# Glaukos - Human Periorbital Tissue and Interaction Simulator

# Final Design Report

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# Abstract

The Human Periorbital Tissue and Interaction Simulator is a test fixture designed, manufactured, and assembled by our USD Capstone Design team for Glaukos Corporation in San Clemente, CA for use during the company's testing of medical devices for the eye. During the first semester of Capstone Design, most of our time was spent refining iterations in the design process and initial prototyping. Our customer proposed three key requirements: realistic anatomical modeling, force measurement and display, and simulated human interaction. In this second semester, our efforts were focused on gathering parts and materials, machining, and assembly, and testing of the different subsystems of the fixture to address these key requirements in the final fixture. To concentrate on each deliverable, the overall project was divided into subsystems of the face model, base, arm and linear actuator, and load cell and servo motor. Parts were manufactured at both USD and Glaukos' machine shops and assembled remotely at the end of the semester. Testing for the load cell, servo motor, and linear actuator was performed throughout the semester, and a series of final testing was performed with the completed assembly to ensure coherence of the different subsystems. Despite minor setbacks caused by factors such as timing and the COVID-19 pandemic, the fixture was finalized before the showcase on May 8, 2020. The test fixture satisfies the customer's requirements because of the specific subsystems used in the design process. In addition, dividing the project allowed for an easier transition to remote work caused by COVID-19. Overall, the test fixture successfully met the customer's expectations and is ready to be incorporated into Glaukos' design process.

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# 1 Introduction

Glaukos Corporation is looking to design and create various drug delivery systems and medical devices specifically for the human eye. Amid the products being created, there is a desire to test new designs in a repeatable manner to test the new ideas. Testing equipment needs to be built for Glaukos Test Engineers to replicate methods that simulate normal human interactions with the eye as well as the surrounding facial (periorbital) tissue. These normal interactions include, but are not limited to, rubbing the eye with the hand, or applying pressure directly with the use of another body part or object. Humans rub their eyes in a variety of ways, and with a variety of pressures. It is critical that Glaukos can better understand how these eye interactions may affect their products located in the eye region.

## 1.1 Problem Statement

Glaukos wants a testing fixture that replicates normal human interactions with the eye and the surrounding facial (periorbital) region to learn how they affect their products.

## 1.2 Requirements

Customer Requirements:

Customer requirements are the physical and functional needs established by our industry sponsor. These are the outcomes that Glaukos has requested in the final design. Below is an outline of the various design requirements set out to us by the customer, Glaukos and developed through multiple meetings and discussions with the Vice President of Engineering.

1. Needs to accurately simulate periorbital facial anatomy
    a. Including skin, tissue, and bone.
    b. Must be life-sized
        i. Minimum-Maximum range of sizes
2. Needs to be able to simulate realistic eye interactions (i.e. eye-rubbing)
    a. X, Y, and Z axis with rotational element Θ
    b. Lever arm must perform eye rubbing motion
    c. Ability to apply a variety of forces
        i. Use load cell at the end effector pushing down into periorbital area to measure external force applied
    d. Ability to apply more force than normal operating force
        i. May design for 3x the expected forces
3. Needs to be able to measure and display the amount of force that is being applied
4. Set up time should be less than an hour
5. System must be safe to operate
    a. There should be no exposed electrical wires or pinch points
6. Needs to be able to be operated by a single user
7. Testing mechanism must be able to repeat test process for a minimum of six months without

maintenance to test fixture

8. Operator able to repeat test cycle repeatedly on single device
9. Anatomical representation must be able to withstand multiple cycles per device without breaking down and then have the ability to be replaced
10. System may have an emergency shut-off
11. Alignment of rubbing component must be able to repeatedly align with desired rubbing location

Functional Requirements:

Functional requirements are things that the customer would like the final design to include and be able to do. Below, is a list of the functional requirements asked for by our customer, Glaukos.

1. Test fixture must perform eye rubbing motion. We will prioritize the simulation of the knuckle rubbing first, then the finger rubbing.
2. Linear actuator must apply forces up to 3x the expected rubbing forces (ability to overdrive)
3. Fixture must include visual display to allow user to determine Pass / Fail of product
4. Testing mechanism must be able to repeat test procedure on a single device
5. Anatomical representation (depending on product) must be able to repeat tests for a reasonable amount of time, and then have the ability to be replaced
6. Set up time should be less than an hour
7. Emergency shutoff

Physical Requirements:

Physical requirements are physical asks that the customer would like the final design to include. Below, is a list of the physical requirements asked for by our customer, Glaukos.

1. Fixture must include accurate anatomical representation
2. Ability to fit in lab testing environment
3. Fixture must be relatively portable

Constraints:

Constraints are limitations or restrictions placed on the project that are uncontrollable. Our project must meet the following constraints upon completion.

1. Project budget must be no more than $2500 (or additional funding must be approved by the sponsoring company).
2. Project must be finished by the end of May 2020.
3. Project design complexity must be within the capabilities of the design team.
4. Project must meet all codes and standards set out by Cal OSHA.
5. Fixture should include an emergency stop and safety guarding.
6. Fixture must operate normally in temperatures ranging from 50 - 90 °F.
7. Limited amount of information can be disclosed, due to NDAs.

8. Customer has asked that we use synthetic and not biological materials.
9. Downward force must not exceed load cell rating; load cell rated at 50lbs (1.5x overdrive = 75 lbs.).

### 1.3 Project Risks

Since this fixture will have moving parts, it is important that we consider the risks that could be associated with misuse. One potential risk for the user could be getting a hand or finger caught between the linear actuator and the face as the linear actuator is applying pressure. To ensure safety, the linear actuator cannot function at a high speed, and it is made clear in the instruction manual to keep hands away from the system while it is running. Additionally, a small risk to the user could be a malfunction in the wiring of the system, resulting in electrocution or in the system catching on fire. To ensure safety, all wires will be covered completely after being soldered. Also, a warning will be issued to never let the system overheat.

A potential risk for the team during construction and testing would be to cut any body part on the edges of the test fixture. To ensure safety, we will deburr all edges thoroughly. The team will also take all precautions mentioned above.

A possible risk to the project delivery is the current impacts of Covid-19. Since we are all under a Stay at Home order, it has been challenging to meet to work on assembly and testing of the fixture together. We have prepared all written reports and documents from using shared documents. We will continue to do everything we can to ensure an on-time delivery of our project but may not be able to hand it off in person as hoped.

## 2 Design Overview

Our team was able to successfully create a fixture to address all the customer requirements designed in **Section 1**. The fixture includes a head model with anatomical accuracy, a linear actuator and servo motor to simulate eye rubbing, and a load cell to report the force being applied. The final design can be seen in **Figure 1** below.

**Figure 1:** Project Final Design

## 2.1 Design Specifications

Specifications:

1. Load cell must display data that is within ± 10% accuracy
2. Servo must be able to overcome reasonable Frictional force
    a. Must obey all equations
    **Relevant Equations:**

**Equation 1:** Torque

$$T = F \times r$$

where T = torque, F = force, r = distance to where force is applied

**Equation 2:** Frictional Force

$$F_f = \mu N$$

where $F_f$ = frictional force, $\mu$= coefficient of friction, N = normal force

**Equation 3:** Pressure

$$P = \frac{F}{A}$$

where P = pressure, F = force, A = area

3. Skin layer thickness must be approximately 1.7 mm in thickness with ± 10% accuracy
4. Simulated Facial anatomical features must be accurate
5. The load cell should be used with forces between 0-50lbs (and never exceeding 75lbs)
6. The linear actuator can apply forces between 0-50lbs
7. On/Off momentary switch must be incorporated for use of the linear actuator and servo motor

$$\text{Force (lbs)} = 30\text{ lbs} \rightarrow \text{Force (N)} \approx 133.447\text{ N}$$

$$T = F \times r$$

$$F_f = \mu N$$

$$\mu\,(\text{skin on stainless steel})_{dynamic} = 0.85\ \mu_{static}$$

$$= 0.85\,(1.1)$$

$$\mu_{dynamic} = 0.935$$

Dynamic

$$F_f = (0.935)(133.447\text{N})$$

$$F_f = 124.773\text{ N}$$

$$T = (124.773\text{N})(1.5 \times 10^{-2}\text{ m})$$

$$T = 1.872\text{ N}\cdot\text{m}$$

Static

$$F_f = (1.1)(133.447\text{N})$$

$$F_f = 146.792\text{ N}$$

$$T = (146.792\text{ N})(1.5 \times 10^{-2}\text{ m})$$

$$T = 2.202\text{ N}\cdot\text{m}$$

**Figure 2:** Hand-written friction calculations

## 2.2 Engineering Standards

The engineering standards that we applied to the design of our test fixture was ISO and, furthermore, the regulations that affect our design are OSHA standards. OSHA standards explain the best methods that employers must incorporate to protect their employees from hazards. Glaukos will be using the test fixture for internal uses, but if they wish to have their tests result in approval of testing on patients (or any other FDA approved tests/clearance), they must get the mechanism FDA approved and follow FDA standards.

## 2.3 Plate, Base, and Rails Subsystem

There are many components within this subsystem: including the base plate, sliding rails, locking carriages, and connecting plates. All are shown in **Figure 3**. The base plate holds the entire mechanism at the bottom. On two opposite ends of the base plate there are sliding rails, each with a carriage that can lock in place. There is one more sliding rail with a locking carriage, with each end of the rail secured using connecting plates (**Figure 4**) on the other two carriages. The carriages allow for mobility in any x-y direction, so when the facial anatomy is added, the face can still be moved.

