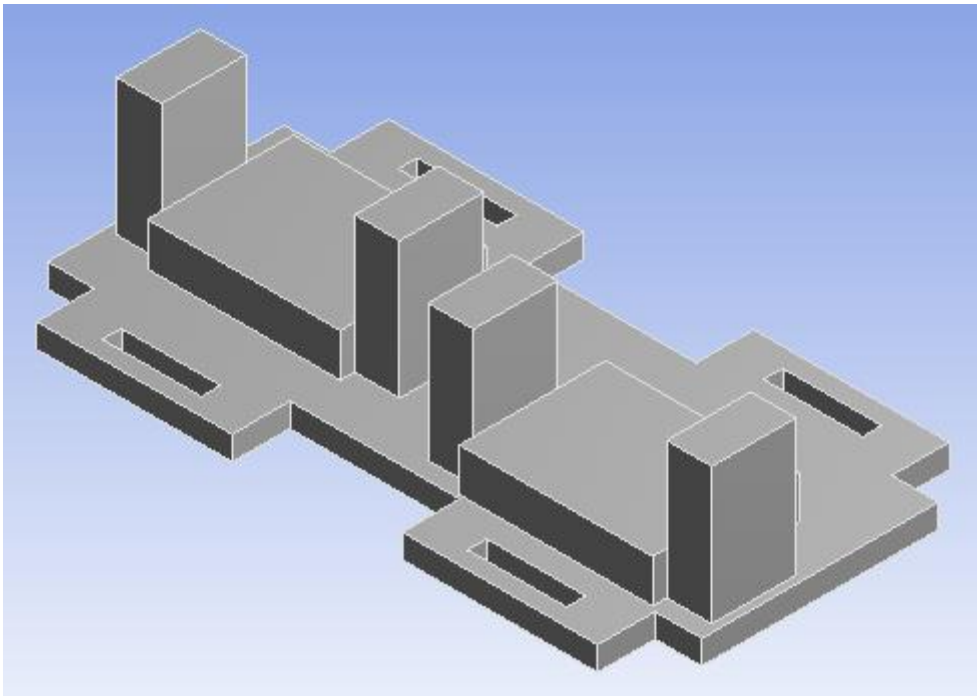


Figure 63. 3D model servomotor holder 2

Material	
Assignment	PLA
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Properties	
Volume	81593 mm^3
Mass	0. kg
Centroid X	68.378 mm
Centroid Y	7.9699 mm
Centroid Z	-33.675 mm
Moment of Inertia ...	0. $kg \cdot mm^2$
Moment of Inertia ...	0. $kg \cdot mm^2$
Moment of Inertia ...	0. $kg \cdot mm^2$

Figure 64. Chart for servomotor holder 2 model geometry information from ANSYS report

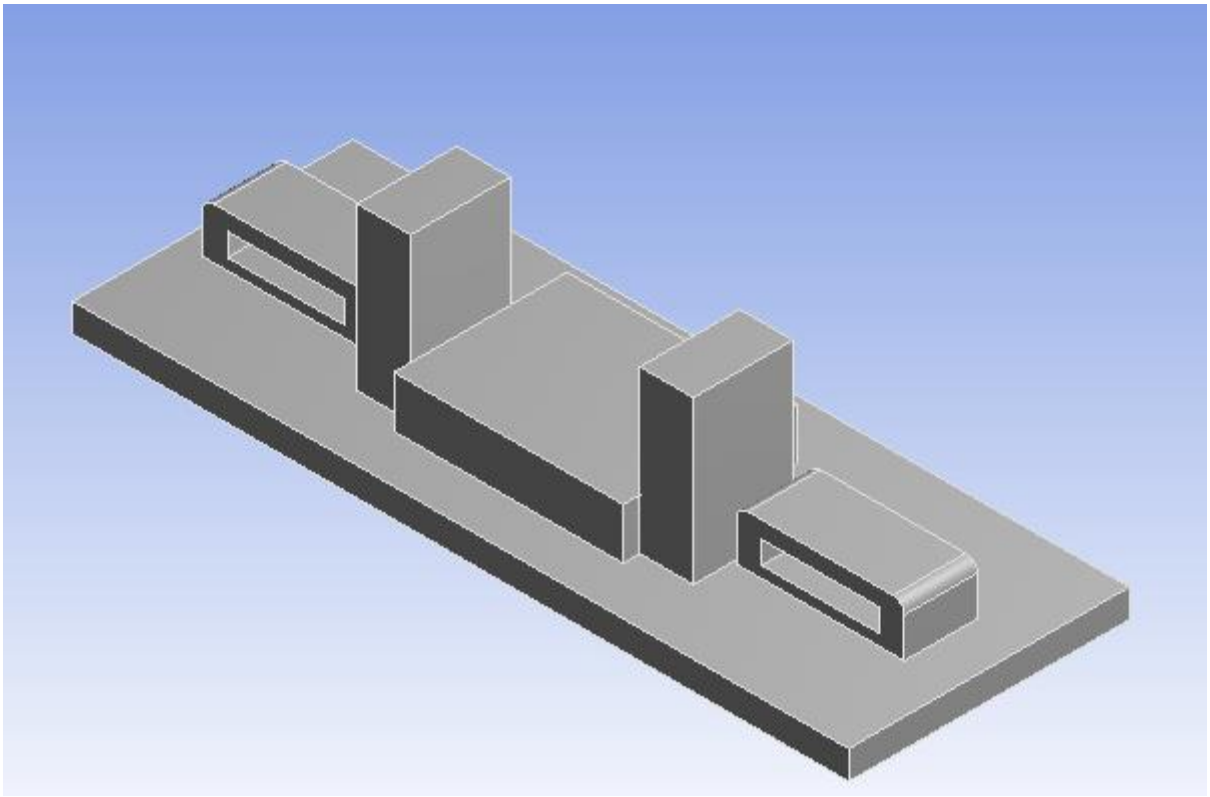


Figure 65. 3D model servomotor holder 3

Material	
Assignment	PLA
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Properties	
Volume	58185 mm^3
Mass	0. kg
Centroid X	68.038 mm
Centroid Y	6.9083 mm
Centroid Z	-35.769 mm
Moment of Inertia ...	0. $kg \cdot mm^2$
Moment of Inertia ...	0. $kg \cdot mm^2$
Moment of Inertia ...	0. $kg \cdot mm^2$

Figure 66. Chart for servomotor holder 3 model geometry information from ANSYS report

ii. MESH

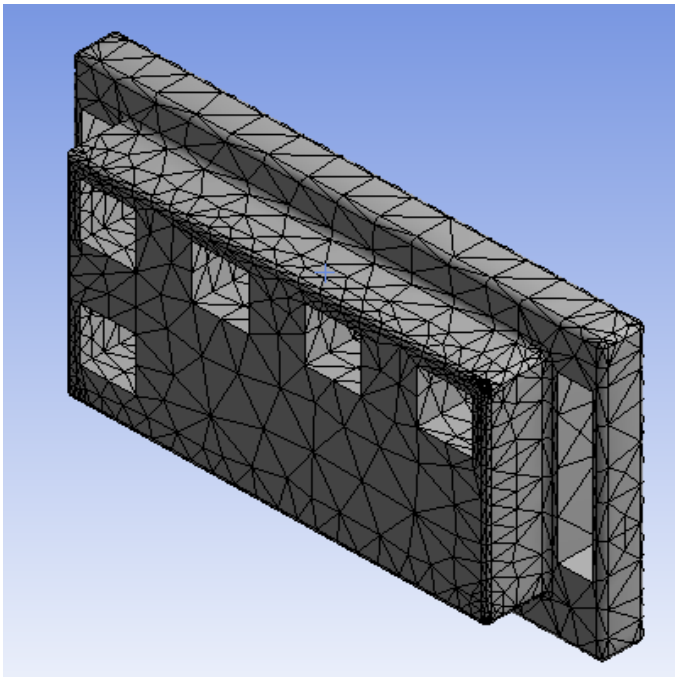


Figure 67. Figure. Meshed geometry of spring plate

Inflation	
Use Autom...	None
Inflation O...	Smooth Transition
Transiti...	0.272
Maximu...	5
Growth ...	1.2
Inflation Al...	Pre
View Adva...	No
Advanced	
Number of ...	Program Controlled
Straight Si...	No
Rigid Body...	Dimensionally Reduced
Triangle Su...	Program Controlled
Topology C...	Yes
Pinch Toler...	Please Define
Generate P...	No
Statistics	
Nodes	12710
Elements	7633

Figure 68. Mesh details from ANSYS report (spring plate)

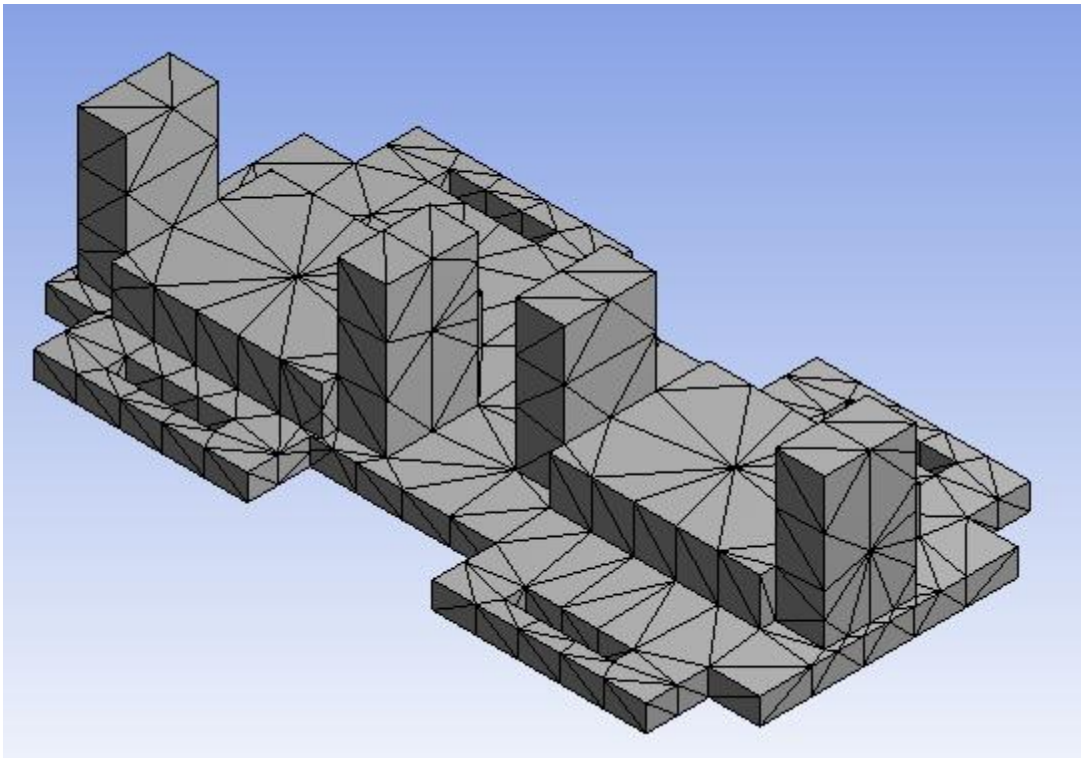


Figure 69. Meshed geometry of servo motor holder 1

Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
☐ Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	158.44 mm
Average Surface Area	326.33 mm^2
Minimum Edge Length	2.0124 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
☐ Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None

Figure 70. Mesh details from ANSYS report (servo motor holder 1)

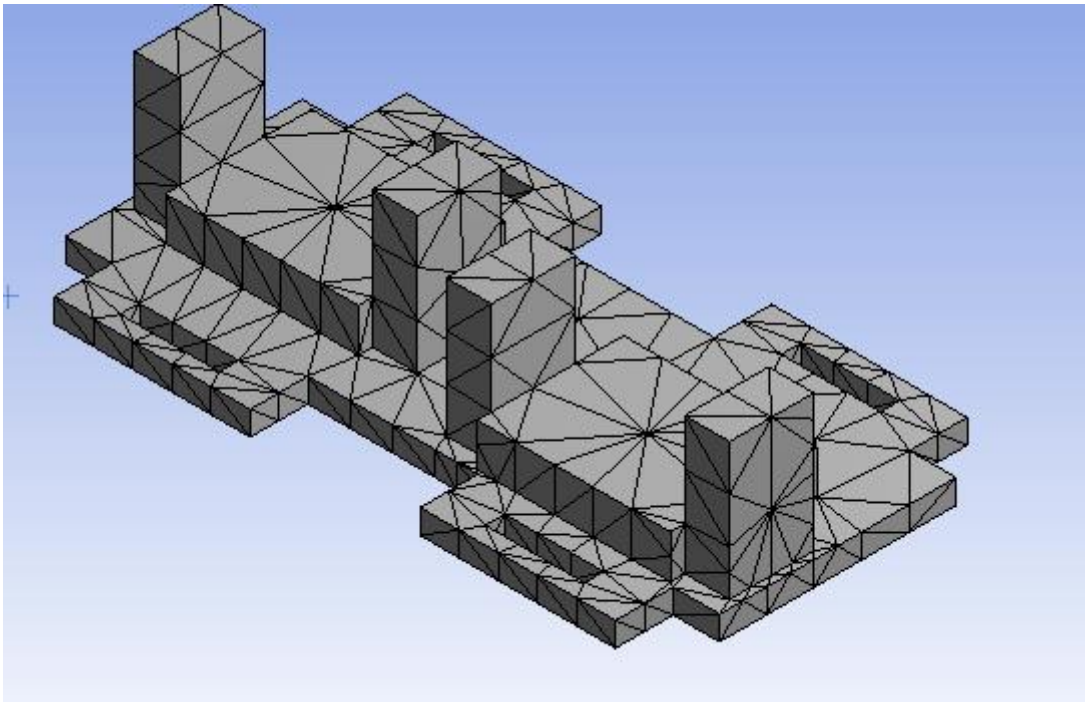


Figure 71. Meshed geometry of servo motor holder 2

Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
☐ Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	158.44 mm
Average Surface Area	326.33 mm^2
Minimum Edge Length	2.0124 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
☐ Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None

Figure 72. Mesh details from ANSYS report (servo motor holder 2)

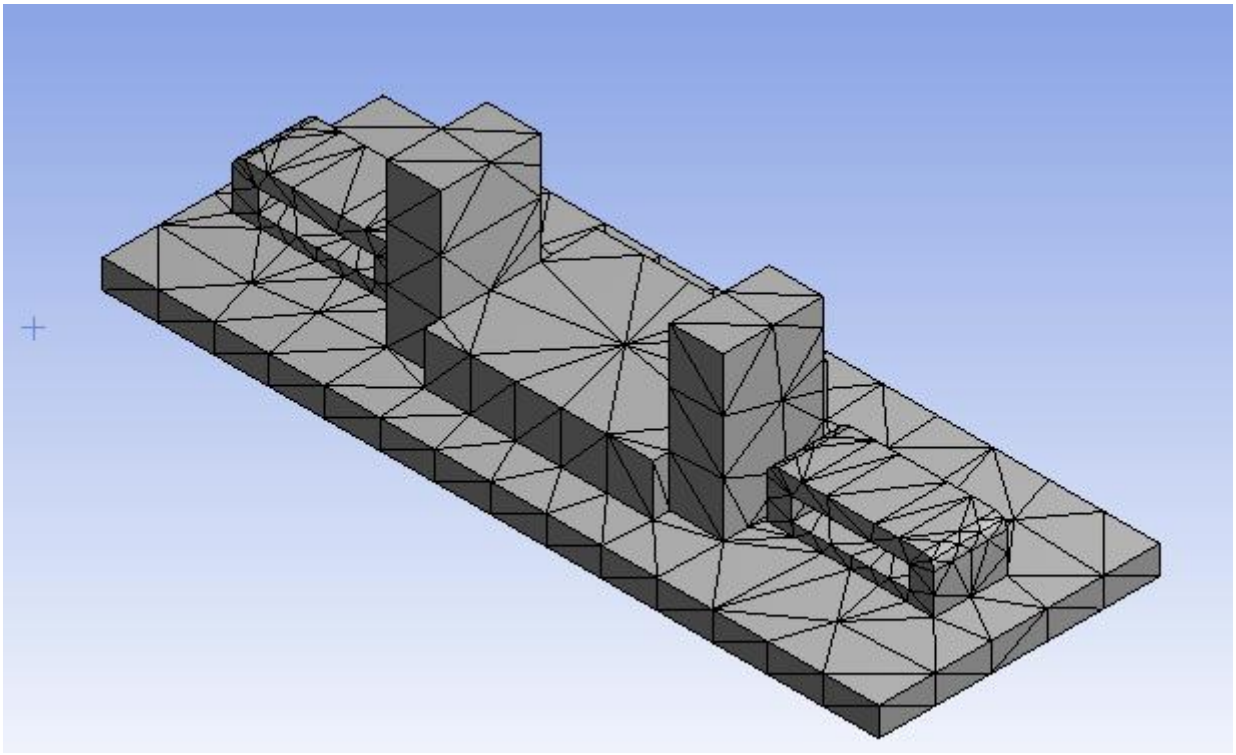


Figure 73. Meshed geometry of servo motor holder 3

Element Size	10.0 mm
Sizing	
Use Adaptive Sizing	Yes
Resolution	Default (2)
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Coarse
Initial Size Seed	Assembly
Bounding Box Diagonal	148.86 mm
Average Surface Area	416.23 mm^2
Minimum Edge Length	2.0124 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None

Figure 74. Mesh details from ANSYS report (servo motor holder 3)

iii. BOUNDARY CONDITIONS

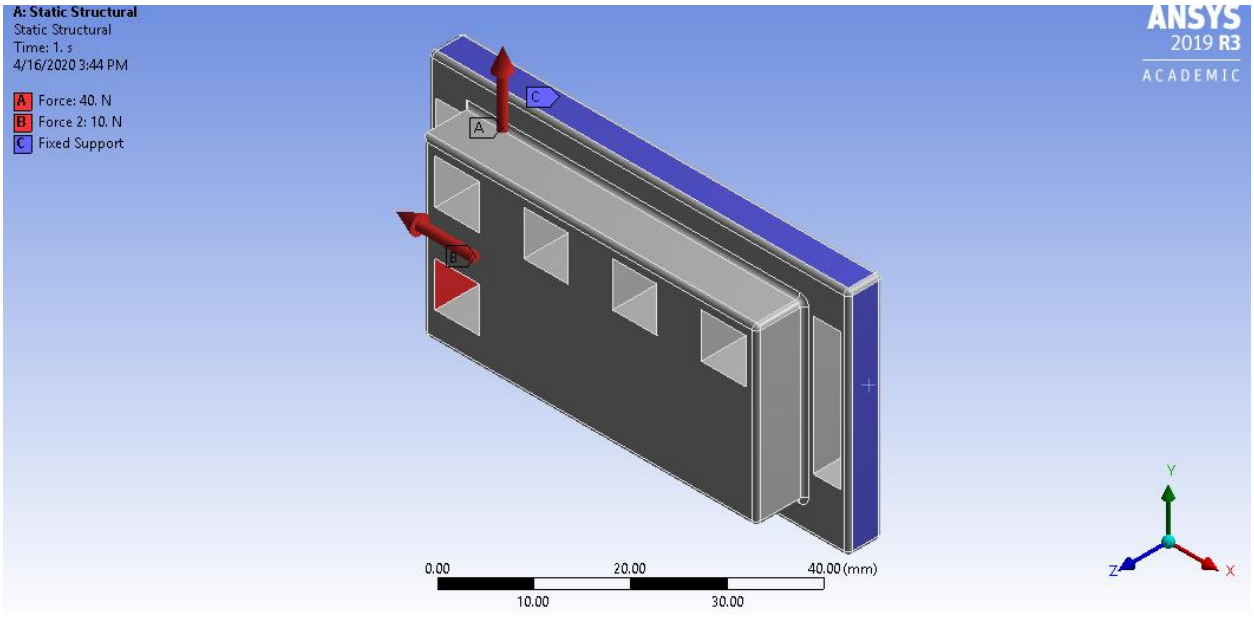


Figure 75. Boundary conditions applied (Spring plate)

