Humanoid Animatronic Learning Simulator for Medical Interactive Training (H.A.L. S.M.I.T.) User Manual

Project Team Members

Gillian Cohen (ME)

Olivia Kiritsis (ME)

Ethan Lauer (RBE)

James Maxwell (ME)

Christopher René (ME)

Advisor

Prof. Pradeep Radhakrishnan (ME/RBE)

Safety Guidelines

Please follow the Safety Guidelines listed below when constructing the animatronic.

- When operating heavy machinery:
  - Wear safety glasses.
  - Tie any long hair back.
  - Do not wear any loose clothing.
  - Wear close-toed shoes.
- When constructing and testing electrical circuits:
  - Know the voltage and current limitations (should not exceed 7.2V and 1A).
  - Have dry hands when touching electrical components.
  - Do not use frayed wires or any broken equipment.
  - Avoid contact with open wires.
  - Don't have food or crumbs by the electrical circuits.
  - No liquids or water near the circuits or on the lab table.
- When soldering:
  - Wear safety glasses.
  - Do not inhale the smoke from the solder.
  - Do not touch the tip of the soldering iron.
  - Wash hands after handling the solder.
- When handling super glue:
  - Avoid contact with bare skin (gloves recommended).
  - Do not ingest.
- When creating silicone molds:
  - Avoid contact with bare skin (wear gloves).
  - Wear safety glasses.

Please follow the Safety Guidelines listed below when operating the animatronic.

- Wear the appropriate attire (lab coat, blue latex glove, minimal loose clothing).
- Have clean dry hands.
- Be mindful of moving parts and keep fingers away from any dangerous areas.
- Have easy access to the power supply for emergency shut off.
- Beware! H.A.L. bites.

Table of Contents

Chapter 1: Getting Started

1.1 Introduction

Welcome! This is the instruction manual for the Humanoid Animatronic Learning Simulator for Medical Interactive Training (H.A.L. S.M.I.T., or H.A.L for short). H.A.L. is an autonomous, modular, easily operable animatronic with the goal to enhance realism in medical simulations. When reading through this manual, make sure to read the Prerequisites in Section 1.2 to ensure you have all the necessary tools to complete the task. If you are constructing H.A.L. from scratch, read through the entire manual. If H.A.L. is already completed, you can skip to Chapter 5 which describes how to operate the animatronic.

1.2 Prerequisites

This section lists all of the necessary equipment needed to create the H.A.L. including software, attire, tools, concepts, and parts. If you are constructing H.A.L. from scratch, make sure you have all of the requirements below. If H.A.L. is already completed and you are just running a simulation, make sure you have any of the items listed with two asterisks (**) next to them. Items with one asterisk (*) are recommended to have nearby. All other items needed if you are constructing H.A.L. from scratch.

1.2.1 Tools:

The following tools should be easily available:

- 3D Printer
- Phillips Head Screwdrivers*
- Arbor Press
- Drill Press
- Flathead Screwdriver*
- Allen Wrench Set (metric and imperial)
- Digital Multimeter*
- Variable Power Supply**
- Needle Nose Pliers
- Wire Cutter and Strippers (22 Gauge/22 AWG)
- Alligator Clips and/or Banana Plugs**
- Soldering Iron and Solder
- 1/16” Hex Allen Wrench
- 1.3mm Hex Allen Wrench
- Adjustable Wrench, or 4mm and ¼” Wrenches

1.2.2 Software:

The software listed in Table 1 are all required to be downloaded on your computer. The version of the software used last is listed as well. If you are downloading a later version, this may change the code slightly.

Table 1: Software Downloads**

Software	Link	Version Used Last
Arduino**	Arduino Link	1.8.10
Teensy Loader**	Teensy Loader Link	Teensy Loader on Mac OS X
PixyMon**	PixyMon Link	v2 Mac version 3.0.24

1.2.3 Attire:

The following attire should be used during the development and the operation of the animatronic. Reference the Safety Guidelines when needed.

- Safety Glasses
- White Lab Coat**
- Blue Latex Glove**
- Close-toed Shoes
- Safety Gloves

1.2.4 Concepts:

Understanding of the concepts listed below are required when constructing the animatronic and recommended when operating or troubleshooting the system.