**Figure 3:** Base Plate with three Sliding Rails and Carriages

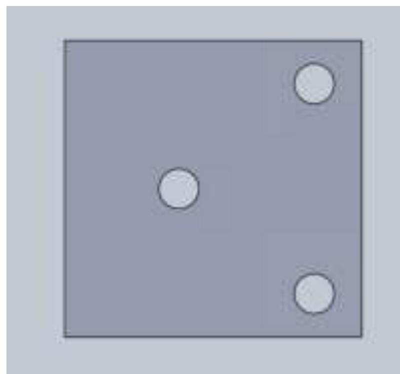

**Figure 4:** Connecting Plates

## 2.4 Skin and Anatomical Model Subsystem

This subsystem includes the Sawbones model head (consisting of representations of muscle and bone structures), the molded silicone skin layer, and the connecting piece between the head model and the supporting plate. This subsystem will be attached directly to the plate, base, and rails subsystem. Additionally, this skin and anatomical model will be interacting with the servo motor which is what will be creating the rubbing motion.

The main goal of the skin and anatomical model subsystem is to create a rubbing surface that will act like a human face would when rubbed with similar forces. To do this, we obtained a Sawbones model head (**Figure 5**) to act as the muscle and bone layers, and to create an accurate facial shape for the skin layer to lay on. The skin layer was then molded out of a silicone that closely resembles the "squishiness" of human skin and was molded to emulate the facial shape of the Sawbones head so that the features line up when the skin is overlaid (**Figure 6**). More details on how this was fabricated can be found in **Section 2.7**.

**Figure 5:** Sawbones Model Head

**Figure 6:** Sawbones Model Head with Silicone Skin Layer Overlaid

## 2.5 Arm and Linear Actuator Subsystem

The arm and linear actuator subsystem were vital connections for the system to be able to apply pressure onto the facial anatomy, thereby making it an individual subsystem. The arm and linear actuator subsystem is composed of two separate hollow aluminum T-slotted frames as shown in **Figure 7**, one 2.5 feet in length and the other a foot in length, as well as the liner actuator itself with the addition of a manufactured linear actuator connector. The connector is shown in **Figure 8**. The purpose for the linear actuator connector is to connect the linear actuator with the T-slotted frame so it can be held in place over the facial anatomy securely. Without the linear actuator being secured to the T-slotted frame, the downward applied force would not be achievable for the end product.

**Figure 7:** Hollow Aluminum T-Slotted Frame

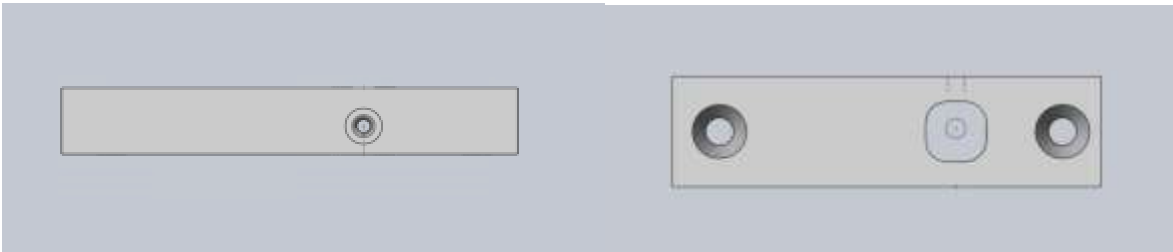

**Figure 8:** Linear Actuator Connector (side and top views)

## 2.6 Servo and Load Cell Subsystem

The servo and load cell subsystem has the goal of capturing data from the force applied to the periorbital region and to simulate a normal rubbing motion. The load cell is capturing the force data through a Lab Jack Data Acquisition Device (DAQ). This displays live data using Lab Jack's provided software, while writing data to a chart for later analysis.

**Figure 9** is a drawing we created of a load cell from Omega Engineering. The load cell has a load range from 0 - 50 lbs., with an acceptable overdrive of 1.5x, thus making the absolute maximum load it can withstand 75 lbs. The load cell is necessary to accurately measure the amount of axial load we are producing via the linear actuator.

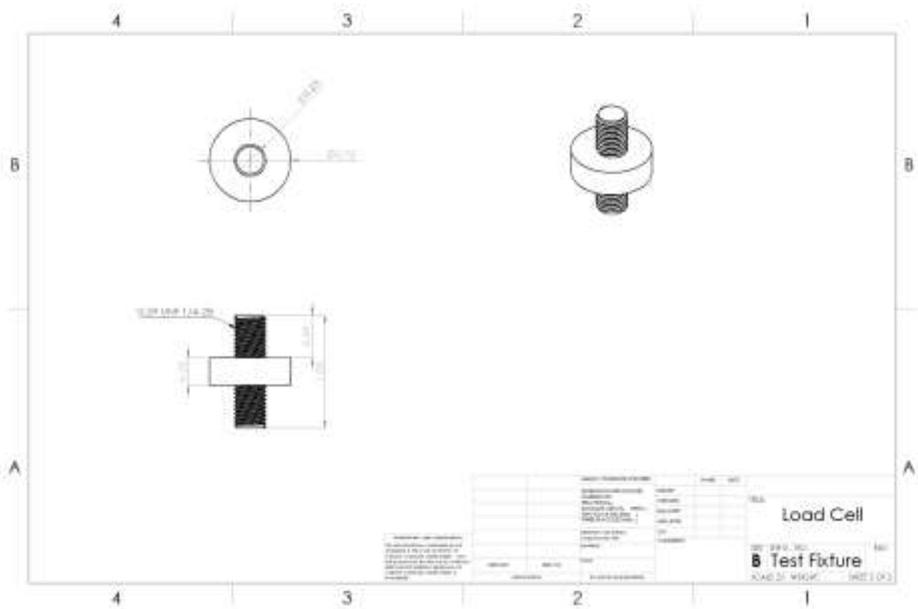


**Figure 9:** Load Cell Drawing

## 2.7 Prototype Fabrication

We worked on the fabrication of our fixture in subsystems. **Figure 10** shows a picture of our entire fixture with each subsystem labeled. Below that, in **Figure 11**, we have two pictures with labels to show where each component of our project is located.

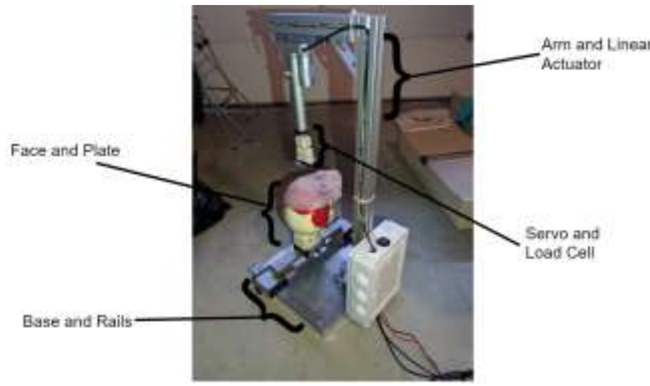


**Figure 10:** Completed Fixture (labeled by subsystems)

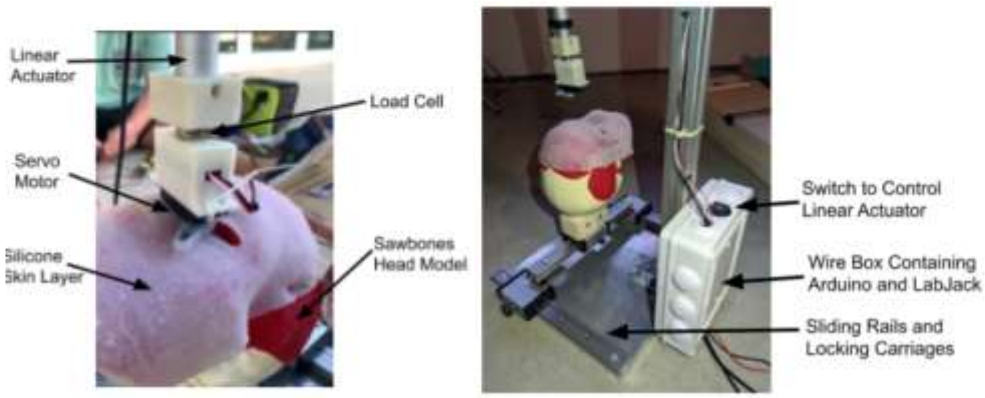


**Figure 11:** Completed Fixture (labeled by components)

Plate, Base, and Rails Subsystem:

For the base, we ordered sliding rails and locking carriages. To adapt them to our design we used the bandsaw and mill in the USD machine shop to cut them to the desired lengths. To fabricate the plates and the base, we created part drawings in Solidworks with detailed dimensions and sent them to Glaukos' machine shop to be made (the USD machine shop was closed at this point due to Covid-19).

Skin and Anatomical Model Subsystem:

Our skin and anatomical subsystem took some creative techniques to execute. The skin layer needed to fit over our Sawbones skill model and to be an accurate thickness. The first step to create the skin layer was to create a mold with facial features. To do this, we utilized a twenty-five-pound bag of plaster, Vaseline, a plastic bin, and our Styrofoam head. We coated the Styrofoam head in a thin layer of Vaseline to help make removal easier and then mixed the plaster in the bin. Once the plaster was ready, we inserted the Styrofoam head as shown in **Figure 12** and placed weights on top to keep it pushed in. Once the plaster hardened, we removed the Styrofoam head and were left with the wonderful mold shown in **Figure 13**.

**Figure 12:** Styrofoam Head inserted into Wet Plaster

**Figure 13:** Completed Plaster Mold

Once the mold was created, the next step was to use it to mold the silicone. At this point, we had already selected the silicone to use for this step (for more information, see **Section 3.3**). We had also conducted research and found a journal article with data supporting that average human facial skin thickness is around 1.7mm (our silicone molding process does not have the capability to create an exact thickness, but instead we created a skin layer with approximately that thickness). Using this information, we set out to find a material we could use for spacers and stumbled upon the discovery that some wooden popsicle sticks were 1.7mm in thickness. We cut these popsicle sticks into little squares, glued them to nails, and then inserted them along the midline of the Styrofoam head as shown in **Figure 14**. Once the Styrofoam head was prepared with the spacers, we pushed it down with weights into the mold filled with the liquid silicone as shown in **Figure 15**. We let this cure for several hours, and then removed the Styrofoam head. Overall, the spacers were successful for the front of the face, but we hand-painted a little more silicone onto the sides of the face to ensure those spots were thick enough for attaching to the Sawbones head model. Once completed, we used nails to attach the silicone skin layer to the Sawbones head model (**Figure 16**) and our facial anatomy replica was complete! One final step that we took was coating the rotating piece of the servo motor with silicone (**Figure 17**) as well to fully represent skin on skin rubbing.