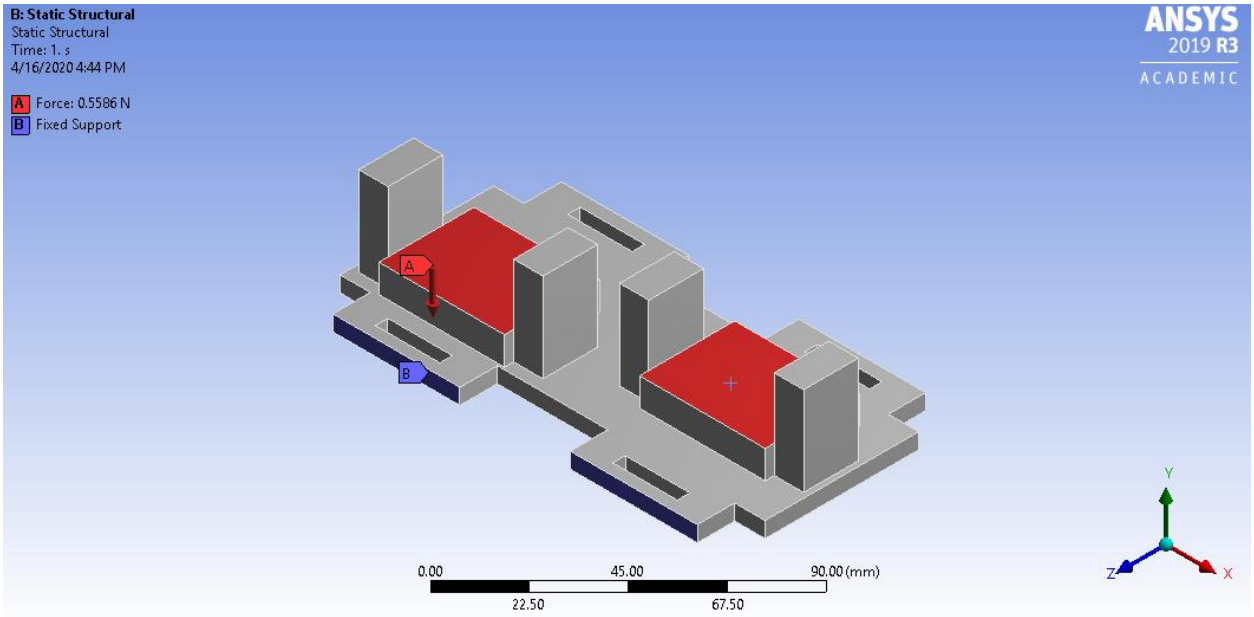


Figure 76. Boundary conditions applied (servo motor holder 1)

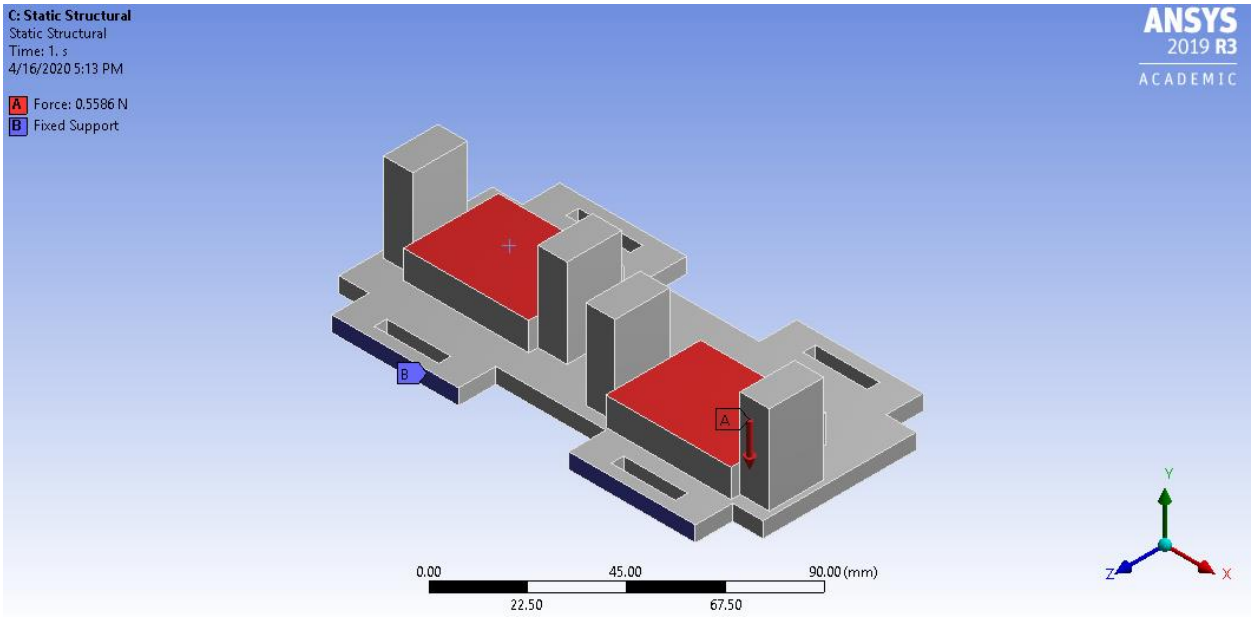


Figure 77. Boundary conditions applied (servo motor holder 2)

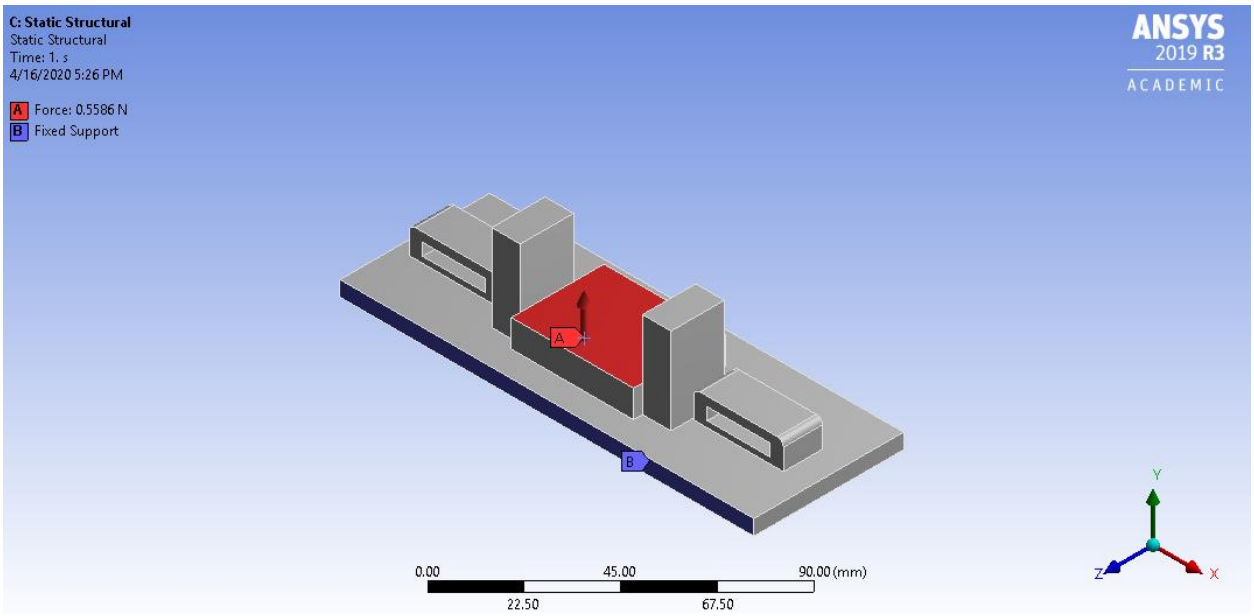


Figure 78. Boundary conditions applied (servo motor holder 2)

iv. EQUIVALENT STRESS

Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	9.0487e-006 MPa
Maximum	0.93225 MPa
Average	0.11455 MPa
Minimum Occurs On	sp-2-FreeParts|Solid1

Figure 79. Results obtained in ANSYS for equivalent stress (Spring plate)

Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	3.7243e-006 MPa
Maximum	9.5094e-003 MPa
Average	9.0014e-004 MPa
Minimum Occurs On	Servomotor_holder_1- ...
Maximum Occurs On	Servomotor_holder_1- ...

Figure 80. Results obtained in ANSYS for equivalent stress (Servomotor holder 1)

Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	3.348e-006 MPa
Maximum	9.8849e-003 MPa
Average	9.1735e-004 MPa
Minimum Occurs On	Servomotor_holder_2- ...
Maximum Occurs On	Servomotor_holder_2- ...

Figure 81. Results obtained in ANSYS for equivalent stress (Servomotor holder 2)

Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	2.6444e-006 MPa
Maximum	4.5569e-003 MPa
Average	3.3911e-004 MPa
Minimum Occurs On	Servomotor_holder_3- ..
Maximum Occurs On	Servomotor_holder_3- ..

Figure 82. Results obtained in ANSYS for equivalent stress (Servomotor holder 3)

v. TOTAL DEFORMATION

Definition	
Type	Total Deformation
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm
Maximum	0.29737 mm
Average	4.6074e-002 mm
Minimum Occurs On	sp-2-FreeParts|Solid1

Figure 83. Results obtained after deformation analysis from ANSYS report (spring plate)

Definition	
Type	Total Deformation
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm
Maximum	1.7622e-002 mm
Average	1.1778e-002 mm
Minimum Occurs On	Servomotor_holder_1- ...
Maximum Occurs On	Servomotor_holder_1- ...

Figure 84. Results obtained after deformation analysis from ANSYS report servo motor holder 1)

Definition	
Type	Total Deformation
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm
Maximum	1.7826e-002 mm
Average	1.1856e-002 mm
Minimum Occurs On	Servomotor_holder_2- Cop..
Maximum Occurs On	Servomotor_holder_2- Cop..

Figure 85. Results obtained after deformation analysis from ANSYS report (servo motor holder 2)

Definition	
Type	Total Deformation
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
Minimum	0. mm
Maximum	2.976e-003 mm
Average	1.3855e-003 mm
Minimum Occurs On	Servomotor_holder_3- Cop...
Maximum Occurs On	Servomotor_holder_3- Cop...

Figure 86. Results obtained after deformation analysis from ANSYS report (servo motor holder 3)

26.2 Calculations

Phalanx Lengths

$L_{DP} = 16\ mm$	$L_{MP} = 23\ mm$	$L_{PP} = 40\ mm$

Angle of Joints

$\theta_{DIP} = 20\ °$	$\theta_{PIP} = 45\ °$	$\theta_{MCP} = 45\ °$
$\theta_1 = 90\ ° - \theta_{DIP} = 700\ °$	$\theta_2 = 90\ ° - \theta_{PIP} = 45\ °$	$\theta_3 = 90° - \theta_{MCP} = 45\ °$

Joint Thickness

$l_{DIP} = 13\ mm$	$l_{PIP} = 17\ mm$	$l_{MCP} = 28\ mm$

Spring

$k = .1090\ {}^{N}/_{mm}$	$L_s = 28.58\ mm$

Servo motor

$D_m = 18\ mm$

User Force

$F_i = 1.31\ lbf$

Positioning

$x = L_{PP} \times \cos(\theta_{MCP}) + L_{MP} \times \cos(\theta_{MCP} + \theta_{PIP}) + L_{DP} \times \cos(\theta_{MCP} + \theta_{PIP} + \theta_{DIP}) = 0.023\ m$
$x = L_{PP} \times \sin(\theta_{MCP}) + L_{MP} \times \sin(\theta_{MCP} + \theta_{PIP}) + L_{DP} \times \sin(\theta_{MCP} + \theta_{PIP} + \theta_{DIP}) = 0.066\ m$
$\emptyset = \theta_{MCP} + \theta_{PIP} + \theta_{DIP} = 111\ °$

Maximum Displacement of wire length

$x_{max} = \left(\left(\frac{l_{MCP}}{2} \times \sin\left(\frac{\theta_{MCP}}{2}\right)\right) + \left(\frac{l_{PIP}}{2} \times \sin\left(\frac{\theta_{PIP}}{2}\right)\right) + \left(\frac{l_{DIP}}{2} \times \sin\left(\frac{\theta_{DIP}}{2}\right)\right)\right) = 9.739\ mm$

Moment and forces of joints

Along x-axis

$t_{DP_x} = \left\lvert F_i \times \left(\frac{L_{DP}}{2} \times \cos(\theta_1)\right)\right\rvert = 0.016\ J$
$F_{DIP_x} = \left\lvert \frac{t_{DP_x}}{(L_{DP} \times \cos(\theta_{DIP}))}\right\rvert = 1.06\ N$
$t_{PIP_x} = \left\lvert -t_{DP_x} + \left(F_i \times \cos(\theta_2) \times \frac{L_{MP}}{2}\right)\right\rvert = 0.031\ J$
$F_{MP_x} = \left\lvert \frac{t_{PIP_x}}{(L_{MP} \times \cos(\theta_{PIP}))}\right\rvert = 1.933\ N$
$t_{MC_x} = \left\lvert -t_{PIP_x} - t_{DP_x} + \left(F_i \times \cos(\theta_3) \times \frac{L_{MP}}{2}\right)\right\rvert = 0.035\ J$

$F_{MC_x} = \left\lvert \frac{t_{MC_x}}{(L_{PP} \times \cos(\theta_{MCP}))} \right\rvert = 1.238\ N$
$t_{net_x} = t_{DP_x} + t_{PIP_x} + t_{MC_x} = 0.082\ J$
$F_{net_x} = F_{DIP_x} + F_{MP_x} + F_{MC_x} = 4.232\ N$

Along y-axis

$t_{DP_y} = \left\lvert F_i \times \left(\frac{L_{DP}}{2} \times \sin(\theta_1)\right) \right\rvert = 0.044\ J$
$F_{DIP_y} = \left\lvert \frac{t_{DP_y}}{(L_{DP} \times \sin(\theta_{DIP}))} \right\rvert = 8.005\ N$
$t_{PIP_y} = \left\lvert -t_{DP_y} + \left(F_i \times \sin(\theta_2) \times \frac{L_{MP}}{2}\right) \right\rvert = 0.004\ J$
$F_{MP_Y} = \left\lvert \frac{t_{PIP_Y}}{(L_{MP} \times \sin(\theta_{DIP}))} \right\rvert = 0.22\ N$
$t_{MC_y} = \left\lvert -t_{PIP_y} - t_{DP_y} + \left(F_i \times \sin(\theta_3) \times \frac{L_{MP}}{2}\right) \right\rvert = 0.035\ J$
$F_{MC_y} = \left\lvert \frac{t_{MC_y}}{(L_{PP} \times \sin(\theta_{MCP}))} \right\rvert = 1.238\ N$
$t_{net_y} = t_{DP_y} + t_{PIP_y} + t_{MC_y} = 0.082\ J$
$F_{net_y} = F_{DIP_y} + F_{MP_y} + F_{MC_y} = 9.463\ N$

Magnitude

$t_R = t_{net_y} + t_{net_x} = 0.165\ J$
$F_R = \sqrt{\left(F_{net_x}\right)^2 + \left(F_{net_y}\right)^2} = 10.367\ N$

Spring Force

$F_s = -k \times (L_s - x_{max}) = -2.054\ m \times \frac{N}{m}$

Total force

$F_{f_x} = F_{net_x} + F_s = 72.178\ N$
$F_{f_y} = F_{net_y} + F_s = 7.41\ N$
$F_{f_R} = F_R + F_s = 8.313\ N$

Tension on Cable

$T_{c1} = \frac{t_{DP_x}}{l_{DIP}} = 1.226\ N$	$T_{c2} = \frac{t_{PIP_x}}{l_{PIP}} = 1.849\ N$	$T_{c3} = \frac{t_{MC_x}}{l_{MCP}} = 1.251\ N$
$T_c = T_{c1} + T_{c2} + T_{c3} = 4.372\ N$		

Torque

$$T_m = F_{fR} \times \frac{D_m}{2} = .075\ j$$

27. Appendix J: Design of Experiments, Experimental Procedures, and Results



Figure 87. Tensile Test of PLA sample

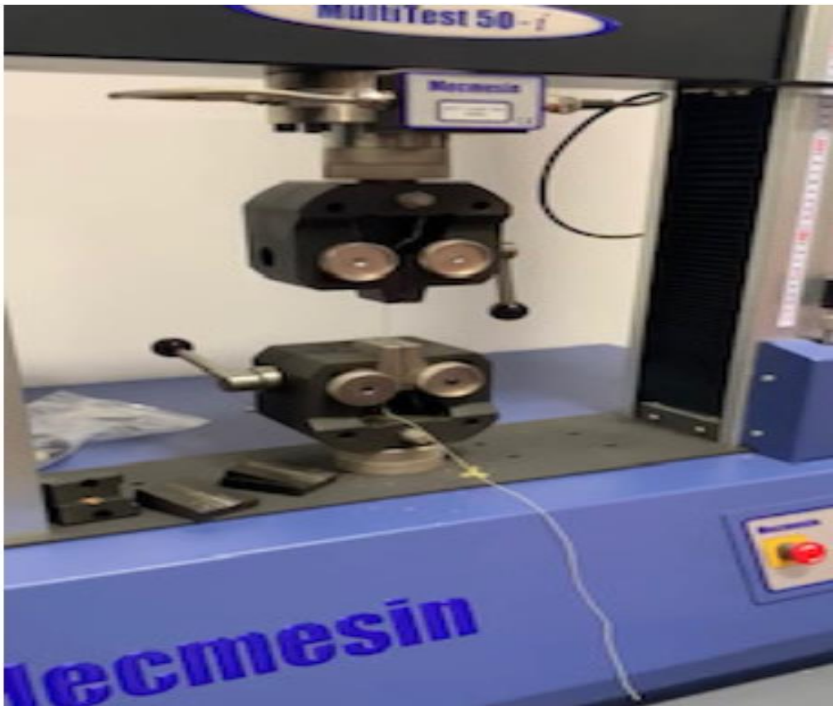


Figure 88. Tensile Test of Kevlar String

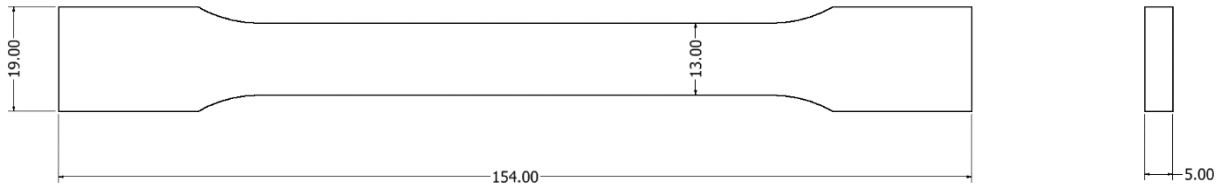


Figure 89. PLA ASTMD638 sample

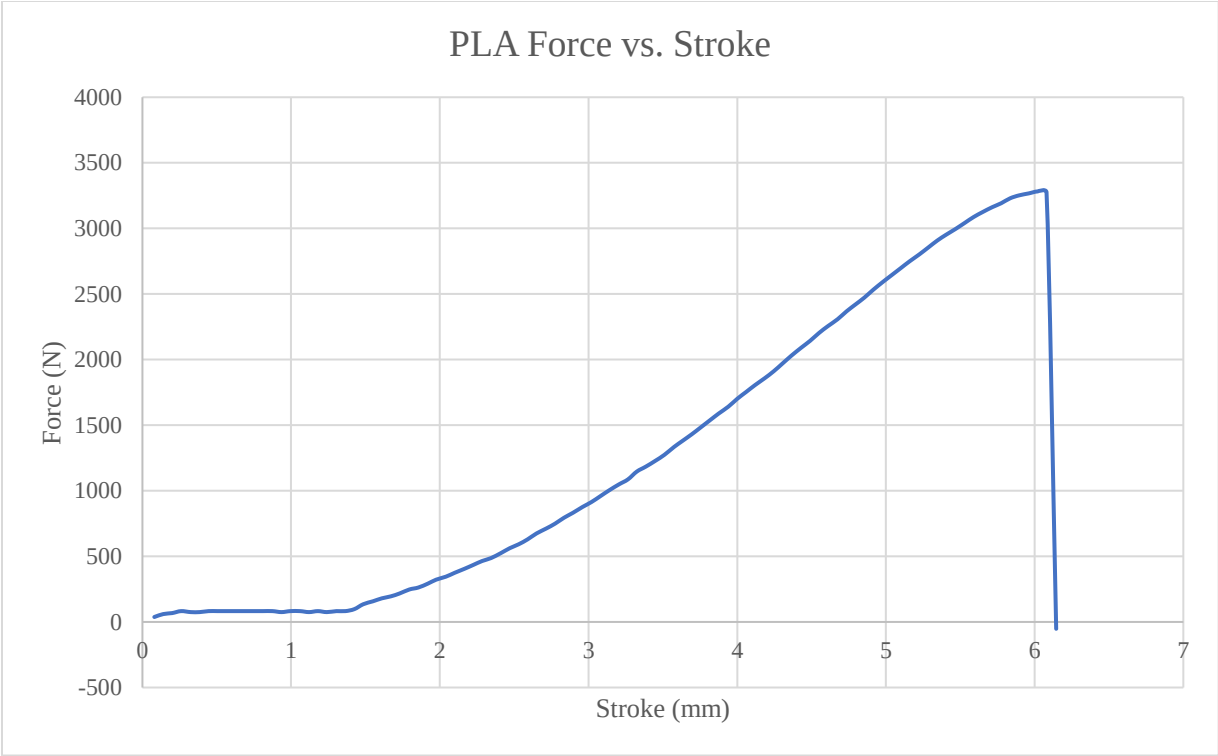


Figure 90. PLA Force vs. Stroke graph

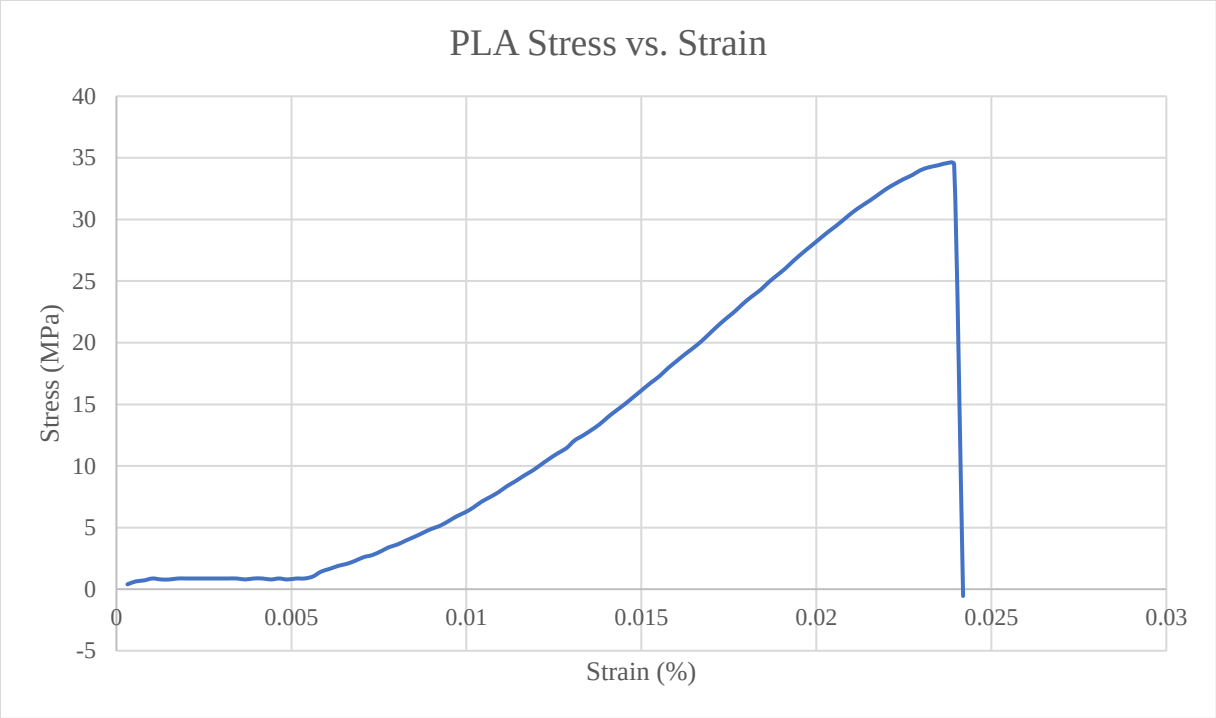


Figure 91. PLA Stress vs. Strain graph

73,845 points
Multiplier 735
Starting point 1000

Numbers	Force	Stroke	Strain New	Stress New
1	37.4644	0.08	0.00031496	0.39436211
2	59.9431	0.14	0.00055118	0.63098
3	67.4359	0.2	0.0007874	0.70985158
4	82.4217	0.26	0.00102362	0.86759684
5	74.9288	0.325	0.00127953	0.78872421
6	74.9288	0.385	0.00151575	0.78872421
7	82.4217	0.445	0.00175197	0.86759684
8	82.4217	0.505	0.00198819	0.86759684
9	82.4217	0.565	0.00222441	0.86759684
10	82.4217	0.63	0.00248031	0.86759684
11	82.4217	0.69	0.00271654	0.86759684
12	82.4217	0.75	0.00295276	0.86759684
13	82.4217	0.81	0.00318898	0.86759684
14	82.4217	0.875	0.00344488	0.86759684
15	74.9288	0.935	0.0036811	0.78872421
16	82.4217	0.995	0.00391732	0.86759684

17	82.4217	1.06	0.00417323	0.86759684
18	74.9288	1.12	0.00440945	0.78872421
19	82.4217	1.18	0.00464567	0.86759684
20	74.9288	1.24	0.00488189	0.78872421
21	82.4217	1.305	0.0051378	0.86759684
22	82.4217	1.365	0.00537402	0.86759684
23	97.4075	1.425	0.00561024	1.02534211
24	134.8719	1.485	0.00584646	1.41970421
25	157.3505	1.55	0.00610236	1.65632105
26	179.8291	1.61	0.00633858	1.89293789
27	194.8149	1.67	0.0065748	2.05068316
28	217.2936	1.73	0.00681102	2.28730105
29	247.2651	1.795	0.00706693	2.60279053
30	262.2509	1.855	0.00730315	2.76053579
31	292.2224	1.92	0.00755906	3.07602526
32	322.1939	1.975	0.00777559	3.39151474
33	344.6725	2.04	0.0080315	3.62813158
34	374.6441	2.1	0.00826772	3.94362211
35	404.6156	2.165	0.00852362	4.25911158
36	434.5872	2.225	0.00875984	4.57460211
37	464.5587	2.285	0.00899606	4.89009158
38	487.0374	2.345	0.00923228	5.12670947
39	524.5018	2.41	0.00948819	5.52107158
40	561.9661	2.47	0.00972441	5.91543263
41	591.9377	2.53	0.00996063	6.23092316
42	629.4021	2.59	0.01019685	6.62528526
43	674.3594	2.65	0.01043307	7.09852
44	711.8238	2.715	0.01068898	7.49288211
45	749.2882	2.775	0.0109252	7.88724421
46	794.2455	2.835	0.01116142	8.36047895
47	831.7099	2.895	0.01139764	8.75484105
48	876.6672	2.96	0.01165354	9.22807579
49	914.1316	3.02	0.01188976	9.62243789
50	959.0889	3.08	0.01212598	10.0956726
51	1004.046	3.14	0.0123622	10.5689074
52	1049.003	3.205	0.01261811	11.0421411
53	1086.468	3.265	0.01285433	11.4365032
54	1146.411	3.325	0.01309055	12.0674832
55	1183.875	3.385	0.01332677	12.4618442
56	1228.833	3.45	0.01358268	12.9350789
57	1273.79	3.51	0.0138189	13.4083137

58	1333.733	3.575	0.0140748	14.0392937
59	1378.69	3.63	0.01429134	14.5125284
60	1431.14	3.695	0.01454724	15.0646358
61	1483.591	3.755	0.01478346	15.6167432
62	1536.041	3.815	0.01501969	16.1688505
63	1588.491	3.875	0.01525591	16.7209558
64	1640.941	3.94	0.01551181	17.2730632
65	1700.884	4	0.01574803	17.9040442
66	1753.334	4.06	0.01598425	18.4561495
67	1805.784	4.12	0.01622047	19.0082568
68	1858.235	4.185	0.01647638	19.5603642
69	1910.685	4.245	0.0167126	20.1124716
70	1970.628	4.305	0.01694882	20.7434516
71	2030.571	4.365	0.01718504	21.3744295
72	2090.514	4.43	0.01744094	22.0054095
73	2142.964	4.49	0.01767717	22.5575168
74	2202.907	4.55	0.01791339	23.1884968
75	2255.357	4.61	0.01814961	23.7406042
76	2307.808	4.675	0.01840551	24.2927116
77	2367.751	4.735	0.01864173	24.9236895
78	2420.201	4.795	0.01887795	25.4757968
79	2472.651	4.855	0.01911417	26.0279042
80	2532.594	4.915	0.01935039	26.6588842
81	2592.537	4.98	0.0196063	27.2898642
82	2644.987	5.04	0.01984252	27.8419716
83	2697.438	5.1	0.02007874	28.3940789
84	2749.888	5.16	0.02031496	28.9461842
85	2802.338	5.225	0.02057087	29.4982905
86	2854.788	5.285	0.02080709	30.0503979
87	2907.238	5.345	0.02104331	30.6025053
88	2952.195	5.405	0.02127953	31.07574
89	2997.153	5.47	0.02153543	31.5489747
90	3042.11	5.53	0.02177165	32.0222095
91	3087.067	5.59	0.02200787	32.4954432
92	3124.532	5.65	0.02224409	32.8898074
93	3161.996	5.715	0.0225	33.2841695
94	3191.968	5.775	0.02273622	33.5996579
95	3229.432	5.835	0.02297244	33.99402
96	3251.911	5.895	0.02320866	34.2306379
97	3266.897	5.96	0.02346457	34.3883842
98	3281.882	6.02	0.02370079	34.5461274

99	3274.389	6.08	0.02393701	34.4672568
100	-52.4502	6.145	0.02419291	-0.5521074

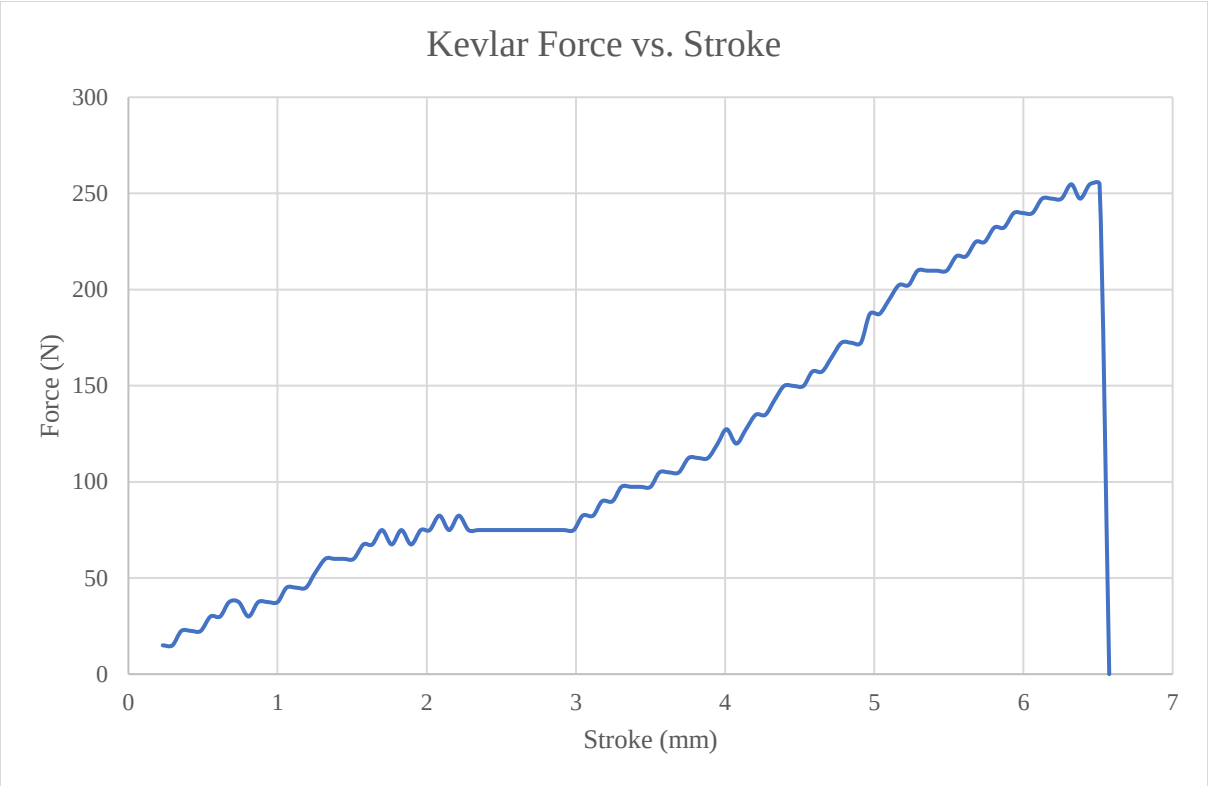


Figure 92. Kevlar Line Force vs. Stroke

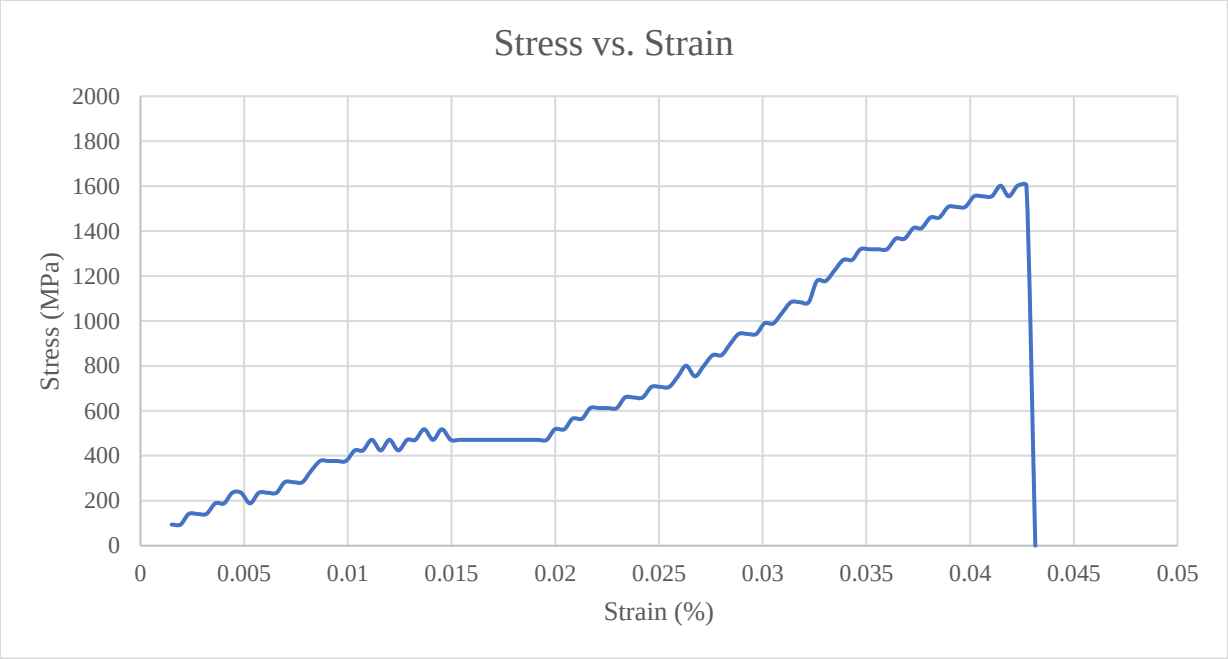


Figure 93. Kevlar Line Stress vs. Strain

358,000 points
Multiplier 769
Starting point 1000

Numbers	Force	Stroke	Strain	Stress
1	14.99	0.23	0.00150919	94.2248323
2	14.99	0.295	0.0019357	94.2248323
3	22.48	0.355	0.0023294	141.33662
4	22.48	0.42	0.00275591	141.33662
5	22.48	0.485	0.00318241	141.33662
6	29.97	0.55	0.00360892	188.449036
7	29.97	0.615	0.00403543	188.449036
8	37.46	0.675	0.00442913	235.561452
9	37.46	0.74	0.00485564	235.561452
10	29.97	0.805	0.00528215	188.449036
11	37.46	0.87	0.00570866	235.561452
12	37.46	0.935	0.00613517	235.561452
13	37.46	1	0.00656168	235.561452
14	44.96	1.06	0.00695538	282.673868
15	44.96	1.125	0.00738189	282.673868
16	44.96	1.19	0.0078084	282.673868
17	52.45	1.25	0.0082021	329.786284
18	59.94	1.32	0.00866142	376.8987