**Figure 14:** Styrofoam Head with Spacers

**Figure 15:** Styrofoam Head pushed into Mold with Liquid Silicone

**Figure 16:** Sawbones Model Head with Silicone Skin Layer Attached

**Figure 17:** Servo Motor End Effector with Silicone Coating

Arm and Linear Actuator Subsystem:

For this subsystem, there were two separate T-slotted frames, one measuring 2.5 feet while the other measuring one foot, and these were both connected by a corner bracket to form an L shape. The L shape was then bolted to the base of the system using another corner bracket. To attach the linear actuator, we manufactured a part to connect it to the arm (**Figure 18**). The part was bolted to the T-slotted frame so that it is directly overhead of the facial anatomy. Then the linear actuator was inserted into the slot and secured using a shoulder bolt. We decided to implement this because drilling into the T-slotted frame used for the arm would have put it in danger of becoming weak and fragile.

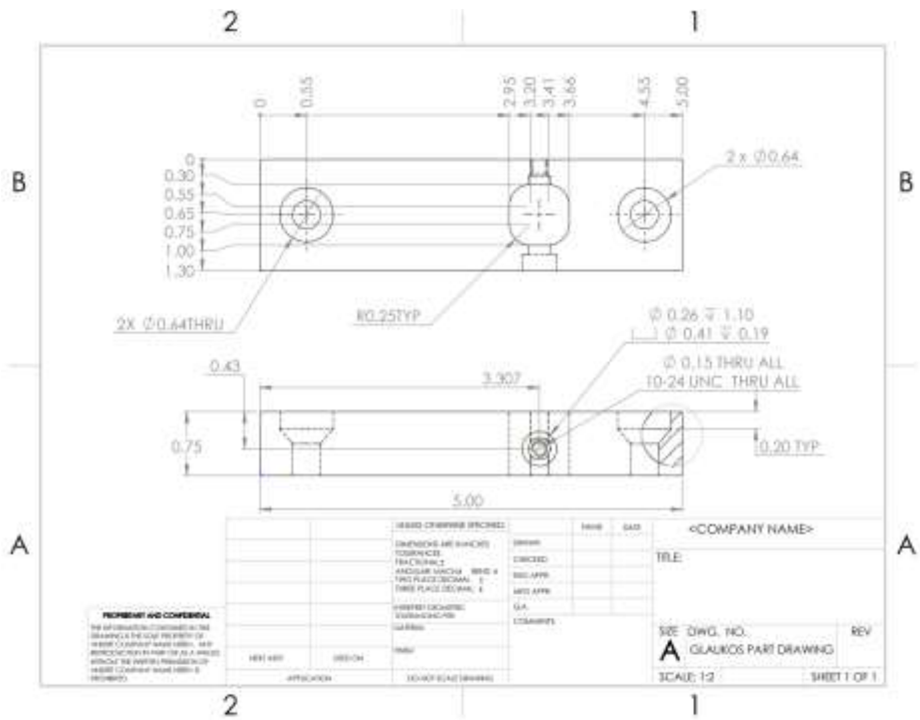


**Figure 18:** Drawing of Linear Actuator Connector

Servo and Load Cell Subsystem:

There were considerations as to where to put the load cell. The initial idea was to put the load cell at the arm before the linear actuator, or on the head itself in the skin. These ideas were avoided because if it were in the skin layer, it would interfere with the consistency and squishiness of the skin and may skew results. Furthermore, it was not placed at the arm directly as it would be harder to mount the servo to the linear actuator. So, it was decided to produce two mounts, using additive manufacturing, connecting the linear actuator to the load cell (**Figure 19**), to which the servo is connected to the load cell seen in **Figure 20**.

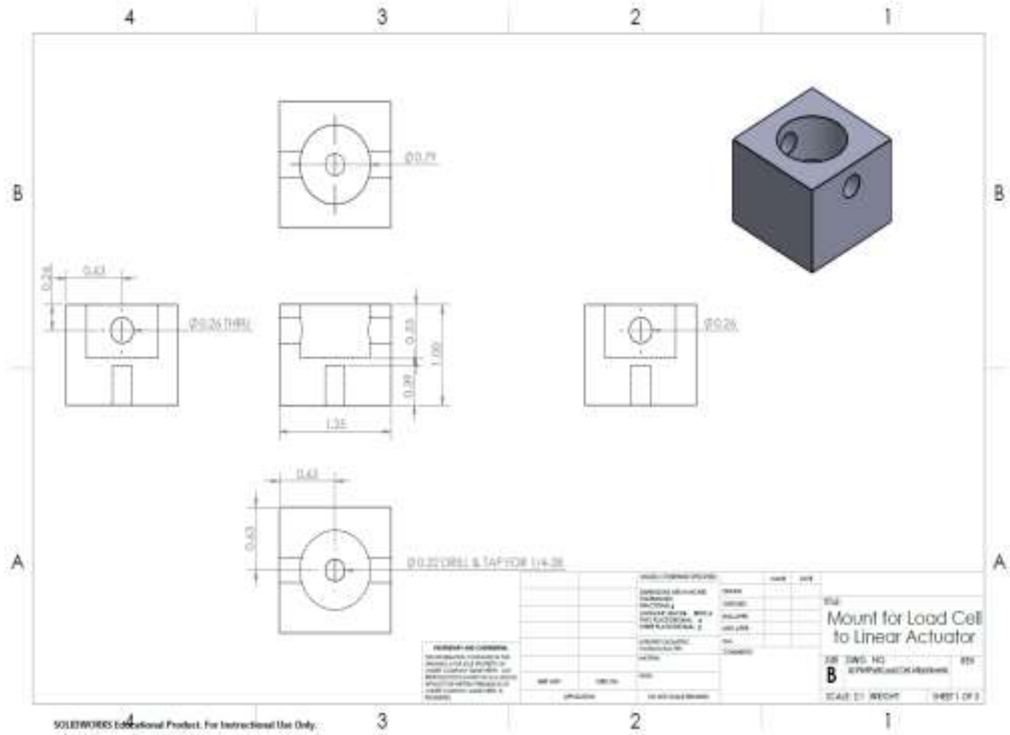


**Figure 19:** Drawing of Linear Actuator and Load Cell Mount

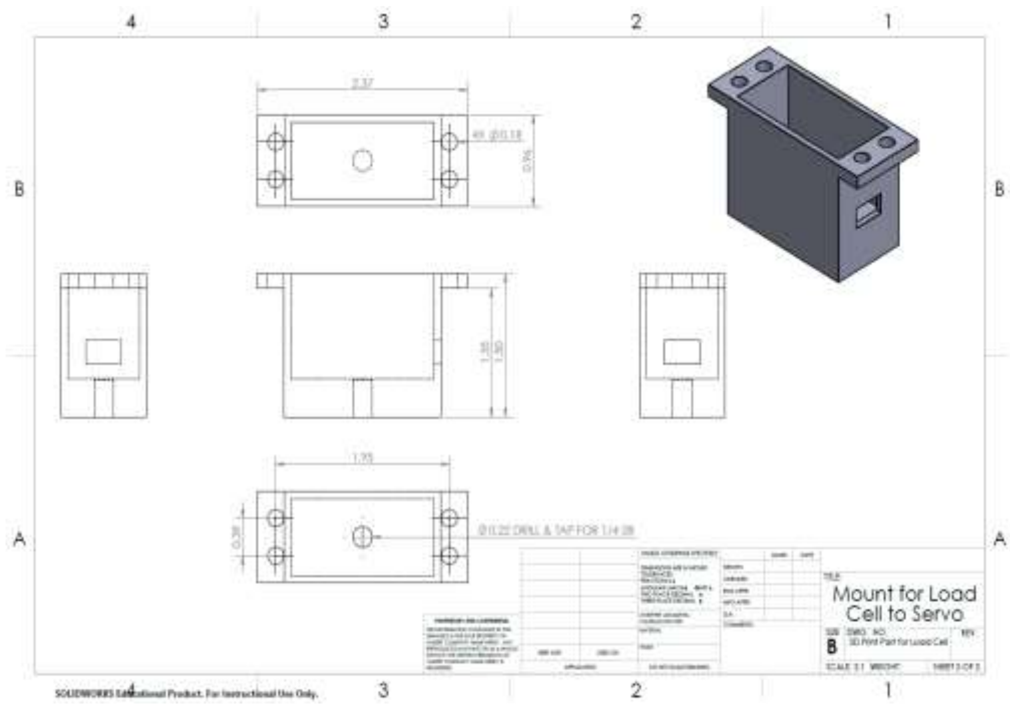


**Figure 20:** Drawing of Servo Mount to Load Cell

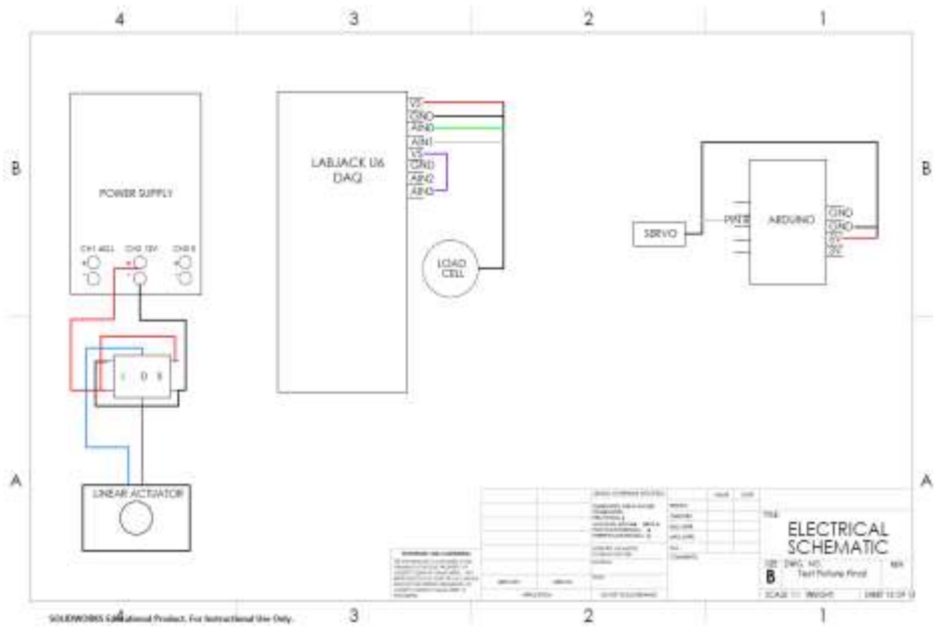


Figure 21: Drawing of Electrical Schematic

# 3 Sub-System Testing and Validation

Due to the Covid-19 pandemic, our team has spent most of the semester making progress on our project remotely. Luckily, we were able to complete most of our component testing before the transition to remote learning happened. Below, we have included details on how we completed the various testing and the results we obtained. It was important to our team that we test the various components of our project to ensure that they will properly serve their function.