19	59.94	1.38	0.00905512	376.8987
20	59.94	1.445	0.00948163	376.8987
21	59.94	1.51	0.00990814	376.8987
22	67.44	1.575	0.01033465	424.010488
23	67.44	1.635	0.01072835	424.010488
24	74.93	1.7	0.01115486	471.122904
25	67.44	1.765	0.01158136	424.010488
26	74.93	1.83	0.01200787	471.122904
27	67.44	1.895	0.01243438	424.010488
28	74.93	1.96	0.01286089	471.122904
29	74.93	2.02	0.01325459	471.122904
30	82.42	2.085	0.0136811	518.23532
31	74.93	2.15	0.01410761	471.122904
32	82.42	2.215	0.01453412	518.23532
33	74.93	2.28	0.01496063	471.122904
34	74.93	2.345	0.01538714	471.122904
35	74.93	2.405	0.01578084	471.122904
36	74.93	2.47	0.01620735	471.122904
37	74.93	2.535	0.01663386	471.122904
38	74.93	2.6	0.01706037	471.122904
39	74.93	2.66	0.01745407	471.122904
40	74.93	2.73	0.01791339	471.122904
41	74.93	2.79	0.01830709	471.122904
42	74.93	2.855	0.0187336	471.122904
43	74.93	2.92	0.0191601	471.122904
44	74.93	2.985	0.01958661	471.122904
45	82.42	3.045	0.01998031	518.23532
46	82.42	3.115	0.02043963	518.23532
47	89.91	3.175	0.02083333	565.347736
48	89.91	3.245	0.02129265	565.347736
49	97.41	3.305	0.02168635	612.460152
50	97.41	3.37	0.02211286	612.460152
51	97.41	3.435	0.02253937	612.460152
52	97.41	3.5	0.02296588	612.460152
53	104.9	3.56	0.02335958	659.57194
54	104.9	3.625	0.02378609	659.57194
55	104.9	3.69	0.0242126	659.57194
56	112.4	3.755	0.02463911	706.684356
57	112.4	3.82	0.02506562	706.684356
58	112.4	3.885	0.02549213	706.684356
59	119.9	3.95	0.02591864	753.796772

60	127.4	4.01	0.02631234	800.909188
61	119.9	4.075	0.02673885	753.796772
62	127.4	4.14	0.02716535	800.909188
63	134.9	4.205	0.02759186	848.021604
64	134.9	4.27	0.02801837	848.021604
65	142.4	4.33	0.02841207	895.133392
66	149.9	4.395	0.02883858	942.245808
67	149.9	4.46	0.02926509	942.245808
68	149.9	4.525	0.0296916	942.245808
69	157.4	4.585	0.0300853	989.358224
70	157.4	4.65	0.03051181	989.358224
71	164.8	4.715	0.03093832	1036.47064
72	172.3	4.78	0.03136483	1083.58306
73	172.3	4.845	0.03179134	1083.58306
74	172.3	4.91	0.03221785	1083.58306
75	187.3	4.97	0.03261155	1177.80789
76	187.3	5.035	0.03303806	1177.80789
77	194.8	5.1	0.03346457	1224.91968
78	202.3	5.165	0.03389108	1272.03209
79	202.3	5.23	0.03431759	1272.03209
80	209.8	5.29	0.03471129	1319.14451
81	209.8	5.355	0.0351378	1319.14451
82	209.8	5.42	0.0355643	1319.14451
83	209.8	5.485	0.03599081	1319.14451
84	217.3	5.55	0.03641732	1366.25692
85	217.3	5.615	0.03684383	1366.25692
86	224.8	5.68	0.03727034	1413.36934
87	224.8	5.74	0.03766404	1413.36934
88	232.3	5.805	0.03809055	1460.48113
89	232.3	5.87	0.03851706	1460.48113
90	239.8	5.935	0.03894357	1507.59354
91	239.8	5.995	0.03933727	1507.59354
92	239.8	6.06	0.03976378	1507.59354
93	247.3	6.125	0.04019029	1554.70596
94	247.3	6.19	0.0406168	1554.70596
95	247.3	6.255	0.04104331	1554.70596
96	254.8	6.32	0.04146982	1601.81838
97	247.3	6.38	0.04186352	1554.70596
98	254.8	6.445	0.04229003	1601.81838
99	254.8	6.51	0.04271654	1601.81838
100	0	6.575	0.04314304	0

28. Appendix K: Assembly Drawings

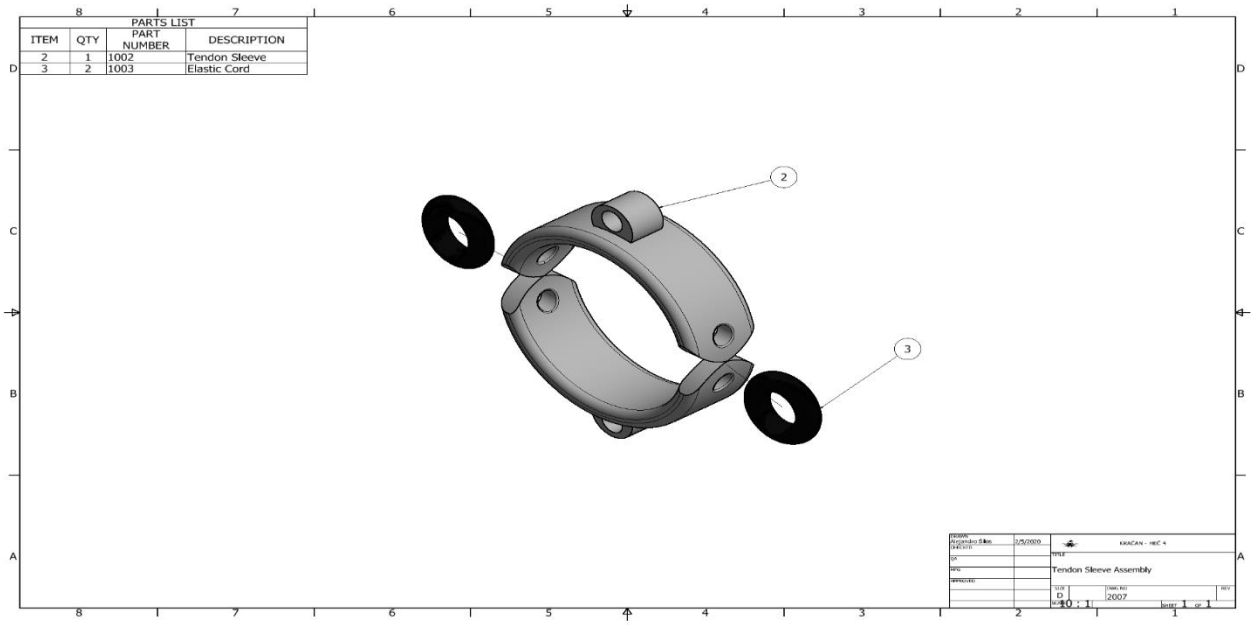


Figure 94. Tendon Sleeve Assembly

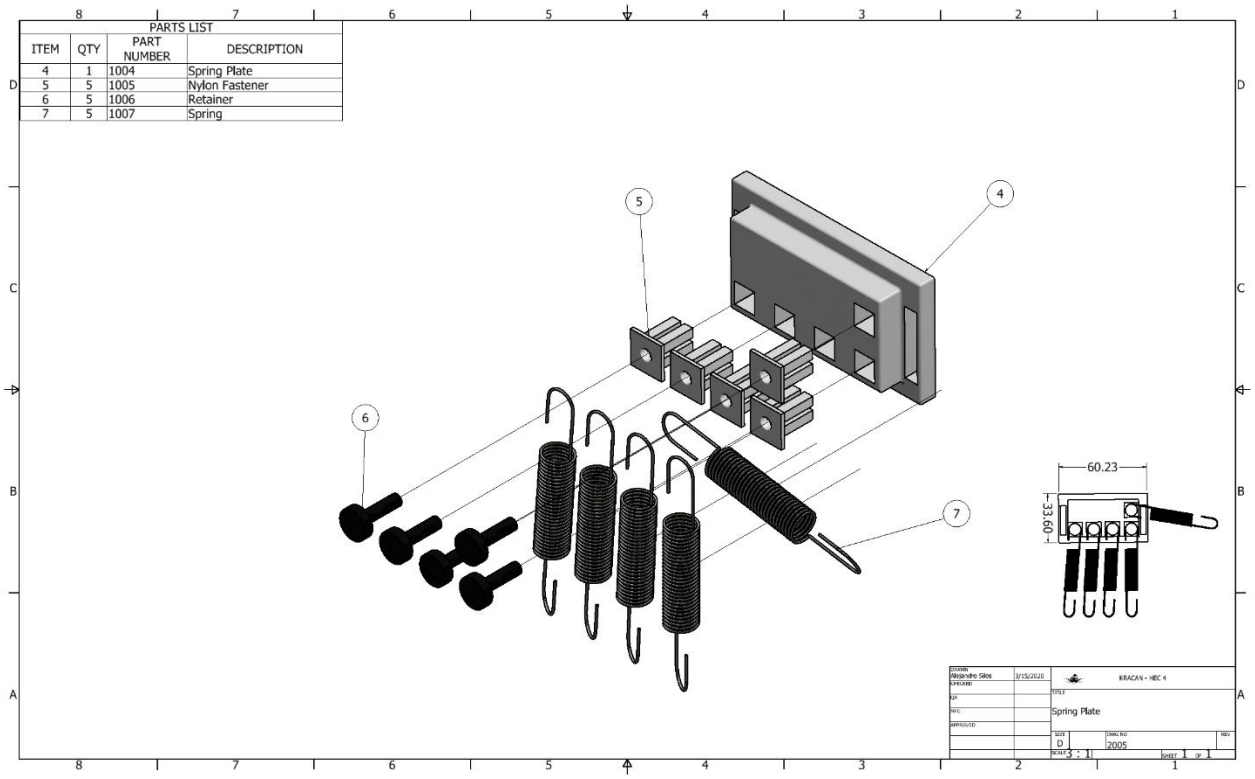


Figure 95. Spring Plate Assembly

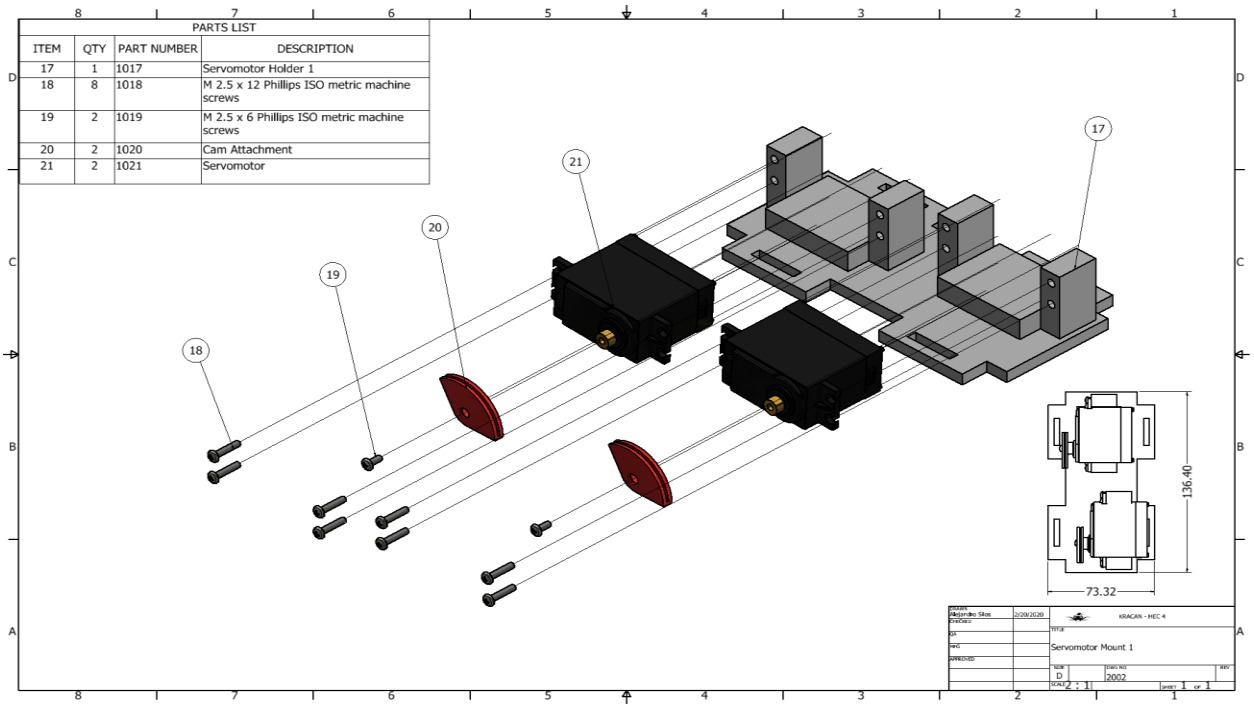


Figure 96. Servomotor Mount 1 Assembly

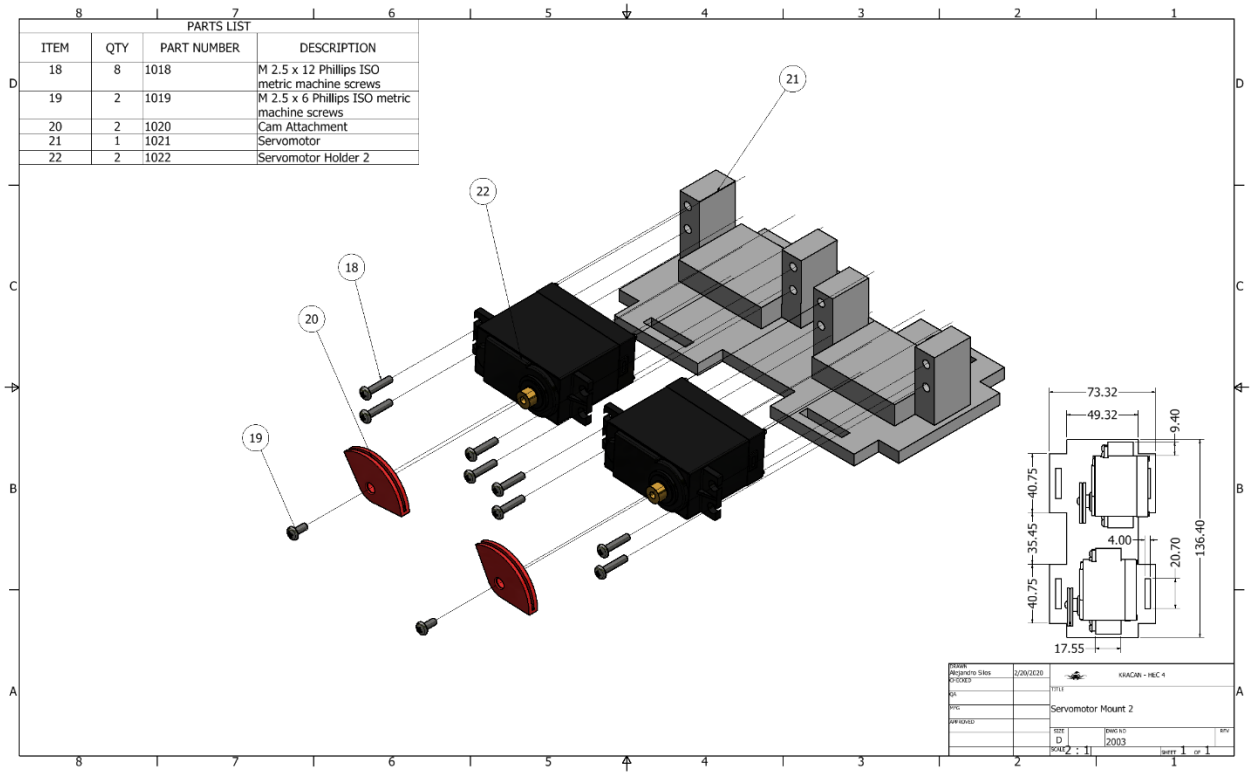


Figure 97. Servomotor Mount 2 Assembly

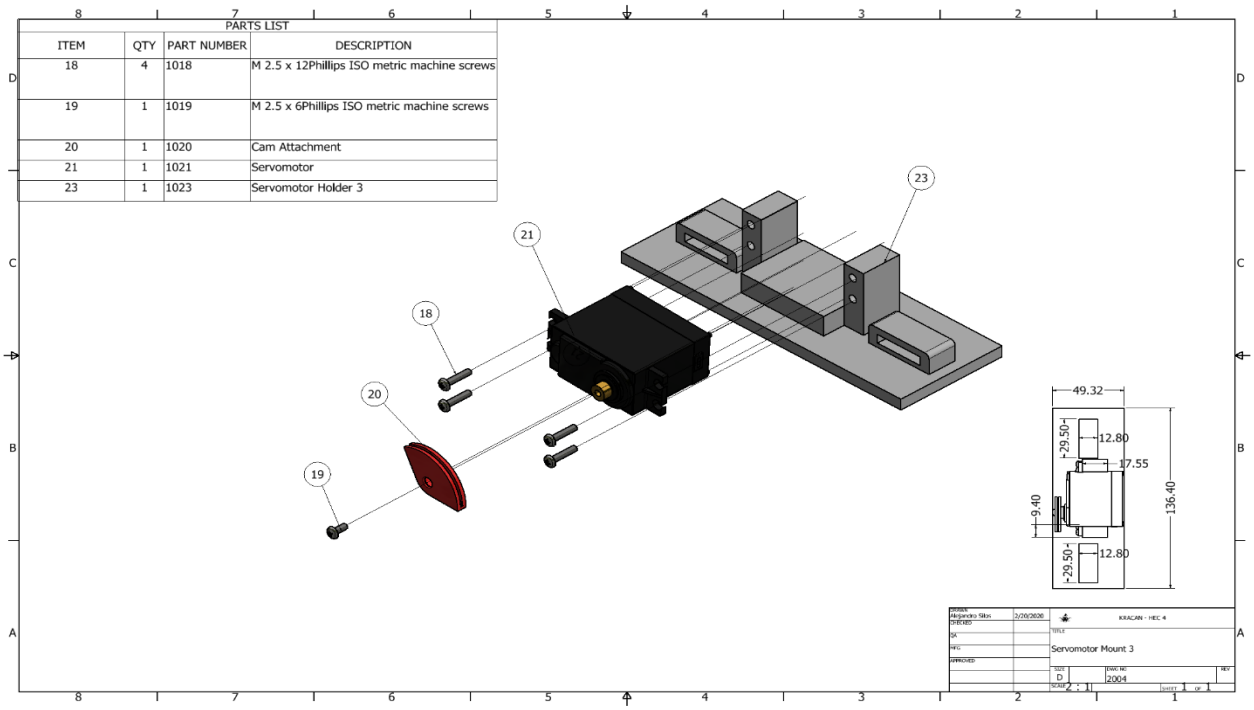


Figure 98. Servomotor Mount 3 Assembly

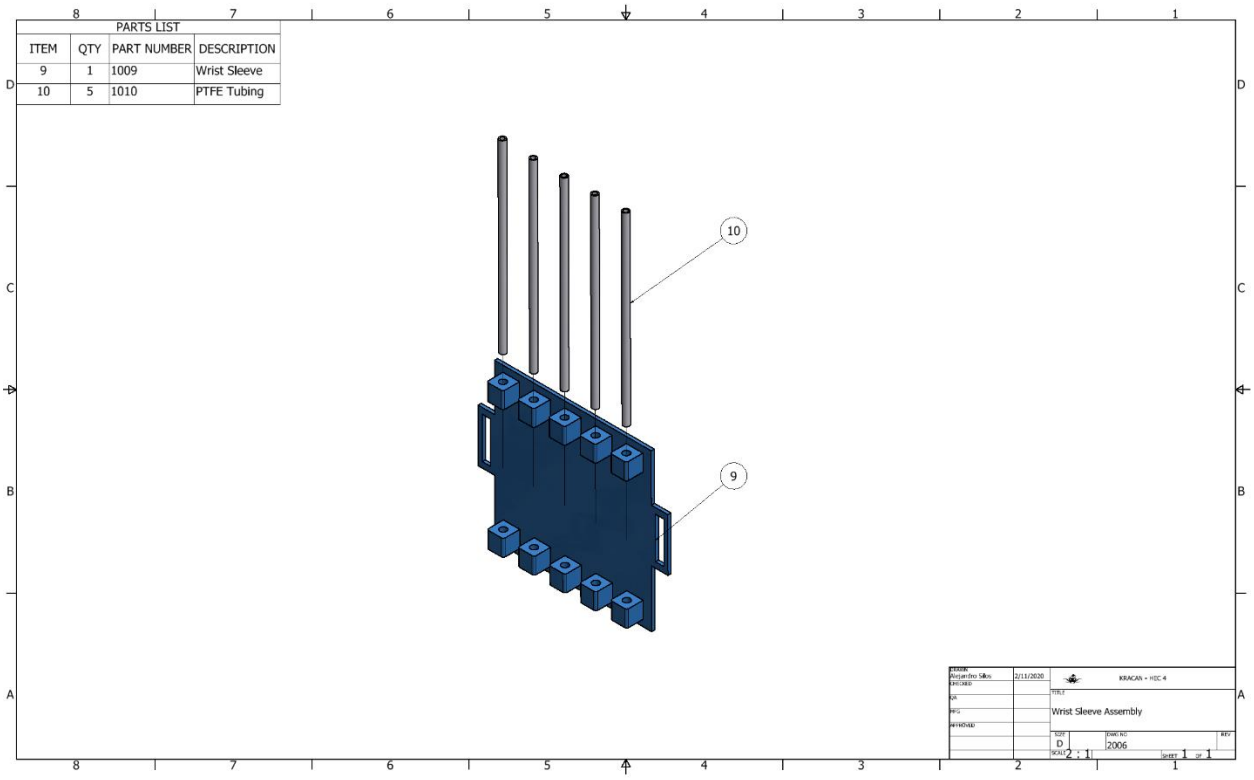


Figure 99. Wrist Sleeve Assembly

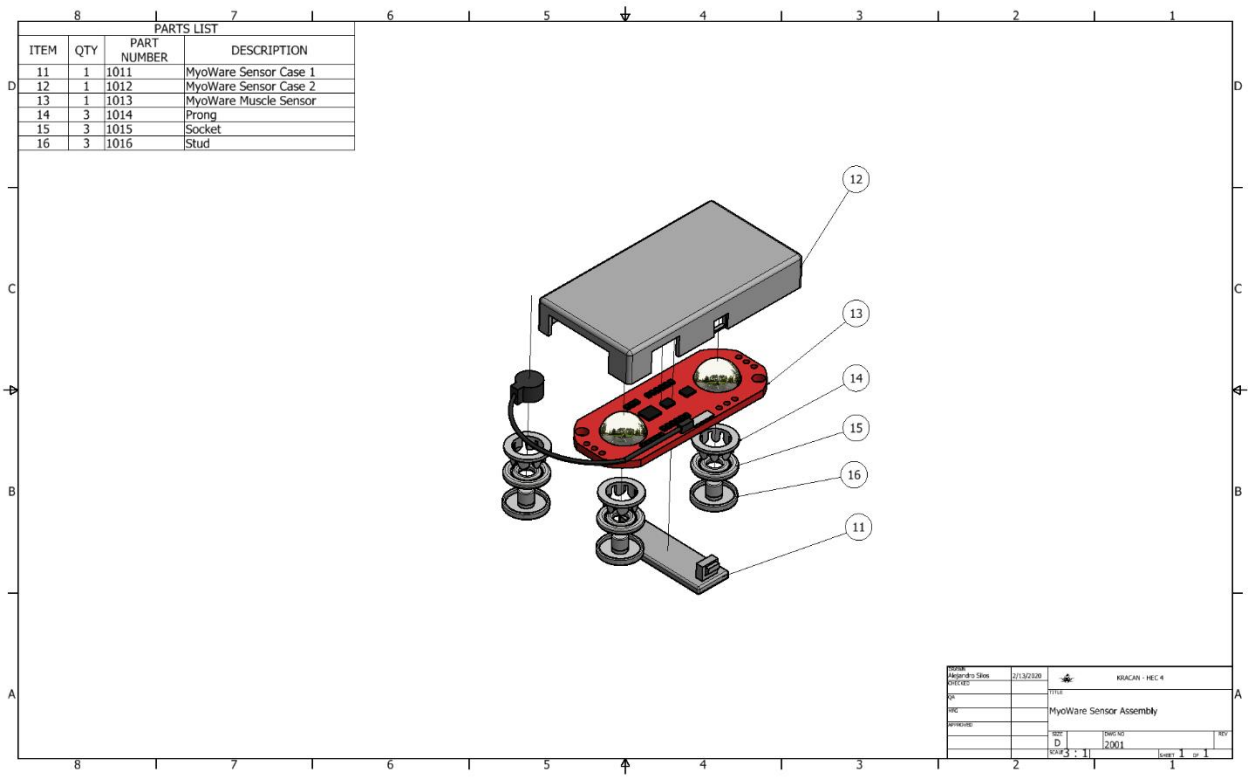


Figure 100. *MyoWare*™ Case Assembly

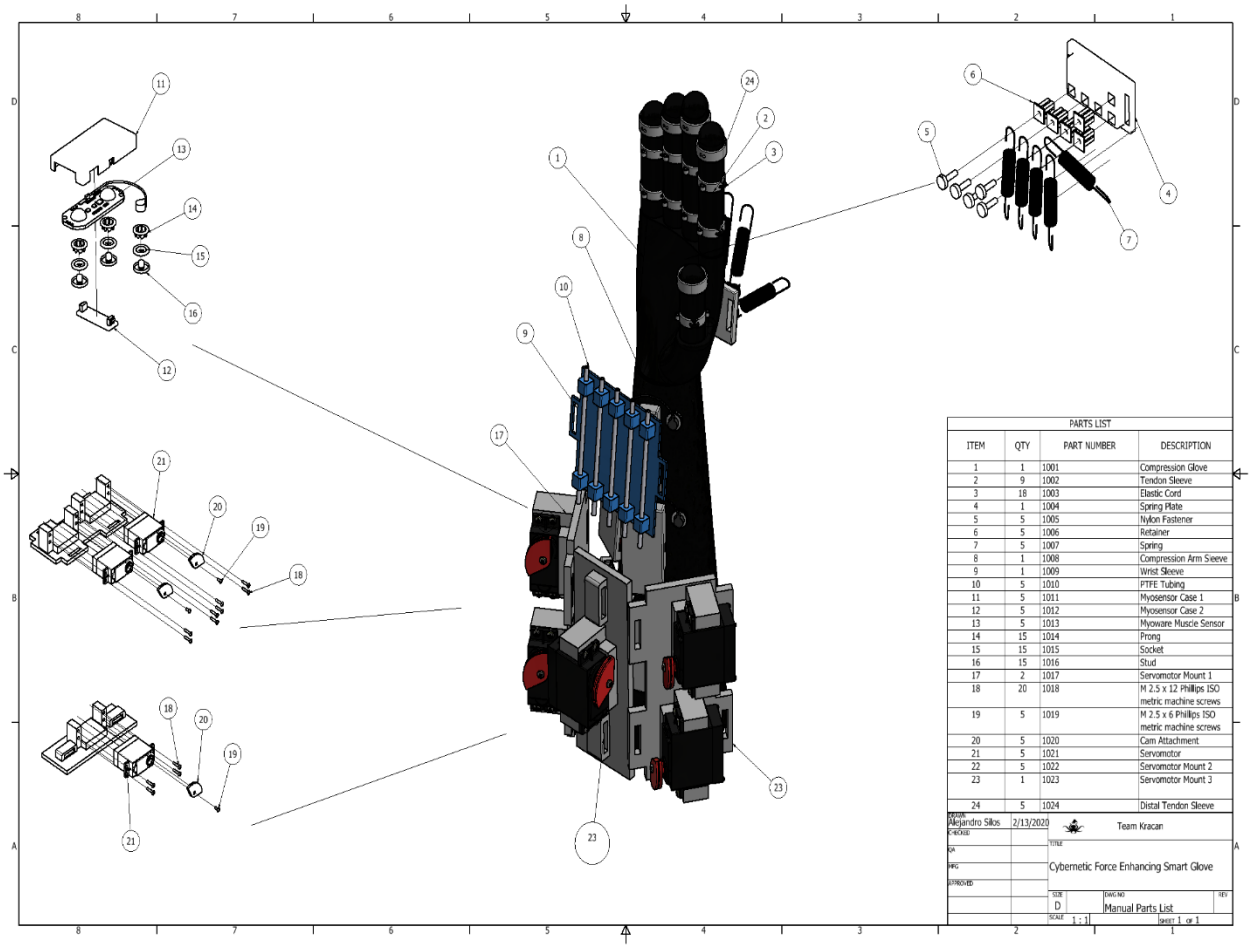


Figure 101. Assembled Cybernetic Force Enhancing Smart Glove

29. Appendix L: Manufacturing Drawings

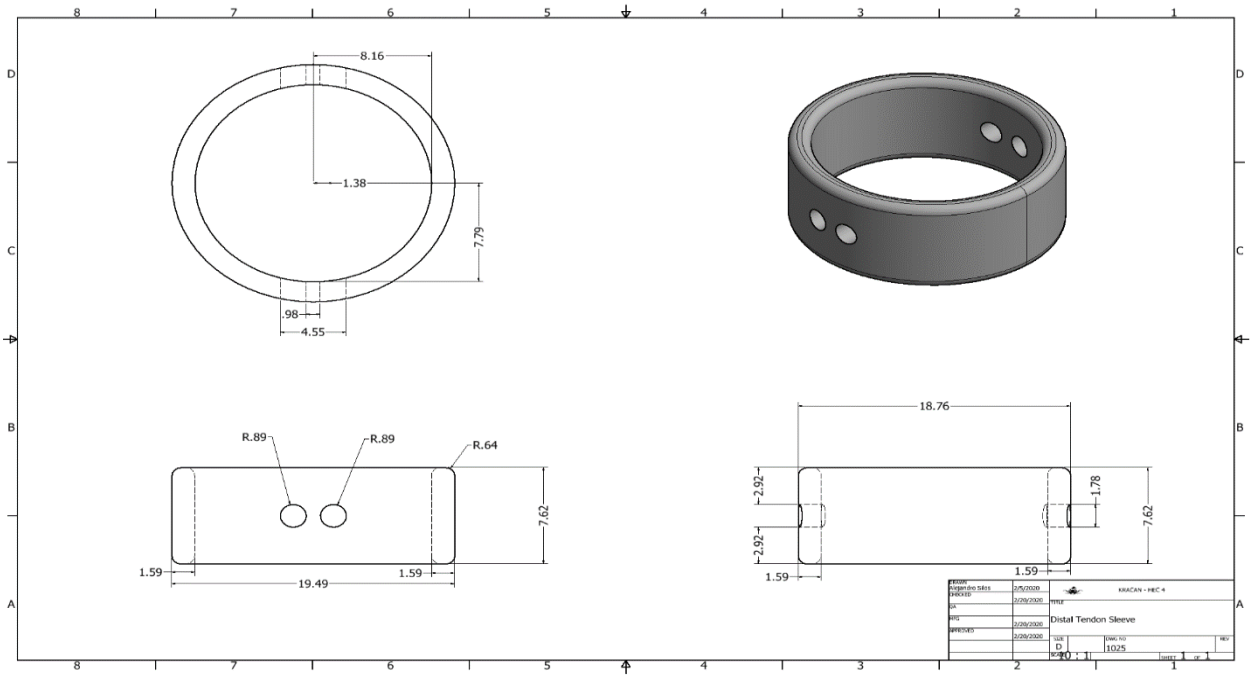


Figure 102. Distal Tendon Sleeve

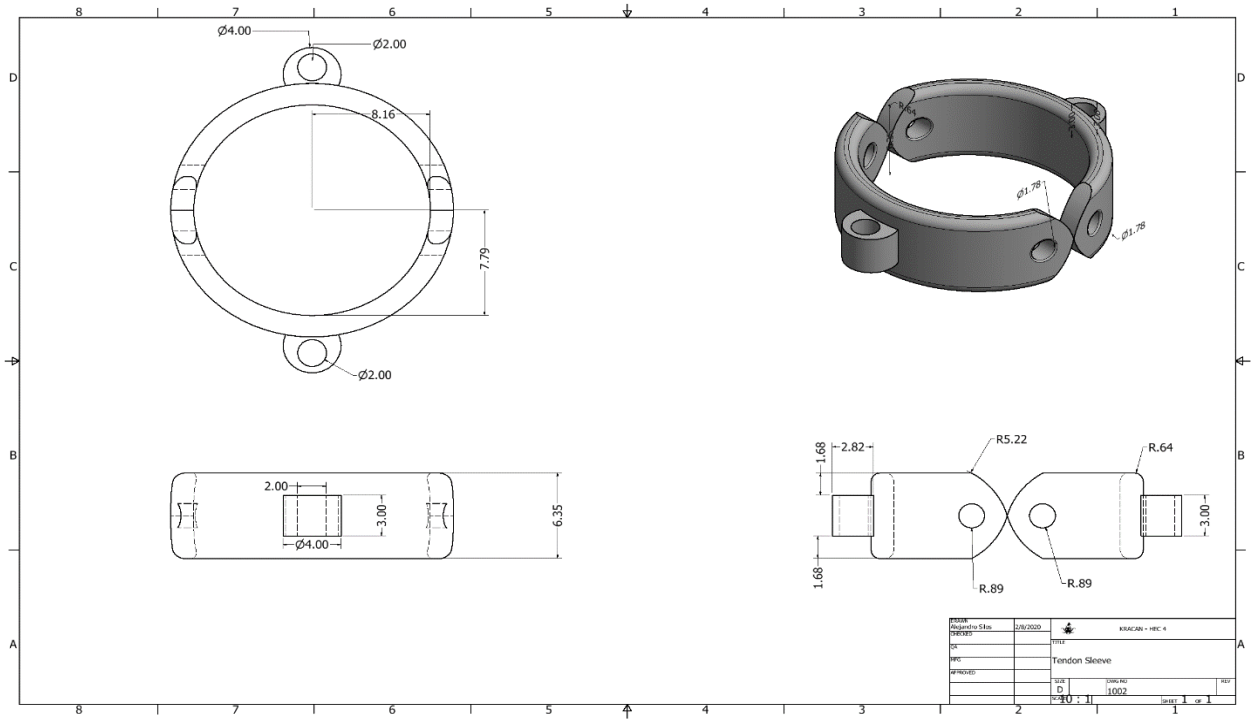


Figure 103. Tendon Sleeve

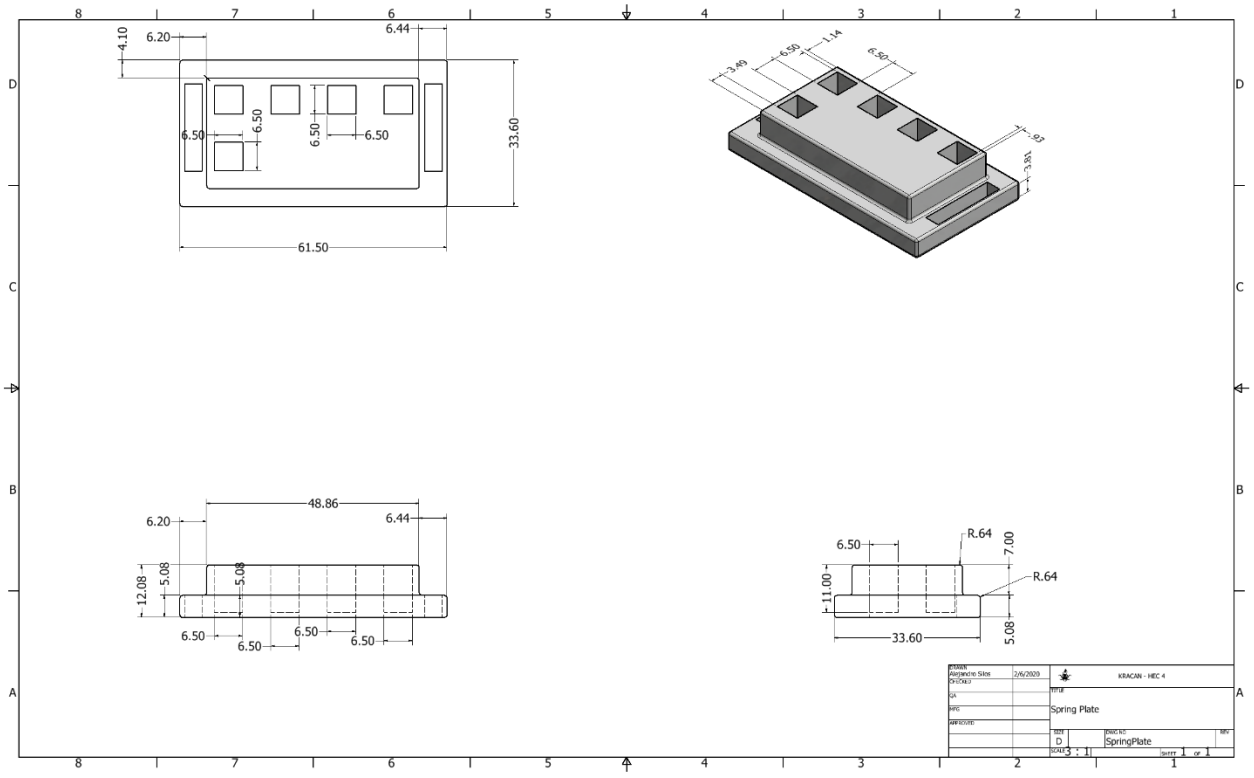


Figure 104. Spring Plate

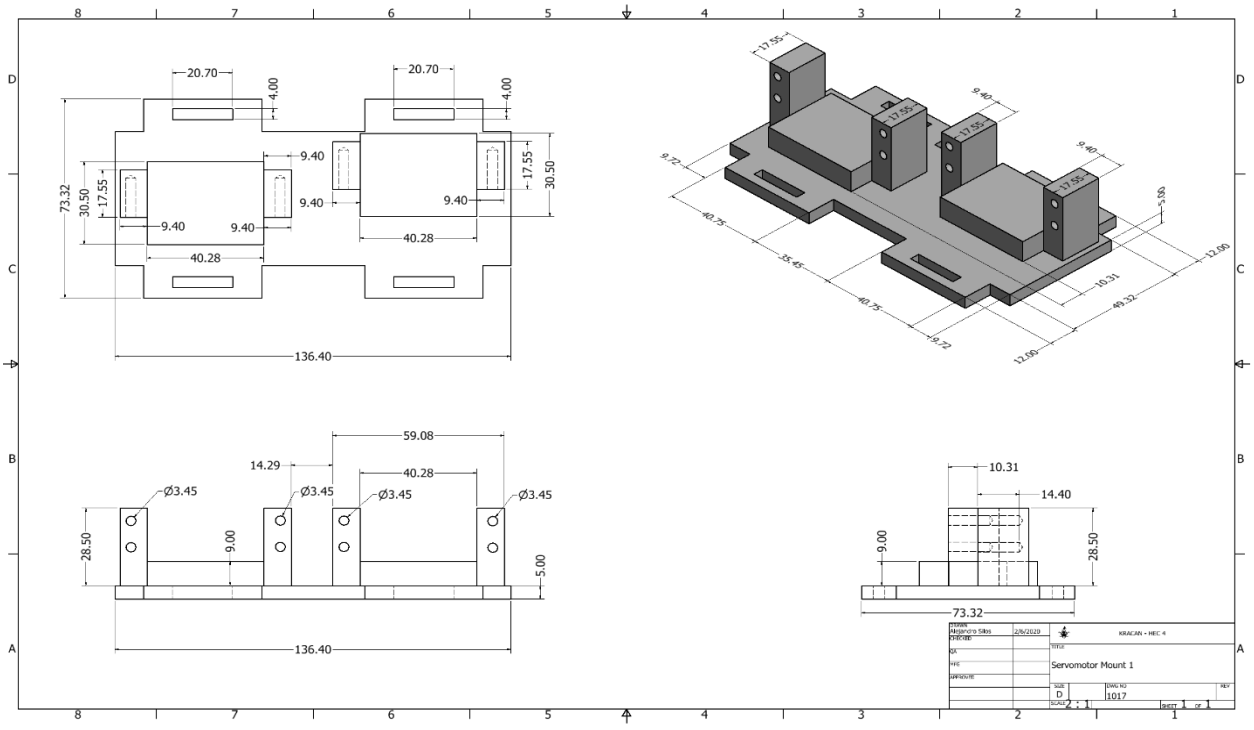


Figure 105. Servomotor Mount 1

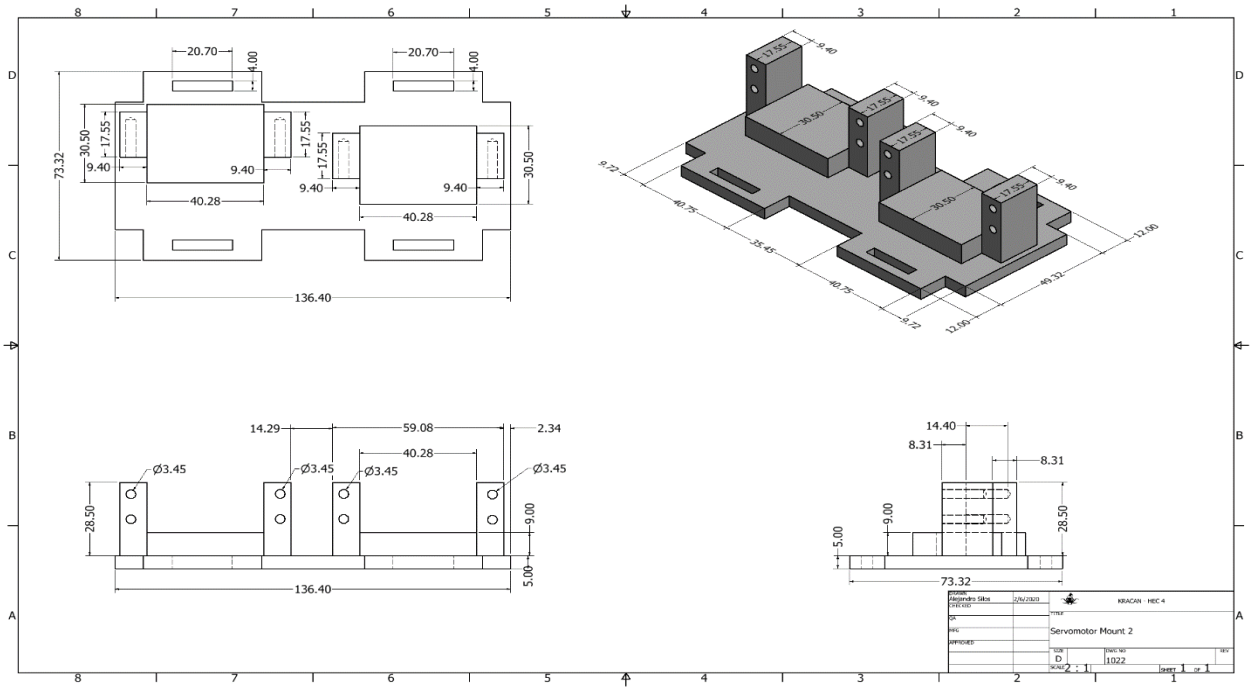


Figure 106. Servomotor Mount 2

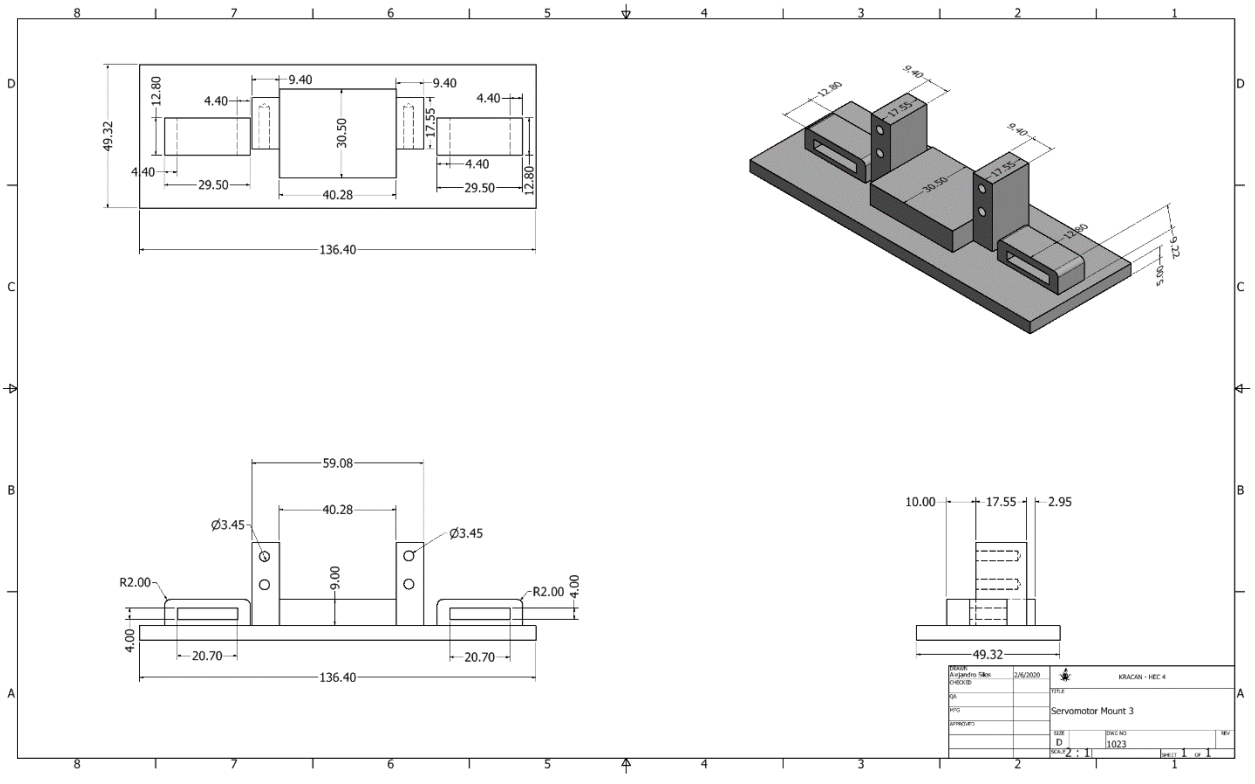


Figure 107. Servomotor Mount 3

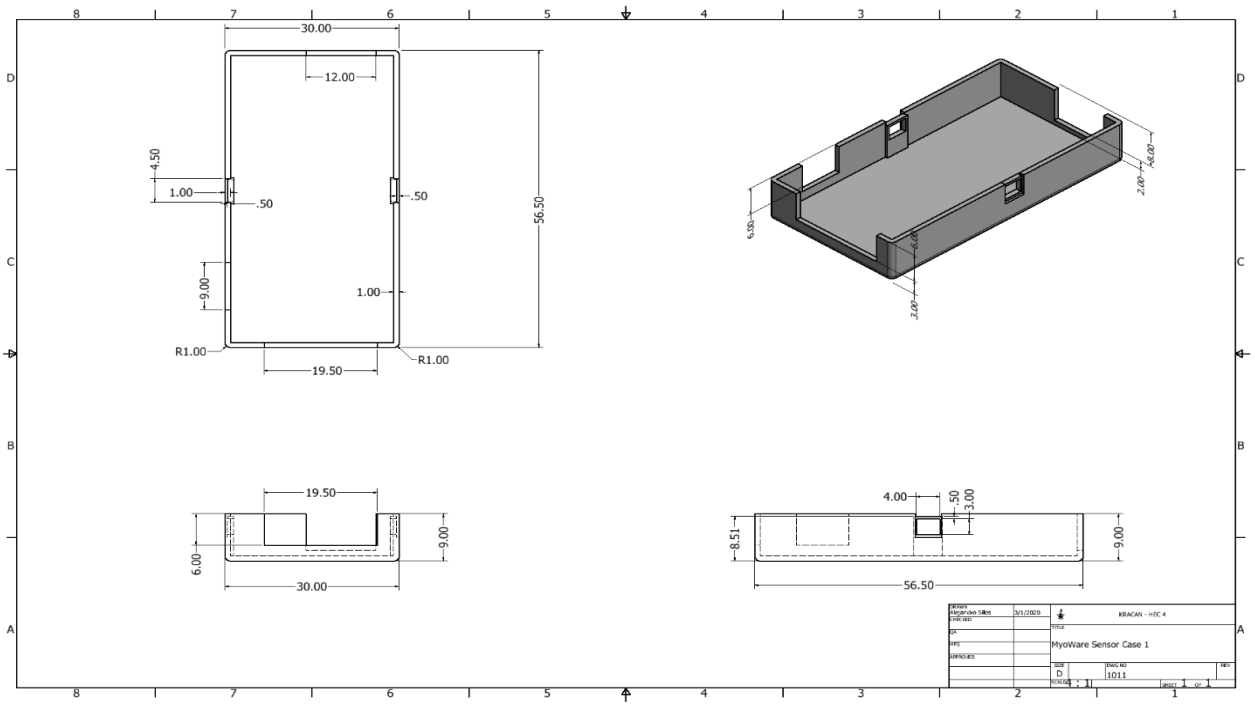


Figure 108. *MyoWare™* Case 1

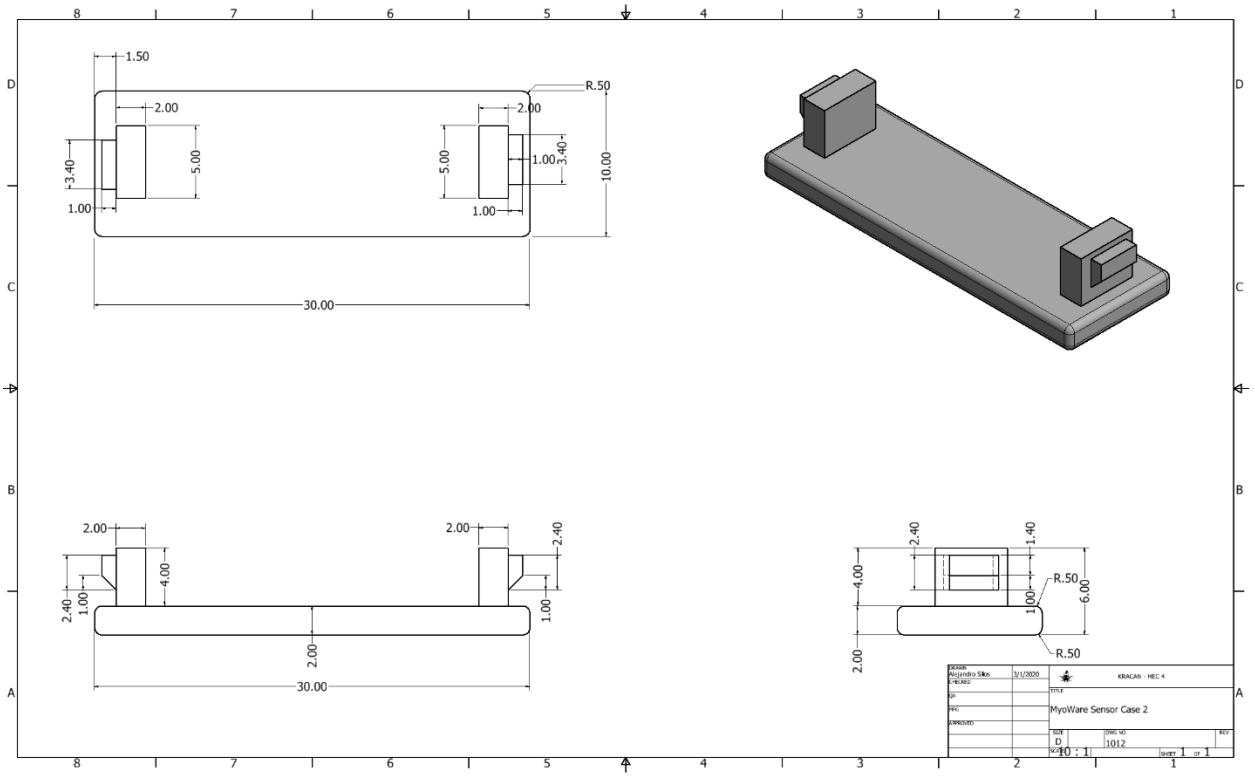


Figure 109. *MyoWare™* Case 2

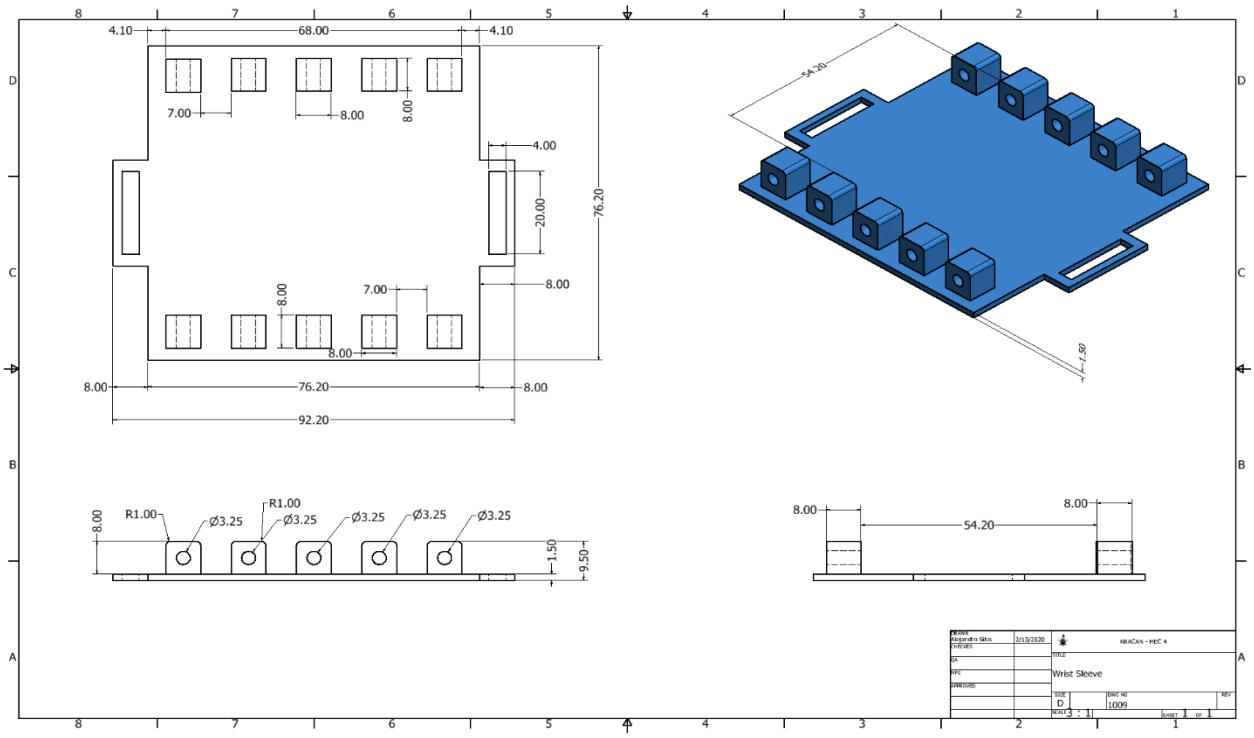


Figure 110. Wrist Sleeve

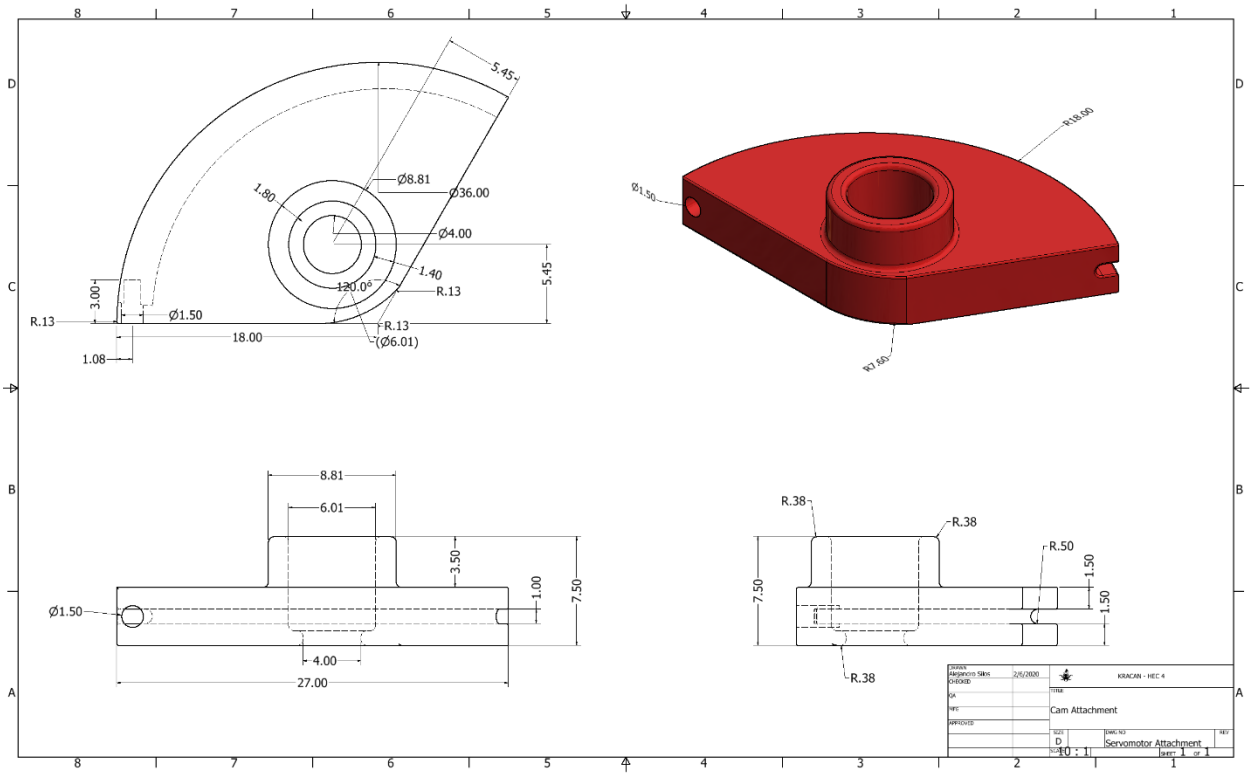


Figure 111. Cam Attachment

30. Appendix H: User Manuals

30. 1 Operations Manual

Cybernetic Force Enhancing Smart Glove

Operations Manual



MECHANICAL/ELECTRICAL ENGINEERING DEPARTMENT
HOUSTON ENGINEERING CENTER
COLLEGE OF ENGINEERING
THE UNIVERSITY OF TEXAS AT TYLER

Overview

The purpose of this manual is to provide trained personnel and the user of this device with guidance on how to conduct a variety of procedures to ensure the performance longevity of this device. The focus is on performing basic maintenance on the internal and external subcomponents of the Cybernetic Force Enhancing Smart Glove. It is the operator's responsibility to carry out the required maintenance procedures and guidelines. This manual also provides the procedures for troubleshooting, ordering parts, and the warranty. For questions of these procedures or additional assistance please contact KRACAN technical support.

Safety and Terms

CYBERNETIC FORCE ENHANCING SMART glove is a Cybernetic Force Enhancing Smart Glove, whose main purpose is to facilitate and add support to a person's hand when being required to perform daily and basic task. One of the main and most important steps for this project is the safety of the person using the glove. The KRACN glove should be treated seriously like any other device that contains sensor, motors, and a power module. Following the safety manual will assure that there will be a low percentage of any malfunction or injuries when operating the device.

In order to operate and use the CYBERNETIC FORCE ENHANCING SMART glove, the user will have to go over the manual to have a better idea on how the glove operates. See the Safety and operations section and if the user has more questions, they contact us for more information.

Cleaning and Maintenance

⚠ Warning: Before cleaning any portion of the glove, disconnect the power cord from the wall outlet.

The Cybernetic Force Enhancing Smart Glove requires cleaning before and after every use. This is due to perspiration and accumulation of unwanted dust particles. Apply small amounts of cleaning detergent around the motors, springs, tendon sleeves. Utilizing standard cleaning procedures wipe down the outer components but avoid causing any moisture to the strings. It is recommended to not use soap or water on any of the external components as it may cause damage to the string, sensors, springs and motors. In between uses a disinfectant spray should be utilized for the compression glove and sleeve. Be cautious of the sensors and allow the material to properly dry before the next usage. After daily use it is recommended to un-attach the glove and arm sleeve to components to give them a thorough washing. The power supply should only be wiped down with a dry cloth to remove any unwanted debris if needed.

Decontamination

Decontamination of the device should be done by trained personnel, or any person who is under the supervision of trained personnel. It is important for the device to not be in use as the decontamination process is taking place. In case of disinfecting a device with blood and/or bodily fluids, consult local disinfecting agencies for regulations and proper guidelines of disinfecting devices. Sanitation cloths and disinfectant spray can be used for cleaning any external parts of the device, but precautions should be taken to not moisten the string. For disinfection of the internal part of the glove it is recommended to remove all components from glove before beginning the process, see Assembly/Disassembly in operations manual for reference. Use disinfecting supplies that do not have bleach oxidizing agents to avoid damage to the cloth.