**Finite Element Analysis:**

The design began with a model in Solidworks to draw out and simulate if the idea was able to be made. We combined the design parts into an assembly to ensure they would all fit together properly. Furthermore, an FEA analysis was done on the chassis to make sure it could withstand the 10 lbf load that was applied to the cantilever beam where the linear actuator will be mounted to. It was found that the maximum displacement experienced where the external load is applied is a value of 4.902e-02 mm. Furthermore, the maximum strain value that occurred in the test fixture was 1.573e-05 MPa and a maximum von Mises stress is experienced at the inner connection point of the main shaft with a magnitude of 2.839 MPa. The study was performed using a 98% H-Adaptive accuracy target with a medium mesh.

**Fermi Problems:**

The frictional forces that are required to be overcome are found using the equations mentioned in **Section 2.1**, Design Specifications, with **Figure 2**, showing the hand calculations. More detail into the frictional calculations are found in **Section 3.1**.

**Free Body Diagram:**

A free body diagram shows all the forces acting on a body. In **Figure 22**, we have a created a free body diagram focused on the periorbital region.

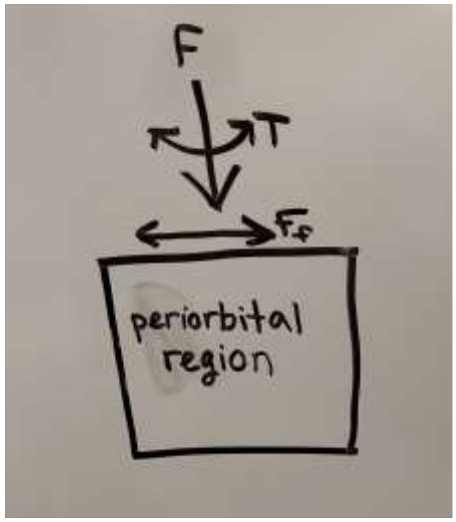


**Figure 22:** Free Body Diagram of Periorbital Region

**Table 1:** Test Plan for Fixture

| Requirements | Test Procedure | Test Results |
|---|---|---|
| Simulate Periorbital Anatomy | The test procedure for the simulation of the periorbital anatomy were as follows: Apply 3 different weights to a durometer that is positioned over silicone samples, and plot curves of the durometer readings for each individually. Repeat, but instead of silicone samples, position the durometer of the human forearm. Plot results to the same graph.<br><br>Performed extensive research on thickness of human skin. | Durometer readings for human skin most closely match the durometer readings for the Ecoflex-0030 sample, therefore we used Ecoflex-0030 for the silicone layer of skin.<br><br>Upon further research of the thickness of human skin, we found that it is approximately 1.7mm, which is the same thickness of a popsicle stick. The popsicle stick was used as spacers to formulate the proper thickness of the silicone. |
| Simulate Realistic Eye Interactions | The test procedure for the simulation of the realistic eye interactions were as follows: | Servo with stall torque rating of 21.5 kg/cm. Low drop off until |

| | | |
|---|---|---|
| | Apply calibration weights in increments of 100 to servo, count how many times it can sweep within a 10 second time window | 11kg of force was applied onto the servo.<br>Servo is not able to produce very quick movements; however, it does not stall like the previous servo, and, it is fast enough to simulate someone who is rubbing their eye |
| Measure / Display Amount of Force being applied | The test procedure for capturing the data of the amount of force applied is as follows: Apply calibration weights in increments of 100 to load cell, make a plot to view trendline and see how linear the actual data looks when compared to the trendline | Load cell follows a very linear trend line, however, when capturing live data from the DAQ noise limits accuracy to within ± 10% |

## 3.1 Sub-system Load Cell and Servo

The load cell calibrations were performed by using the Lab Jack LJLogUD software to display the feedback from the load cell. Calibration weights were used and placed in 100-gram increments, where each increment was read and plotted to a chart in Excel. From there, the data was plotted and a trendline was generated to find a correlation between the analog output of the load cell (voltage), to the desired output (grams).

The data points captured for each 100 grams seen in **Figure 23**, follow a very linear path and almost match with the trendline exactly thus showing the load cell is accurate even with the amount of forces the test fixture will be applying.

The trendline found from the calibration of the load cell was found to be y = -2,167,714.02x - 3,049.34. The trendline will be used for the scaling equation to display the reading in grams on the Lab Jack LJLogUD software. The scaling equation is defined as Load = ((Slope * Vsignal) + Offset) * (Vexc/Vexccal). So, the equation would be as follows: slope would be the -2,167,714.02, Vsignal would be analog input read from the load cell through the Lab Jack DAQ, offset would be the - 3,049.34 found in the trendline, and Vexc/Vexccal will be the excitation voltage provided by the DAQ and the target excitation voltage. Thus, resulting with a scaling equation of y=(((-2167.714.02*c)) +-3,049.34) *(d/5).

There are, however, issues with the current setup. After discussing with Lab Jack technical support, there was no way to help filter some noise, for example it is unable to average the readings from the DAQ, or change the polling rate of the DAQ to the load cell leading to quite a bit of noise in the data collected. With the noise in the data, this leads to a ± 10% error in the data collected to the actual results based on the calibration weights being placed on the load cell. Furthermore, there is inherent noise with the DAQ due to the excitation voltage source from the DAQ itself, thus leading to the problem of inaccuracies within the data that is being collected.

The benefits to the current system are, less programming is involved as the DAQ has software that is provided, a more professional appearing setup with a dedicated external DAQ and what most companies in industry will do for a data collection solution, a simpler solution than what is required from the Arduino controlling both the servo and data acquisition, and it is relatively cheap for a DAQ. The external DAQ simplifies the solution for capturing data, as it solves the controls issue with reporting data from load cell and Arduino performing the servo sweep. The Arduino struggled to send step signals to control the servo, while capturing data from the load cell at the same time, due to limitations with the written code, and other coding solutions would be required. Or would require two Arduinos, one capturing data, and the other to write to the servo. Furthermore, using the external DAQ allows for the writing of the data to a CSV file in a click, whereas, a relatively complex solution was used to interface the Arduino to write data to Excel.

The first attempt at a solution for controlling the servo and capturing data was using one Arduino that combined both aspects. This solution had an external ADC board that was used to interface between the load cell and Arduino. This solution is better than the Lab Jack DAQ as it came with a code library that you could access within the Arduino ecospace. This code library included noise filtration methods such as averaging the results, and the ability to change the polling rate. Thus, using an ADC board to interface with the Arduino is a better solution as it allows for much more accurate readings of the load cell.

The pitfalls of the external ADC board interfacing with the Arduino are, there is no dedicated technical support team (although the Lab Jack support team was limited), had a controls issue that required a complex method of switching between polling and reading signals, and finally had more steps required to interface with Excel to export the data rather than reading it instantaneously and displaying it.

We went with the DAQ system as it solved the issue with the Arduino and sweep performance. It also was easier to capture and write data. However, we would choose the ADC route as it overall gave better readings. Currently, the Lab Jack DAQ is reading within +- 10% and requires a calibration each time it powers on. The solution we recommend would use a different DAQ that might work better with noise filtration, or another ADC board. Due to the current situation with the COVID-10 outbreak, we were unable to get another ADC board in time to allow for more accurate results.

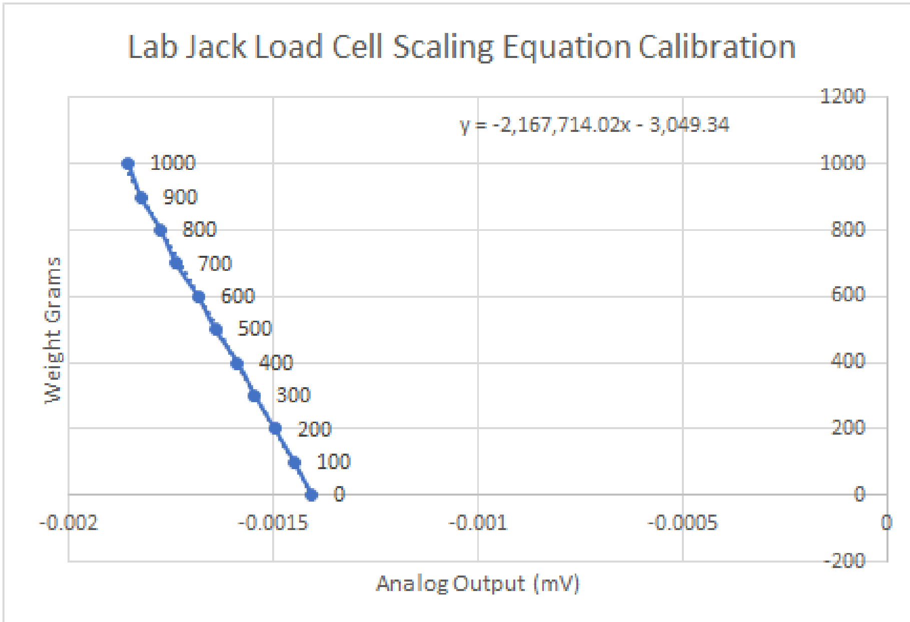


**Figure 23:** Load Cell Calibration Chart

Moving on to the servo testing and validation, the servo load tests were conducted by placing calibration weights in 100-gram increments on top of the servo which is facing down sweeping against a desk. The initial servo used was great for prototyping and concepting, however, in **Figure 24**, it significantly drops in speed coming to a near stall at 1.1 kg. Thus, leading us to determine that the servo does not have enough torque to overcome such loads.