Storage

The glove should be stored in a dry environment to prevent oxidation damage on the components that may occur due to potential relative humidity. Avoid storing the device next to item that might fall and. There are no temperature restrictions for the conditions of storage for this device. Keep the device out of children's reach.

Inspection

The amount of maintenance required by the glove will be indicated by its use. The device should be inspected before every use and every six months to improve the service and performance of the product. Before using the device, it is important to make sure that the string is securely fastened to the cam shaft of the motors, and tendon sleeves. Carefully inspect for any tears on the glove, arm sleeve, strings and tendon sleeves. Check all sensors and electrical connections for tightness and examine all components for any worn out pieces that require replacement. Put a light amount of lubrication oil on the shaft of the motor every year or six months depending on the consistent usage of the device. If any discrepancies are noted during inspection, they must be corrected before continued used of this glove.

Repair/ Replacement

It is recommended for repairs and services to the device only be performed by trained personnel or at the KRACAN service centers. To order any replacement parts please will out the form below and send to the address below the KRACAN logo. See Disassembly/Assembly section of operations manual as guidance.



CYBERNETIC FORCE ENHANCING SMART GLOVE

2811 Hayes Rd,

Houston, TX. 77082

(713) 718 – 6870

Email address:

Point of contact:

PURCHASE ORDER NO:

BILL TO:

ADDRESS

CITY/STATE/ZIPCODE

EMAIL ADDRESS

SHIP TO:

ADDRESS

CITY/STATE/ZIPCODE

EMAIL ADDRESS

SHIPPING METHOD	**SHIPPING ITEMS**	**SHIP VIA**	**PAYMENT**	**DELIVERY DATE**

ITEM NO	DESCRIPTION	QTY	UNIT PRICE	TOTAL

COMMENTS / NOTE

SUBTOTAL	
DISCOUNT	
SUBTOTAL LESS DISCOUNT	
TAX RATE	
SHIPPING/HANDLING	
OTHER	
TOTAL	

THANK YOU!

AUTHORIZED SIGNATURE **DATE**

Troubleshooting

Kracan technical support team can provide additional assistance to repair or troubleshoot any problems. Major service and repair must only be performed by authorized technical support, which can be contacted at KRACAN@uttyler.edu. Table 1 provides quick solutions to the most common troubleshooting errors.

Table I. Troubleshooting solutions

Problem	Possible Cause	Solution
Does not function	Lack of power to unit	Check the connection to the power supply
Power light does not work	Loose connection	Check all connectivity of every cord
		Check connection to the power supply
Power light for Muscle Sensors does not work	Bad connection	Check connections to the microcontroller.
One or more motors do not work.	Bad connection	Check connections to the microcontroller.
	System Malfunction	Restart system
If the solutions posted above des not resolve the problem, contact KRACAN technical support.		

Product Warranty

Cybernetic Force Enhancing Smart Glove is guaranteed for one year from the date of delivery, against defective materials under normal use and service. This one-year warranty includes defects on all mechanical and electrical components. Damage caused by use in unsuitable environmental conditions, abuse or failure to maintain the product in accordance with user and service instructions is not covered. Any alteration, modification, or repairs not authorized or done by Kracan will void this warranty. The factory warranty will only cover the original purchaser of the device. The Cybernetic Force Enhancing Smart Glove contains parts that will be worn out from consistent

usage. These parts are will only be covered by the warranty if it occurs under 90 days after the date of delivery.

Disassembly of the Cybernetic Force Enhancing Smart Glove:

In case there is a need to replace a part or make slight adjustment the user can utilize the following procedures. However, it is highly encouraged to seek the services of a trained technician from Team Kracan for these desired services.

1. First step is to ensure that the device is not in use, if so, remove the device from the user. Make sure to unplug the power source from the wall outlet to prevent any injury or damage to the device.
2. Disconnect the microcontroller from the power source, as well as from the glove components and the sensors.
3. Using a cross slot/ Philips screwdriver remove the screws from all five of the servomotor tip attachments. Remove the attachments from the servomotors and untie the Kevlar string from each.
4. Untie the Velcro straps of the servomotor holders and remove them from the glove. Make sure that the servomotors are not connected to the microcontroller.
5. Untie Velcro straps on the wrist sleeves and slide the Kevlar string out of each of the PFTE tubes (part # 1010). If needed the tubes easily slide out of the holds on the wrist sleeve.
6. Untie the Kevlar string from the distal tendon sleeve (part #1025) and slide the string out of the guide of the tendon sleeves (part #1002). The tendon sleeves are attached to the compression glove so removal can damage the device. It is advised to seek services of a technician to remove, replace or adjust these components.

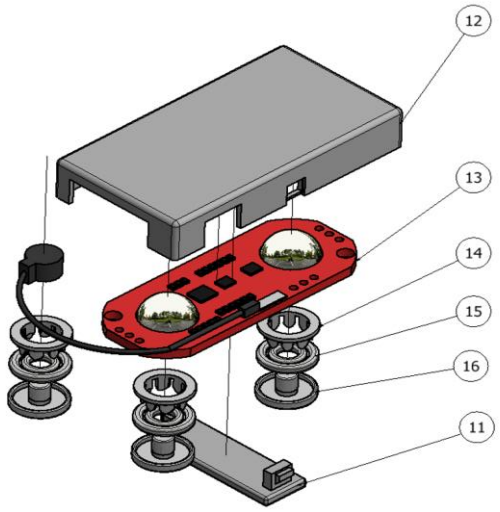
7. Detach the springs (part #1007) from the tendon sleeves that are closer to the knuckles. The spring plate can then be detached by untying the Velcro strap. Be cautious of the sensors attached to the spring plate.
8. The MyoWare™ sensors and their casing can be removed by undoing the snaps in the sensor and the fasteners. There are three snap fasteners for every sensor, also remove the wire attached to each sensor.

Assembly of subcomponents for the Cybernetic Force Enhancing Smart Glove:

The following procedures will serve as guides for assembling the subcomponents of the Cybernetic Force Enhancing Smart Glove. Although these procedures provide the necessary steps for assembling/disassembling the components, it is highly encouraged to request the services of technician or trained personnel.

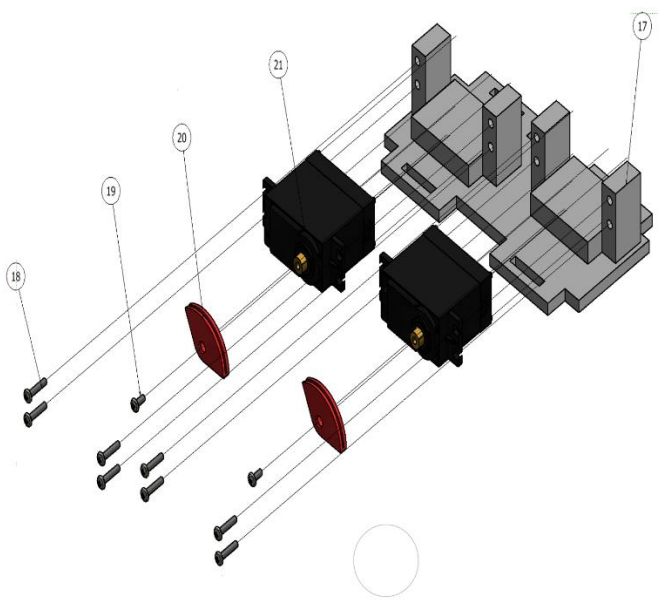
MyoWare™ Sensor Case:

1. Place part # 1012 in between the end muscle electrode snaps on the posterior side of the MyoWare™ muscle sensor (part #1013). Make sure the columns on part #1012 are facing up.
2. Part #1012 is then snapped into place within part #1011 to create the MyoWare™ housing case.
3. Snap fasteners are then connected to the three end muscle electrode snaps.



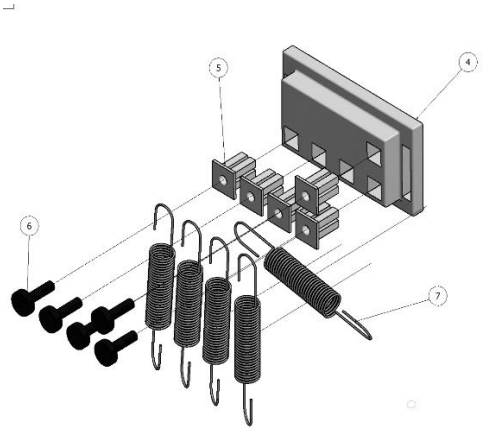
Servomotor Holders:

1. Place the servomotors on the mounting stations along each holder, they snap into place.
2. Align the holes on the servomotor's mounting tabs with the premade holes of the holders. Using a cross slot/ Philips screwdriver connect the pan phillip 2.5 x 12 screws (part #1018), each servomotor requires four screws.
3. Attach the servomotor tip (part #1020) to the shaft of the motor and then screw one pan phillip 2.5 x 6 (part #1019) to connect them.
4. All three holders are then connected via two Velcro strips which runs through the slots.
5. Connect the Kevlar string to the part #1020 which is located on the shaft of each servomotor.



Spring Plate:

1. Nylon fasteners (part #1005) are placed onto the holes on the top of the spring plate (part #1004). These fasteners have a tight fit, but adhesive can be added to ensure firmness and reduce mobility of the fasteners.
2. Tie the hook ends of the springs (part #1004) onto the nylon retainers (part #1006) and then place the retainer into the fasteners.



30.2 Parts Listing

Cybernetic Force Enhancing Smart Glove

Parts Manual



MECHANICAL/ELECTRICAL ENGINEERING DEPARTMENT
HOUSTON ENGINEERING CENTER
COLLEGE OF ENGINEERING
THE UNIVERSITY OF TEXAS AT TYLER

How to use the manual:

This manual contains the complete part list and the information of the components which make up the Cybernetic Force Enhancing Smart Glove. Included in each page are the parts list, a guide to the assembled subcomponents, and the devices electrical schematic. Each part can be identified by their part number and the name is given in the description, followed by the quantity. Included in the illustration is the assembly of various components and their placement.

Important Precautions:

This device should not be operated without having completely read and understood the operations manual. User should consult with a physician before operating this device. If you are unable to understand the warnings, cautions, or instructions, contact healthcare professional, or technical personnel before attempting to use this equipment. **DO NOT** use this product if it has been damaged, inspect all parts before use. In case of damage, contact Team Kracan for further instruction. In the case of discomfort, numbness or swelling of operational arm, immediately remove device and contact a healthcare professional before continuing with the use of the device.

⚠ **Warning: Possible Injury.** Do not operate this medical device unless accompanied by qualified clinician, medical provider, or trained personnel to ensure maximum safety of user. In case of injury seek immediate medical attention.

Avoid contact with the power supply during use of device to prevent a serious injury. Refer to operation manual guide on handling the power source.

Keep clear of liquids when handling this device. Exposure to liquid will damage device and possibly cause an injury to the user.