A servo replacement was found that has a 21.5 kg/cm stall torque. The test results are found in **Figure 25**, which show a drop in sweeps per second at 11 kg. This drop in sweep speed is not an issue, as the average person will not be applying 11 kg of force to the periorbital region when rubbing, even in a worst-case scenario that is overloading. Furthermore, it is seen that the sweep speed is not very fast in the second servo, however, it is also negligible as it is about the correct speed that one rubs the eye, so even with the decrease in sweep speed, it is about the same speed that person would rub the eye.

Friction will be addressed by calculations using the formulas above in the design specification section, as well as the information gathered from the paper by Veijgen. The paper addresses the coefficients of friction of skin in contact with stainless steel. As well as the different variations in pressure and linear relationships between the static coefficient of friction with the dynamic coefficient of friction. It was found that the static frictional coefficient of a finger on stainless steel ranges from 0.34 to 0.95. However, the dynamic frictional coefficient of a finger on stainless steel is 1.1 under a 0.05 N, while it is 0.55 under a 0.45 N load. However, a strong correlation was found between the static and dynamic coefficient of friction. The correlation showed a linear relationship between the two which can be seen as $\mu_{dynamic} = 0.85 * \mu_{static}$ (Veijgen, 2013) This can also be addressed by finding the resistive force of friction by gathering that force data via a spring scale. A stainless-steel block can be pulled by a spring scale along a surface of skin to find the friction force, thus allowing us to find the coefficient of friction.

A quick estimate of the torque was made from calculations using **Equations 1 and 2** from **Section 3.3**. The written-out friction calculations can be found in **Figure 2** above (design specifications).

It was found that the servo would need to produce at least 1.872 N-m to overcome the dynamic load of friction, while 2.202 N-m was required to overcome the static load of friction.

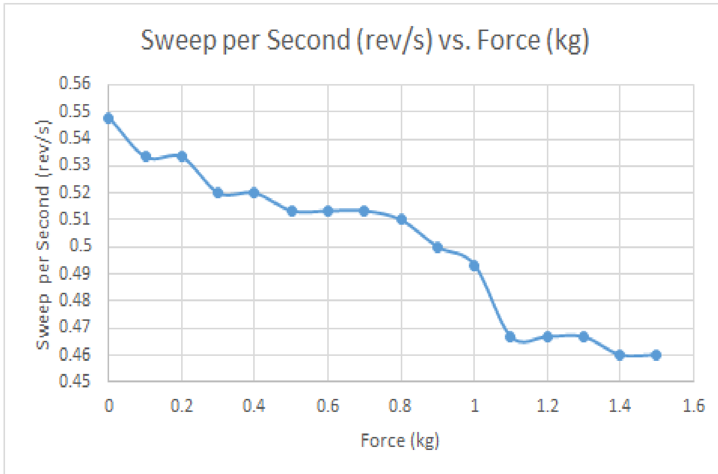


**Figure 24:** Initial Servo Testing

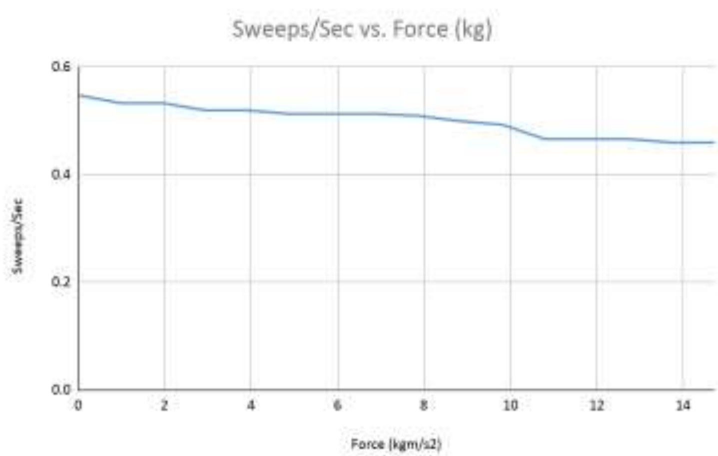


**Figure 25:** Current Servo Load Test Chart

## 3.2 Sub-system Arm, Linear Actuator, Base, and Rails

When we initially made our first prototype in the Fall semester, our base was much larger, and we realized our team members had difficulty carrying it by themselves. To improve on this and make our fixture easier to be carried by one person for set-up, we reduced the overall size of the base. To test if the new size was able to be carried by an average operator, we had some of our classmates try to carry it across the room and were able to determine that the new size was a success.

Similarly, we determined that it is important for the rails to be adjusted manually by one operator. Our initial prototype utilized t-slotted framing and dowel pins for the sliding. When testing this prototype, we realized that the motion was too jerky and challenging for one person to adjust. Based on this, we changed our design to include sliding rails and locking carriages. This improvement allowed for smooth sliding of the carriages and a quite easy way to lock the carriages in place once aligned. We tested the use of the sliding rails and locking carriages with our classmates and found that they were able to be operated successfully by a single person.

To test the linear actuator, we found a linear actuator that can produce 225 lbs., with a maximum travel distance of 10mm/s. The linear actuator performance was tested by adding the calibration weights on top of a plate the linear actuator was pushing. The maximum weight tested was 5kg, as this would be likely, the most amount of pressure we would need to apply to the periorbital region.

## 3.3 Sub-system Skin and Anatomical Model

One of our requirements for this project was to create a skin layer that accurately represents human skin. After extensive research, we found the company Smooth-On which sells a variety of liquid silicone for molding. We requested samples from Smooth-On and were pleased to receive seven different options. To determine the most accurate sample, we performed testing with a durometer type O. We took multiple durometer readings at each location while applying different known weights for each sample, and then took the averages. We then performed the durometer testing on our team members and professor to obtain readings from actual human skin. Below, in **Figure 26**, is a graph of all our data collected. As you can see, the data from the Ecoflex 00-30 sample and the human skin test are remarkably similar, and our team was able to determine that that would be the best silicone type to use. Thanks to our durometer testing, we were able to mold a skin layer out of Ecoflex 00-30 that accurately simulates human skin.

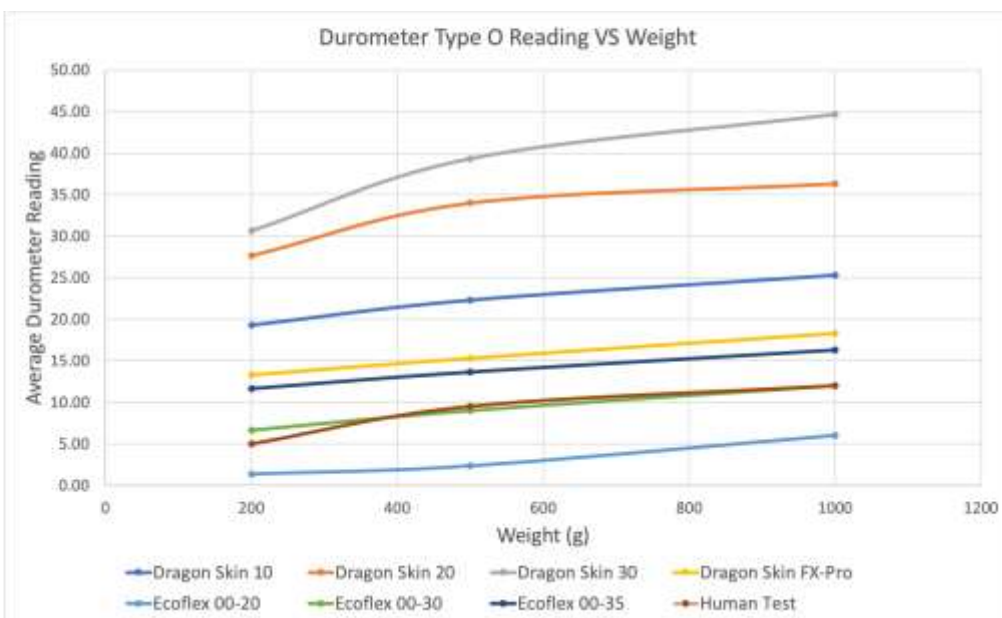


**Figure 26:** Durometer and Silicone Sample Testing Results

# 4 System Integration and Validation

## 4. 1 System Integration

During our remote learning, we divided work amongst our team members based on subsystems. Although we were not able to assemble the subsystems together until the very end, we each made sure to assemble all the components within our subsystems while working individually. By grouping work initially at the subsystem level before the final assembly, the system integration went very smoothly. For example, the work on the load cell and servo were done in conjunction, while the skin layer and skin testing were done in conjunction. This allowed for system integration to begin within each subsystem. Once we were able to meet together to combine the subsystems together, the assembly went smoothly, and the systems integrated as desired. Each subsystem continued to function as it had before and combined functions allowed for a successful fixture.

We were able to successfully integrate our system fully (shown in **Figure 1** and in the assembly drawing within our FDR folder) and fulfill our user and client's needs. Each subsystem has passed its requirements, seen above in **Section 3**. Because our subsystems were all fully functional and passed testing independently, we only had to complete limited trials and runs to confirm that the fully assembled fixture was also completely functional.