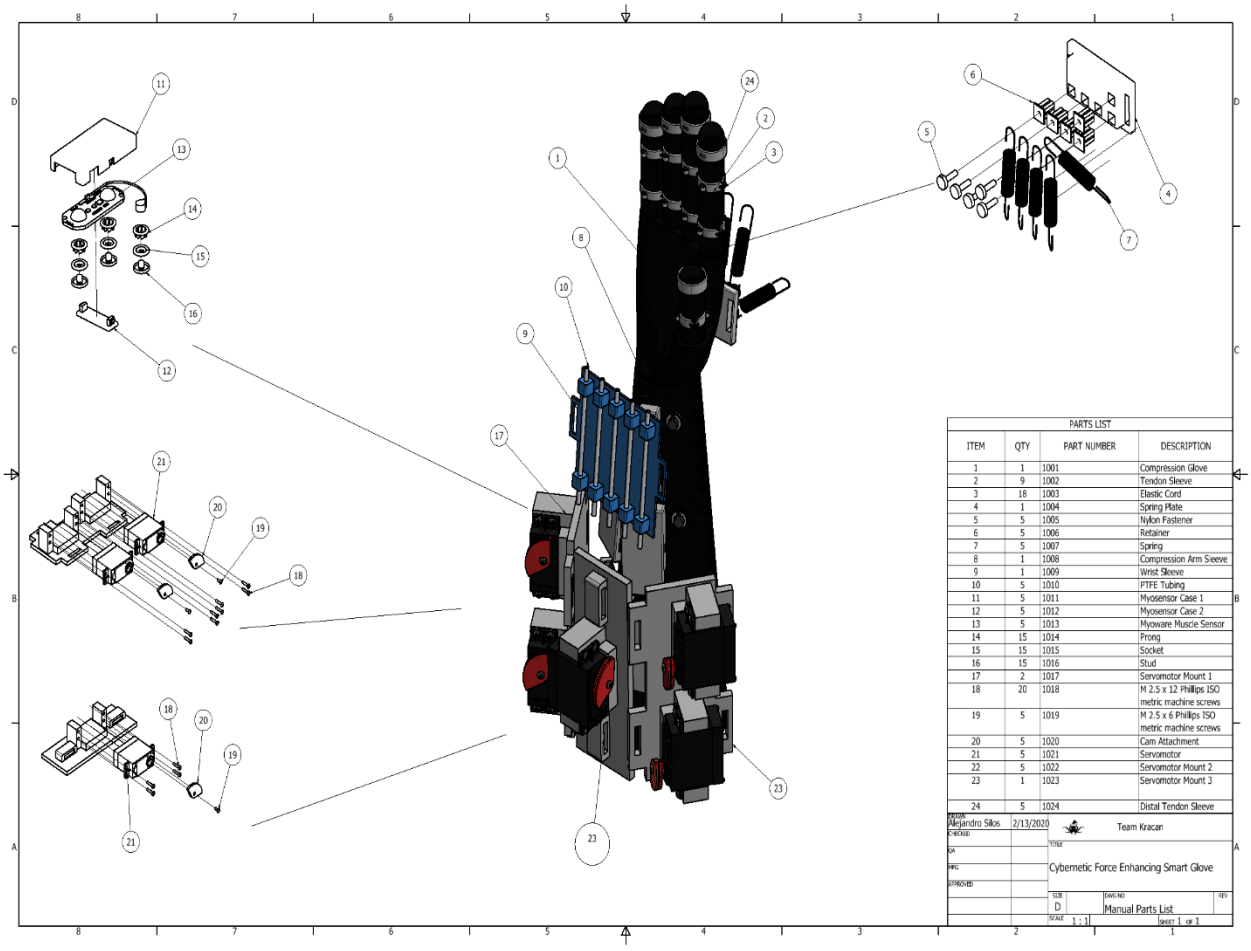
Equipment Specifications:

Specifications	Values
Weight	< 1 kg
Safe Working Force	31 lb./finger
Overall Length	23 in
Overall Width	8 in
Power Source	DC power supply with ground +5V and +12 V >125 Watts >16 Amps at max withdraw
Connectivity	250,00 Baud serial protocol through USB connection
Patient Type	Adult

Table of Contents

Parts List……... 1
Component Subassemblies…….. 2
Electrical Schematics……... 3

Part List



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	1001	Compression Glove
2	9	1002	Tendon Sleeve
3	18	1003	Elastic Cord
4	1	1004	Spring Plate
5	5	1005	Nylon Fastener
6	5	1006	Retainer
7	5	1007	Spring
8	1	1008	Compression Arm Sleeve
9	1	1009	Wrist Sleeve
10	5	1010	PTFE Tubing
11	5	1011	Myosensor Case 1
12	5	1012	Myosensor Case 2
13	5	1013	Myoware Muscle Sensor
14	15	1014	Prong
15	15	1015	Socket
16	15	1016	Stud
17	2	1017	Servomotor Mount 1
18	20	1018	M 2.5 x 12 Phillips ISO metric machine screws
19	5	1019	M 2.5 x 6 Phillips ISO metric machine screws
20	5	1020	Cam Attachment
21	5	1021	Servomotor
22	5	1022	Servomotor Mount 2
23	1	1023	Servomotor Mount 3
24	5	1024	Distal Tendon Sleeve

DRAWN: Alejandro Silos 2/13/2020
CHECKED
QA
MFG
APPROVED

Team Kracan

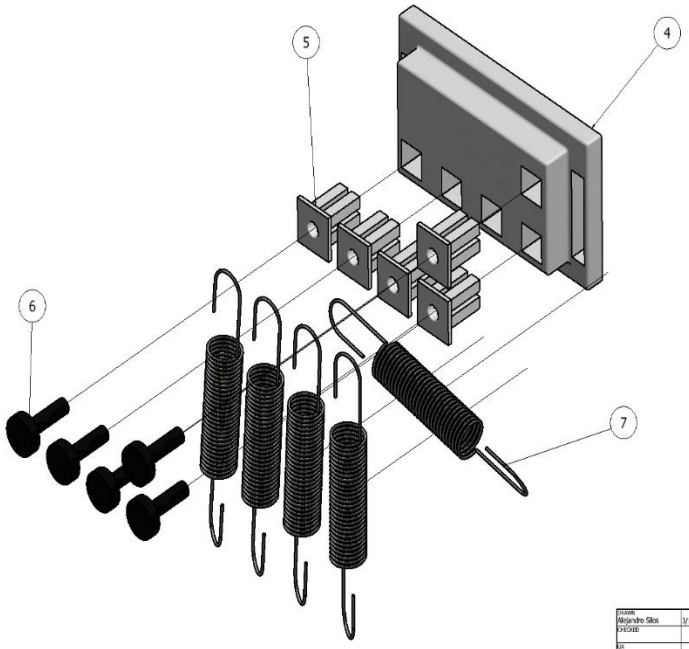
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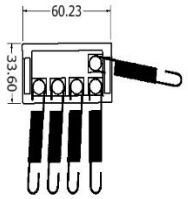
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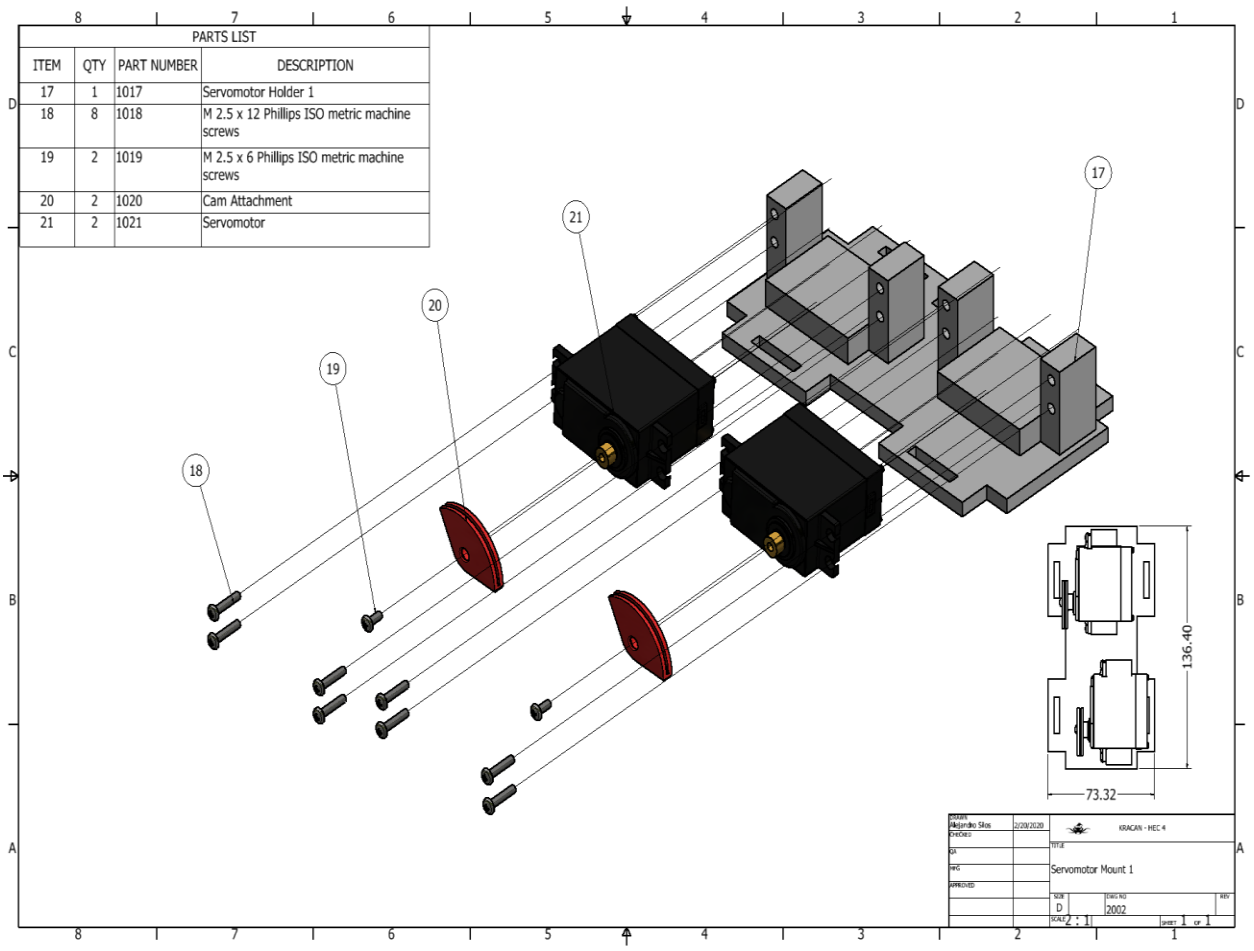
Component Subassemblies

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
4	1	1004	Spring Plate
5	5	1005	Nylon Fastener
6	5	1006	Retainer
7	5	1007	Spring



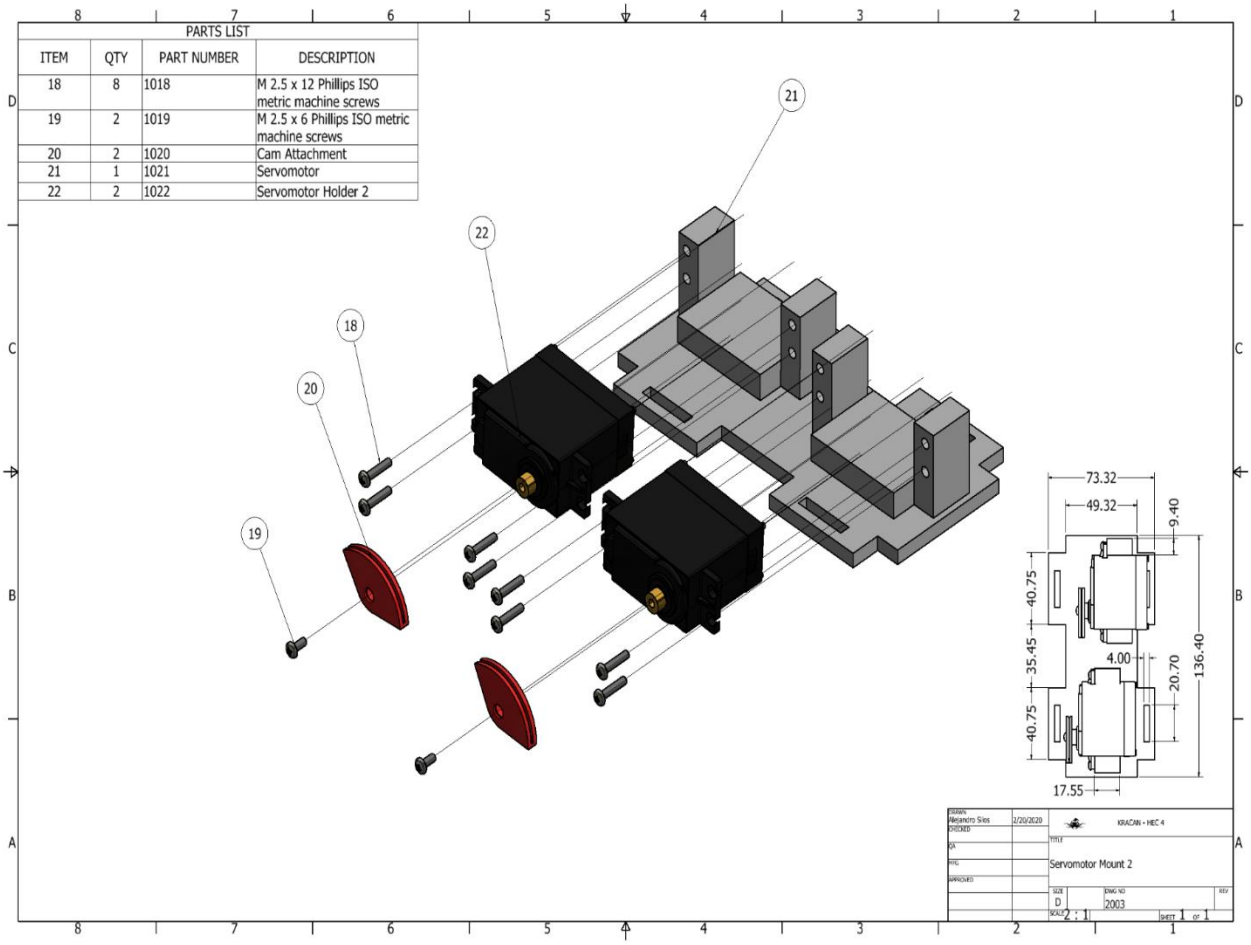


Alejandro Silos
3/15/2020
KRACAN - REC 4
Spring Plate
SIZE D
DWG NO 2005
REV
SCALE 5 : 1
SHEET 1 OF 1


PARTS LIST
ITEM | QTY | PART NUMBER | DESCRIPTION
17 | 1 | 1017 | Servomotor Holder 1
18 | 8 | 1018 | M 2.5 x 12 Phillips ISO metric machine screws
19 | 2 | 1019 | M 2.5 x 6 Phillips ISO metric machine screws
20 | 2 | 1020 | Cam Attachment
21 | 2 | 1021 | Servomotor
17
21
20
19
18
136.40
73.32
Alejandro Silos
2/20/2020
KRACAN - HEC 4
Servomotor Mount 1
D
2002
SCALE 2 : 1

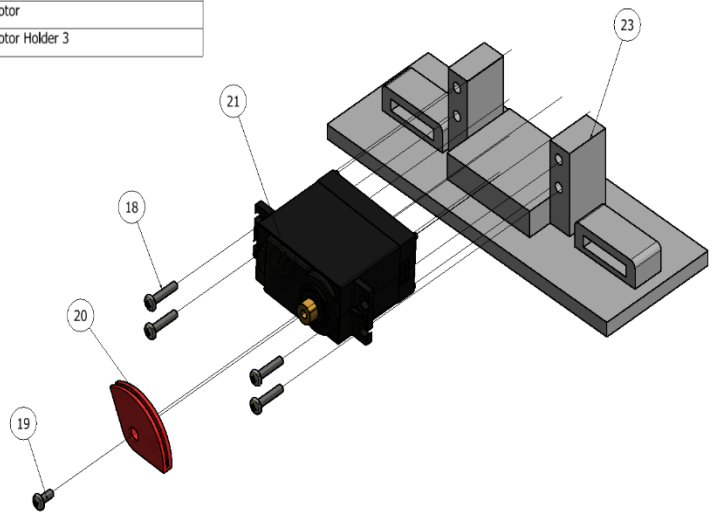
PARTS LIST

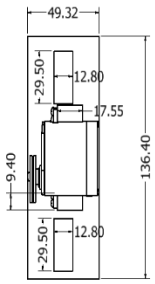
ITEM	QTY	PART NUMBER	DESCRIPTION
18	8	1018	M 2.5 x 12 Phillips ISO metric machine screws
19	2	1019	M 2.5 x 6 Phillips ISO metric machine screws
20	2	1020	Cam Attachment
21	1	1021	Servomotor
22	2	1022	Servomotor Holder 2



PARTS LIST

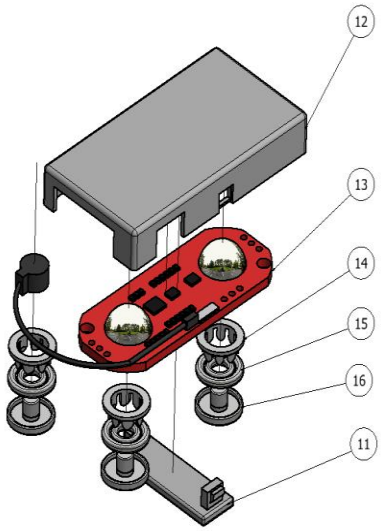
ITEM	QTY	PART NUMBER	DESCRIPTION
18	4	1018	M 2.5 x 12Phillips ISO metric machine screws
19	1	1019	M 2.5 x 6Phillips ISO metric machine screws
20	1	1020	Cam Attachment
21	1	1021	Servomotor
23	1	1023	Servomotor Holder 3





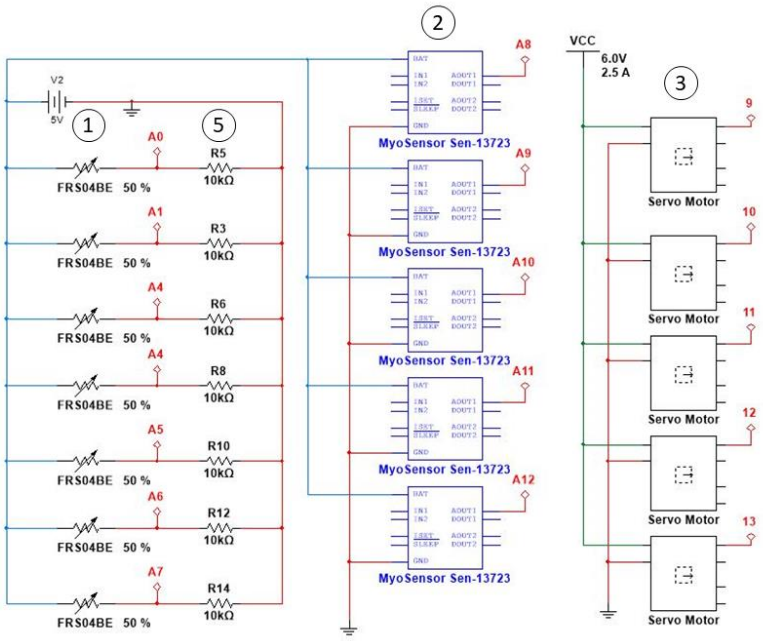
DRAWN Alejandro Silos	2/20/2020	KRACAN - HEC 4
CHECKED		
QA		TITLE: Servomotor Mount 3
MFG		
APPROVED		
		SIZE: D; DWG NO: 2004; REV
		SCALE: 2 : 1; SHEET 1 OF 1

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
11	1	1011	MyoWare Sensor Case 1
12	1	1012	MyoWare Sensor Case 2
13	1	1013	MyoWare Muscle Sensor
14	3	1014	Prong
15	3	1015	Socket
16	3	1016	Stud



DRAWN Alejandro Silva	2/13/2020	KRACAN - HEC 4
CHECKED		TITLE: MyoWare Sensor Assembly
QA		
MFG		
APPROVED		SIZE D; DWG NO 2001; REV
		SCALE 3 : 1; SHEET 1 OF 1

Electrical Schematics





Item	Component	Quantity
1	FSR04BE Force Sensor	7
2	MyoSenro Sen-13723	5
3	MG996R Servo Motor	5
4	Mega2650	1
5	10k resistors	7