## 4.2 System Validation

**Table 2:** System Validation

| Subsystem Requirement | Test Conducted | Results |
|---|---|---|
| Load Cell data must be within ± 10% of the actual value | Calibration outside of test fixture, and verified weights on test fixture | Pass* (with large amounts of noise) |
| Servo must overcome downward force, and frictional force | Servo to overcome load of 5000 g and sweep with metal end effector on silicone to see if movement will occur, then sweep with silicone end effector to see if movement will occur | Pass |

After final assembly of the test fixture, a calibration was done on the load cell before being put back into the test fixture. The calibration showed allowed for the adjustment of the scaling equation to get accurate readings. A key requirement is having the load cell readings within ± 10% of the actual value. Those readings were verified by having calibration weights placed on the load cell while having the test fixture upside down to verify these weights. The weights were verified, although with some noise, so once the load cell was integrated, it did meet the requirements.

Tests were then run starting with the positioning of the face to a position we want to test, followed by applying a force from the linear actuator for the load cell to read. Once the force is applied the servo will then be turned on, having a sweeping motion that simulates a rubbing motion. The validation occurred when, even with the servo end effector having a silicone material, it overcomes the frictional forces, as well as the force down that is applied to the periorbital region and continues the sweeping motion. The servo was then validated as it not only had the sweeping movement occur with the metal end effector against the silicone, but also with the silicone end effector rubbing on the silicone skin on the face with a downward load of 5000 grams. The test with the servo motor showed that the silicone skin layer caused some movement to the silicone wrapping the end servo effector. The movement was minor, and did not affect the simulated rubbing motion, but the servo may need a new silicone coating for the end effector after extended use.

# 5 Project Management

## 5.1 Covid-19 Pandemic Adjustments

During the current pandemic, many adjustments had to be made. In early March, our university transitioned to an online learning format which drastically changed what the rest of the semester would look like. After this, we had to think quickly to create a plan in order to successfully complete our capstone project.

We were given a week to move off campus, and in this time, we transported all our materials to Erica's garage, which allowed us to have all the materials in one location with easy access. At this time, we believed we would still be able to meet as a group to continue progress and assembly on the project. As it turned out, California was put into a shelter-in-place order just days later. Once the shelter-in-place took into effect, we realized we would not be able to meet as a group as often as we had initially planned. To adjust to this, our team split the project into subsystems that we could work on individually. Nathan focused on the coding and wiring of the load cell and servo motor. Kellen worked on the mechanical side of the arm and attachments for the linear actuator. Paolo and Erica worked on different aspects of the silicone skin layer and the periorbital anatomy.

After the subsystems were completed, our team decided it was necessary to meet in person for assembly. To do this, we met in person twice to complete the finished product. When meeting, we took as many safety precautions as possible. We worked outside, wore face masks, and tried to keep a six feet distance between us whenever possible. Although the Covid-19 Pandemic created a lot of challenges for our team, we were able to work together to ensure that we still delivered the best project possible to our industry sponsor.

## 5.2 Safety

For this project, the major safety concern is ensuring that the operator can safely operate the equipment. First, we need to ensure that the fixture will stay stationary while in use on a flat surface. This issue is addressed, however, due to its weight. Furthermore, since the equipment is heavy, we need to include clear instructions on how to move it should that be necessary. When the machine is in use, there will be moving parts such as the linear actuator and the servo motor. These parts could be a source of safety concerns, such as the pinching of fingers, if the operator is not careful. Because of this, it is important that we create instructions to make sure the operator is clear on how to operate the equipment. It should be clearly labeled not to touch the linear actuator or servo motor while the equipment is running. Additionally, the equipment utilizes wires, which the operator must be aware not to touch while the machine is operating. For safety reasons, wires will be covered when possible and all electrical components will be grounded.

## 5.3 Manufacturing

The entire system costs a total of $2,363.24, which can be quite expensive in some regards. But looking at the individual subsystem production, the entire mechanism can be suitable for widespread use. With the entirety of the project, most of the components were purchased from a specific vendor and were implemented as they are. The main examples of this are the facial anatomy with simulated muscle, sliding rails with carriages, load cell, linear actuator, and servo motor. With that being said, this system was designed for a very specific use for our industry sponsor. This is likely not a fixture that would ever need to be manufactured widespread. However, if this fixture proves to be useful for our industry sponsor, they may desire to create more of them for internal use.

Currently, the most challenging component for widespread manufacturing is the silicone skin layer. Although we do now have a plaster mold and have determined a type of silicone to use, the results of molding the silicone skin layer will vary slightly each time it is done. The process for molding the skin layer is not an exact science so it will vary slightly due to different techniques used or different people performing the molding. Some of the possible variations include differences in the thicknesses, evenness of thickness, surface textures (depending how many times the same mold is used), and location of the spacers. We have included more information on this in Section 6 Future Work.

## 5.4 Project Deliverables

1. Complete Product of Testing Mechanism: The entirety of our project. A fully functioning product, with all subsystems put together to perform the given requirements put together by Glaukos.

2. Downward Force: The overall testing mechanism can apply a downward force onto the periorbital region with the use of a linear actuator.

3. Accurate Anatomical Resemblance to Human Face: Molded silicone skin with the same thickness and hardness as human skin, mounted over Sawbones skull and muscle model.

4. Data Acquisition Program: Captures and displays a live reading of data from the load cell.

5. Complete User Manual: The user manual shows instructions on how to operate the test fixture. This manual is located in the FDR folder.

6. Complete CAD Drawing Manual: Bill of materials and all CAD drawings are contained in a PDF, additionally, the completed assembly and Solidworks drawing are in the FDR folder.

7. <u>Remaining Supplies and Materials:</u> We will be giving Glaukos all remaining materials including the plaster mold, remaining silicone, extra hardware (nuts, screws, and bolts), and more.

## 5.5 Schedule

The largest challenge that we faced this semester was Covid-19. The spread of this pandemic led to the transition to remote learning for the majority of the semester. For a class as hands-on as Senior Design, this was a significant challenge. Due to this, there were major adjustments to our schedule, and the testing and assembly of our fixture became harder.

We successfully completed almost all our material orders by early-March. Although this is a couple weeks behind what we had initially projected, it did not cause any delays to our project progress. We were also able to complete testing on the skin samples, load cell, and servo motor by late February as planned. Unfortunately, due to delays in response by the prospective companies, we were not able to acquire contact test equipment to perform eye-rubbing forces tests nor were we able to perform the tests before beginning remote learning.

Initially, we planned to have the final test fixture assembled by mid-March. Due to the effect of Covid-19 on classes, we experienced severe delays on this timeline. First, we were set back a week when we had to transition to online learning. After we moved to our respective homes for remote learning, a shelter-in-place order was set in which we were no longer allowed to meet as a team in person. Due to these developments, we have had to adjust our schedule to allow each of our members to focus on a different part of the project. Our updated goal now is to meet, from a social distance, at the end of April to combine our subsystems into one fixture. Project completion presentations will be conducted in early-May, so we are focused on finding a way to complete both assembly and system testing by then.

## 5.6 Budget

An overall total of $2,363.24 was spent on this project. This funding was provided by our Industry Sponsor, Glaukos through the USD School of Engineering. Below you can see that we broke down the expenses by which subsystem they were for in **Figure 27**.

The budget for the servo motor and load cell were by far the largest. This is because we bought a quality load cell that had a large upfront cost. In addition to the load cell itself, we had to purchase other materials to be able to use the load cell as desired. The arm and linear actuator were the cheapest subsystem. The t-slotted framing that we used for the arm was found in the machine shop. Because of this, we only really had to buy a linear actuator and some brackets for this subsystem.

The major expense from the face and plate subsystem was the Sawbones model head. Because we chose the option with replica muscle and bone structure, it was a larger cost. Another major expense from the base and rails subsystem was the smooth gliding rails and self-locking carriages we bought. These improved our design immensely and were well worth the cost.


**Figure 27:** Subsystem Budget Breakdown

## 5.7 Personnel

Our Capstone Design team is made up of four Senior level Mechanical Engineering Students. As a team, we have a well-rounded set of skills and strengths. Below, we have explained in more detail the roles we took in this project.

**Erica Jenkins** - Project Manager

- Drive completion of tasks and communicate with team members upcoming deadlines
- Create and update Gantt charts to track milestones and ensure project remains on schedule
- Organized and managed project budget
- Compile and review input from team members for final design report

**Nathan Hoong** - Systems Engineer

- Assist in creation of CAD models/drawings
- Develop subsystems that complete requirements for test fixture, i.e. ability to apply force, rotational movement, and ability to sense force
- Integrate all subsystems into full test fixture via consolidated program/UI to run test fixture

**Kellen Gaeir** - CAD Engineer

- Produce and regulate CAD models/drawings
- Test critical functions and machine parts
- Make connection for linear actuator to shaft

**Paolo Garcia** - Chief Editor/Communication Lead

- Maintain regular contact with industry mentor for updates, specifications, and design questions
- Communicate with pressure sensor companies for product inquiry and test procedures
- Compile and review input from team members for design report

# 6 Conclusions and Future Work

The main objective of our group was to satisfy our customer's key requirements of anatomical modeling, realistic eye interaction simulation, and force measurement and display. To achieve this, our final test fixture combines the subsystems of the face and base, the arm and linear actuator, and the load cell and servo motor. The use of different molding techniques, base configurations, and online electrical resources during the design and assembly processes all contributed to the success in meeting our objectives. Furthermore, our group balanced the various constraints of available materials and tools, budget, time, and the unforeseen COVID-19 pandemic using collective knowledge and skills to address any problems encountered. In conclusion, our capstone design project sharpened our critical thinking, intuitive teamwork, and sharp communication and was a valuable learning experience for all.

Some future work would be to improve the accuracy of the load cell data. A few solutions for this are getting another Arduino to control the servo motion and having another Arduino capture and write data to an external file. Alternatively, a single Arduino can be used to control the servo and read data from the ADC while finding a better workaround for the control issue. Lastly, we recommend finding a different DAQ that allows for noise filtration techniques, such as averaging of the results or changing the polling rates. Unfortunately, due to the COVID-19 pandemic, we were unable to get the external ADC board in time to get more accurate results. The team highly recommends changing the current DAQ due to these inaccuracies with one of the solutions mentioned.

For maintenance of the test fixture, regular cleaning of the silicone skin layer, silicone servo tip, and base is recommended. If needed, a replacement skin layer can be created using the original plaster mold, Styrofoam head model, and liquid silicone, and attached to the Sawbones head model with screws or nails. Similarly, a replacement silicone servo tip can be created by placing the servo tip in a thin layer of liquid silicone in a bowl, then trimming to size with scissors. These replacements would account for the wear-and-tear of the silicone skin from friction or use of lubricants after multiple cycles since the current facial skin mold will likely deteriorate after repeated use. Additional research and experimenting could be done to create a more streamlined and repeatable molding process.

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# 8 Appendices

## 8.1 Team Member Resumes

**Kellen Gaeir**
kgaeir@gmail.com
(619)368-9708

**Objective**

Mechanical Engineering major who is an analytical problem solver, effective communicator, and works well in collaboration with others. Looking for a full-time job starting after May 2020.

**Education**

**University of San Diego, Shiley Marcos School of Engineering** — **San Diego, CA**
BS/BA in Mechanical Engineering — Expected May 2020
Overall GPA: 3.32

**Relevant Coursework**

-Design of Machine Elements
-Dynamics
-Kinematics and Design of Machinery
-Manufacturing Processes
-Machine Shop Practice-Milling, Lathes, CNC, Welding
-Materials Science
-Thermodynamics
-Finite Element Analysis

**Professional Experience/Projects**

**DPR Construction, San Diego, CA - Project Engineer** — **Internship: March 2019 - September 2019**

- Worked on the upcoming San Diego Sheriff Technology and Information Center as a Project Engineer under a General Contracting Company (DPR)
- Suggested use of Plangrid software to manage project, allowing owners to track issues in the field and easily share information with subcontractors, saving significant time
- Developed Plangrid account for entire construction project which is still being used
- Entrusted to issue RFIs (requests for information) and specifications for the construction project
- Conducted Quality Control walks throughout the on-going construction and tracked vital punch list items
- Generated mark-ups for distribution and communication among different subcontractors

**Senior Capstone Project - Glaukos** — **Fall 2019 - Spring 2020**

- Designed a simulated human periorbital bone and tissue structure with key anatomic features
- Designed a contact force system that can be moved into position and apply/measure the force applied periorbital simulator
- Applied an off the shelf video system that can be used to monitor the device and capture images as needed during the testing

**User-Centered Design, USD Course Project - Include Autism** — **Spring 2018**

- Visited Include Autism, an afterschool program for children with autism, every week to become familiar with the children as well as the program and determine user needs
- Tasked to provide a project design of our choice that could be used by the program on a daily basis to improve their everyday initiatives
- Proposed an app to help track children's activities and tested it among the staff at Include Autism

**Leadership/Activities**

**Athlete at The University of San Diego, Football 2016-2018**
**Self Employed Math Tutor at San Diego State University**

- Calculus 1, 2, and 3, and Differential Equations

**Skills**

**Computer Skills:** Proficient in Solidworks, MS Excel, MS Word, Powerpoint, Finite Element Analysis
**Gallup Strengthsfinder:** Competition, Analytical, Arranger, Strategic, Responsibility

# Paolo García

5720 Lauretta St. Apt. 10, San Diego, CA 92110 (*current*) | 109 Apaka St. Dededo, GU 96929 (*permanent*)
paolokgarcia98@gmail.com | 858 267 8581

**EDUCATION**

**University of San Diego,** San Diego, CA
*B.S./B.A. Mechanical Engineering, Spanish Minor*
Anticipated Graduation: December 2020, GPA: 3.31

**Father Dueñas Memorial School,** Mangilao, GU
May 2016, GPA: 3.9

**WORK EXPERIENCE**

**United Mechanical,** Dededo, GU (Contact: Rex Carganillo, 671 488 6788)
*Engineering Intern*, May-August 2019
- Review and perform calculations for HVAC design in line with NAVFAC requirements
- Maintain communication with subcontractors for design specifications and material submittals
- Assist Project Manager during site visits at various locations

**USD Mission and Ministry,** San Diego, CA (Contact: Mary Kruer, 619 260 5903)
*Student Coordinator,* August 2018-May 2019
- Efficiently organize, set up, and break down university events
- Schedule, coordinate, and train event volunteers

**ASC Trust,** Hagatña, GU (Contact: Candy Okuhama, 671 477 2724)
*Intern*, June-August 2017
- Organize digital documents and perform data review on MS Excel
- Handle confidential information in line with company's security protocol

**VOLUNTEER ACTIVITIES**

**San Diego Rapid Response Network: Migrant Shelter,** San Diego, CA
*Shelter Operations Volunteer,* February 2019-Present

**Bayside Community Center,** Linda Vista, CA
*Community Garden and Farmers' Market Volunteer,* February-May 2017

**Big Brothers Big Sisters of Guam**
*Student Mentor,* September 2015-May 2016

**ACADEMIC PROJECTS**

**Wobbler Engine,** Machine Shop Practices
- Machined and assembled individual parts from various metal materials using a vertical mill and lathe in machine shop according to specifications and tolerances on engineering drawing
- Completed engine successfully performed with a supply of pressurized air at 4 psi

**Fire-Response Robot,** Introduction to Engineering
- Designed using SolidWorks, laser-cut, and fabricated a remote-controlled, model firetruck robot to pick up and deliver a mass after ascending an incline, while working around constraints of overall weight and size
- Programmed and uploaded to Arduino embedded software processor

**Elevator Project,** Electromechanical Systems Design
- Constructed and wired model elevator to receive user input and deliver elevator car to desired level using DC motors and reed switches (magnetic sensors)
- Programmed using Raspberry Pi 3B in Raspbian OS

**Mobile Education Garden,** User-Centered Design
- Created prototype for specific user (Bayside Community Garden) in the form of a mobile garden to address user's needs under specific constraints

**RELEVANT COURSES**

Applied Mathematics (Matrix Algebra, Differential Equations), Applied Thermodynamics, CAD Practices, Calculus (I, II, III), Dynamics, Electrical Circuits, Electromechanical Systems Design, Engineering Probability and Statistics, Engineering Programming, Fluid Mechanics, Machine Shop Practices, Manufacturing Processes, Material Sciences, Mechanics of Materials, Physics (Mechanics, Electricity/Magnetism), Statics, Thermal Sciences, User-Centered Design

**SKILLS**

Experience using Microsoft Office (Word, Excel, PowerPoint), SolidWorks, AutoCAD, Vertical Mill, Lathe, CNC Milling, Welding, C, Languages: English, Spanish, Tagalog

# Nathan J. Hoong

nhoong@sandiego.edu linkedin.com/in/nhoong/ (858) 837-1983

## Education

**University of San Diego, Shiley Marcos School of Engineering** **San Diego, CA**
BS/BA in Mechanical Engineering *Expected May 2020*
*Major GPA: 3.18 Overall GPA: 3.05*

## Professional Experience

**Capstone Project,** *Glaukos, San Clemente, CA* *Sept – Present*

- Design a simulated human periorbital bone and tissue structure with key anatomic features
- Develop a contact force system that can be moved into position, apply/measure force applied to periorbital simulator
- Integrate a video system that can be used to monitor the device and capture images as needed during testing

**R&D Controls Engineering Intern,** *Philips Respironics, Carlsbad, CA* *Jun – Aug 2019*

- Sole intern working independently on creating an automated test fixture for prototype ventilator on the Respironics team
- Facilitated multiple design reviews soliciting feedback and offering insight into design process to meet requirements
- Collaborated with test engineers to gage usability requirements ensuring compatibility with current workflow
- Developed code for automated actuator controller using LabVIEW graphical programming environment
- Engaged in final product testing at Westpak performing vibration, shock, & drop tests, as well as clinician trials

**Undergraduate Research Assistant,** *University of San Diego Advisor: Dr. Diana A. Chen, San Diego, CA* *Sept – May 2019*

- Developed learning aid that provides a physical representation of tension and compression in a truss system
- Designed components for learning aid in Solidworks and produced parts using Ultimaker 2+ 3D printers
- Implemented learning aid in lower division engineering statics course

**Manufacturing Engineering Intern,** *Senior Aerospace Jet Products, a div. of Senior plc, San Diego, CA* *May – Aug 2018*

- Assisted manufacturing department in improving and implementing a new workflow system
- Modified past tool designs using Solidworks for the production of engine mounting solutions
- Strategically analyzed tool storage patterns and developed identification and serialization system for inventory
- Exceeded project goals by completing one-year projected plan in three months

## Project Experience

**Wobbler Engine** *Sept – Dec 2018*

- Fabricated the flywheel, base plate, valve plate, crank disk, cylinder, piston, and crankshaft using a manual lathe, manual mill, and drill press
- Created operations sheets for the fabrication of the listed components above
- Assembled and tested the wobbler engine to run on air with a result of a minimum air input of 2.3 PSI

**Baja Society of Automotive Engineers** *Sept – May 2018*

- Analyzed and modified frame and chassis components in Solidworks for a single manned off-road vehicle
- Modified of the engine dynamometer for CVT testing to ensure optimum drivetrain operation

**Emergency Response Vehicle Project** *Sept – Dec 2016*

- Mentored, advised, and supported a cohort of 24 first-year engineering students by connecting them with the appropriate resources.
- Operated vehicle using raspberry Pi and C++ to move to a destination and drop off the payload

**First Robotics** *Sept – May 2016*

- Designed and analyzed frame components of the robot using Autodesk Inventor
- Fabricated and tested frame components using machinery such as a bandsaw, table saw, and drill press
- Presented design to 40+ students, faculty, and sponsors at the 2016 end of year recap event

## Skills

- **Software:** Google Tools, Microsoft Office Suite, AutoCAD, Solidworks, and Autodesk Inventor, MATLAB
- **Languages:** Java, C++, LabVIEW

## Relevant Coursework

- Finite Element Analysis, Design of Machine Elements, Introduction to Robotics, Materials Science, Machine Shop Practices, Mechanics of Materials, Manufacturing Processes, Fluid Mechanics

## Leadership & Professional Affiliations

**Corresponding Secretary,** Theta Tau Professional Engineering Fraternity Sept 2016 – Present

- Represented University of San Diego at regional & national meetings and coordinated events with surrounding chapters

**Member,** American Society of Mechanical Engineers (ASME) Sept 2016 – Present
**Member,** Society of Automotive Engineers (SAE) Sept 2016 – Present

# Erica Jenkins

ejenkins@sandiego.edu || (650) 796-5556

## EDUCATION

**University of San Diego, Shiley-Marcos School of Engineering** Expected Graduation - May 2020

- BS/BA Mechanical Engineering, Minor in Environmental Science Overall GPA - 3.54 / Engineering GPA - 3.70

## WORK EXPERIENCE

**Operations Engineering Intern - Dexcom** January 2019 – Present

- Run, maintain, and improve prioritization of change orders for Operations Department
- Assist with execution of numerous equipment qualifications (including FAT, SAT, and PQ for auto-boxer machine)
- Designed, fabricated, and tested a calibration fixture for use on manufacturing floor

**Intramural Supervisor - USD Campus Recreation** (promoted January 2018) January 2017 – January 2020

- Assisted with the planning and execution of leagues serving a population of 1,000+ students
- Led staff meetings and trainings, while also providing emotional and logistical support to a staff of 30+ officials
- Oversaw crisis management and emergency responsiveness

**Teaching Assistant - USD Intro to Engineering Course** Fall 2017

- Taught a class of 30+ engineering students skills such as Solidworks, Arduino, circuits, and formal documentation

## ENGINEERING SKILLS

- **Relevant Coursework:** Applied Thermodynamics, CAD Practices, Design of Machine Elements, Dynamics, Fluid Mechanics, Geomorphology, Heat Transfer, Machine Shop Practices, Manufacturing Processes, Material Science, Organizational Behavior, Probability & Statistics, Solar Energy, Water Challenges & Solutions
- **Software:** Confluence, Microsoft Office (including Excel, PowerPoint, Word), Smartsheets, SolidWorks
- **Machines:** bandsaw, laser cutter, manual lathe, manual mill, sheet metal brake, welding

## ENGINEERING PROJECTS AND EXPERIENCE

**USD Senior Design Capstone Project – Industry Sponsored by Glaukos** Fall 2019 – Present

- Project Manager of a 4-person team; lead team in formal documentation and ensure all deadlines are met
- Designing, fabricating, and testing an accurate periorbital anatomy and eye interactions simulating fixture

**Air Powered Wobbler Engine** Fall 2018

- Worked on a 2-person team; created operation sheets and executed machining
- Machined a small-scale pressurized air engine from aluminum, steel, and polymers utilizing various machines

**Elevator Design Project** Fall 2017

- Communications Manager of a 5-person team; led team in formal documentation of project
- Coded, wired, and documented creation of miniature elevator utilizing a Raspberry Pi, LEDs, and reed sensors

**Controllable Vehicle Project** Fall 2016

- Project Manager of a 3-person team; led team in meeting deadlines and completing all tasks
- Designed, built, and tested controllable vehicle utilizing Solidworks, Progecad, and laser cutter

## LEADERSHIP POSITIONS

**President of Theta Tau – USD Professional Engineering Fraternity** January 2019 – January 2020

- Elected by peers to lead the Lambda Epsilon Chapter of 60+ members at the University of San Diego
- Other Positions Held: Brotherhood Chair, Pledge Educator, Most Outstanding Member (member since Jan. 2017)

**President of Residence Hall Council, USD** August 2016 - May 2017

- Planned and led meetings, oversaw events, and completed initiatives for residence hall of 400+ students

## AWARDS AND RECOGNITIONS

- **Dean's List Honors –** Shiley-Marcos School of Engineering, USD Multiple Semesters
- **Alcala Scholarship –** University of San Diego Fall 2016 – Spring 2020
- **Outstanding Leadership Award –** Shiley-Marcos School of Engineering, USD Spring 2019
- **Beta Delta Chapter of Pi Tau Sigma –** International Mechanical Engineering Honor Society Spring 2019

## 8.2 Resource Guide

Tips and Tricks:

1. Measure twice, order once!
2. Always check the machine shop for hardware and material, they just might have what you need!
3. Vaseline makes for an easy removal when making plaster molds.
4. Wear gloves and put down something that can get dirty when using the liquid silicone (it is hard to remove if you spill).
5. Try out your ideas and improve upon them as you go!

Useful Vendors:

**Sawbones** - anatomical head models (https://www.sawbones.com/)

**Smooth-On** - variety of liquid silicone products (we used Ecoflex 00-30) (https://www.smooth-on.com/)

**McMaster** - large variety of hardware and mechanical parts (https://www.mcmaster.com/)

**Omega Engineering**- load cells, strain gauges, thermocouples, motion control, process switches, etc. (https://www.omega.com/en-us/)

**Digikey** - electronic components (https://www.digikey.com/)

**Mouser** - electronic components (https://www.mouser.com/)

**TekScan** - pressure sensors (https://www.tekscan.com/)

**PPS** - pressure sensors (https://pressureprofile.com/tactarray/conformable-tactarray)

## 8.3 Detailed Analyses

Below, **Figure 28** shows a detailed process diagram for our entire fixture. This diagram shows the flow of inputs and outputs for the use of this fixture.

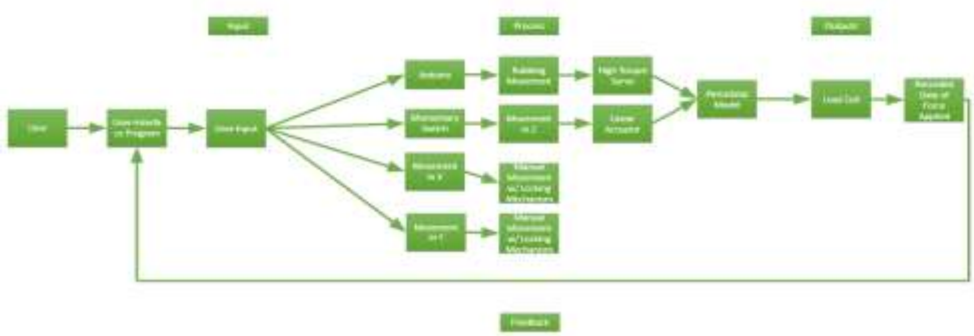

**Figure 28:** Process Diagram

## 8.4 Detailed Budget

Below is a table including all items that were purchased for this project, as well as their costs. More information on our project budget can be found in section 5.6 Budget.

**Table 3:** Detailed Budget Breakdown

| | | | | |
|---|---|---|---|---|
| **Total** | **2363.24** | | | |
| | | | | |
| **Item** | **Unit Cost** | **Quantity** | **Total Cost** | **Cost w/ tax + shipping** |
| Sawbones Model Head | 150.00 | 1 | 150.00 | 176.63 |
| Subminiature Tension and Compression Load Cell | 594.00 | 1 | 594.00 | 655.04 |
| Styrofoam Head | 12.99 | 1 | 12.99 | 14.00 |
| Locking Carriage | 70.58 | 3 | 211.74 | N/A |
| Sliding Rails | 130 | 1 | 130 | 354.99 |
| Rocker Switches | 7.99 | 1 | 7.99 | 8.61 |
| Linear Actuator | 38.95 | 1 | 38.95 | 43.05 |
| HX711 Load Cell Reader (Digikey PN: 1568-1218-ND) | 8.58 | 1 | 8.58 | N/A |
| Arduino Mega (Digikey PN: 1050-1018-ND) | 38.5 | 1 | 38.5 | N/A |
| G6RN-1 DC5 SPDT (Digikey PN: Z987-ND) | 3.2 | 4 | 12.8 | 83.51 |
| 93070A177 - M8 Low Profile Socket Head | 10.62 | 1 | 10.62 | N/A |
| 96276A210 - Steel Thin Hex Nut | 9.8 | 1 | 9.8 | N/A |
| 92855A543 - Low Profile M5 | 9.51 | 1 | 9.51 | 29.93 |
| Durometer - Type O | 27.79 | 1 | 27.79 | 29.94 |
| Smooth-On Ecoflex 30 | 32.21 | 1 | 32.21 | 55.68 |
| Silver Gusset Bracket | 11.92 | 2 | 23.84 | 30 |
| Calibration Weight Set | 13.25 | 1 | 13.25 | 13.25 |
| Power Supply | 208.95 | 1 | 208.95 | 208.95 |
| Cables | 7.39 | 1 | 7.39 | 24.46 |
| Cables | 14.97 | 1 | 14.97 | N/A |
| LabJack U6 DAQ | 431.25 | 1 | 431.25 | 431.25 |
| WEISE DS3218 Control Angle 270 High Torque Update Servo 20KG | 17.49 | 2 | 34.98 | 37.69 |

| | | | | |
|---|---|---|---|---|
| Plaster | 15.99 | 1 | 15.99 | N/A |
| Tray for molding | 10.27 | 1 | 10.27 | 28.3 |
| Vaseline | 6.67 | 1 | 6.67 | 7.19 |
| Smooth-On Ecoflex 30 | 32.21 | 1 | 32.21 | 55.68 |
| Plastic Junction Box | 19.71 | 1 | 19.71 | 19.71 |
| Additional Plaster | 17.6 | 1 | 17.6 | 18.96 |
| Screws / Nuts for base | 27.96 | 1 | 27.96 | 36.42 |

## 8.5 Assembly Drawing and BOM

See electronic copies in the Final Design Project Folder.

## 8.6 Purchased Component Specifications

See electronic copies in the Final Design Project Folder.