- Electrical Engineering/Circuit Experience
  - Basic electrical understanding
  - Can create clean circuits on a breadboard
  - Can read a circuit diagram
- Computer Science/Programming Experience
  - Understands C++
  - Basic understanding of object-oriented programming
  - Experience using Arduino IDE (recommended but not required)
- Mechanical Engineering Experience
  - 3D Printing
  - 2D / 3D Modelling (SolidWorks / AutoCAD or similar)

- Basic Tools (arbor press, drill press, screwdrivers, etc.)
- Operation of a laser cutter
- Operation of manual or CNC lathe

Table 2: List of abbreviations

Abbreviation	Description
BPM	Beats Per Minute
CAD	Computer Aided Design
FSR	Force Sensitive Resistor
LCD	Liquid Crystal Display
PLA	Polylactic Acid
RGB	Red, Green, Blue
I^2C	I-Squared-C Communication
SDA	Serial Data
SCL	Serial Clock
STL	Standard Tessellation Language
TPU	Thermoplastic Polyurethane
UI	User Interface

Table 3: Nomenclature

Nomenclature	Description	Additional Notes
V	Volts	Used for electrical analysis
A/mA	Amps/Milliamps	Used for electrical analysis
Ω/kΩ	Ohms/Kiloohms	Used for electrical analysis
lb	Pound	Used for parts list size
mm	Millimeter	Used for length
Hz/MHz	Hertz/Megahertz	Used for Frequency
M#	Millimeter Screw Size	M4 would be 4mm screw
°	Degrees	Used for angles
kg	Kilogram	Used for mass
ft	Feet	Used for length

1.2.5 Parts List:

All of the parts listed below are required for H.A.L. to function properly. Make sure you have every part as well as the correct quantity of each part by checking Tables 4 and 5.

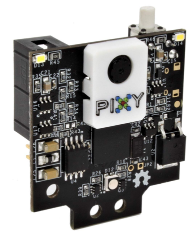
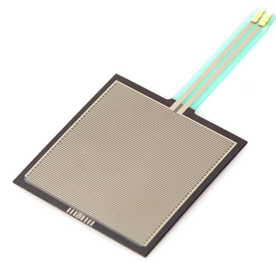
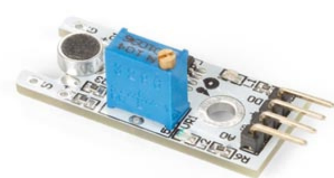
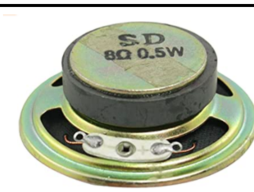
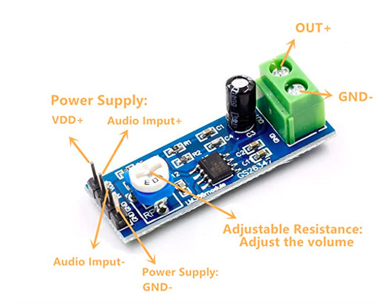
Table 4: Mechanical parts list

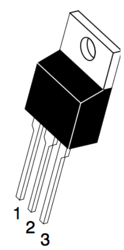
Part Name	Quantity	Image
Turnigy TGY-D56MG Servo	12	
Tower Pro Servo	4	
DSS-M15S 270o with Feedback Servo	3	
1.75mm PLA Filament	3 1kg spools	
1.75mm TPU Filament	1 1kg spool	

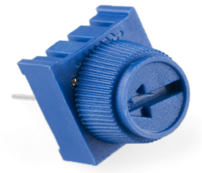
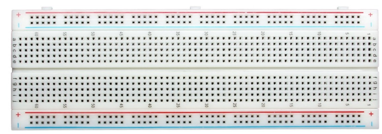
[¼” Acrylic](#)	2 18”x24” sheets	
[¼” Birch or similar hardwood](#)	2 18”x24” sheets	
[Silicone](#)	1lb bottle	

Table 5: Electronics Parts List

Part Name	Quantity	Image
[Teensy 3.5 Microcontroller](#)	1	

Adafruit PCA9685 16-Channel Servo Driver	2	
Pixy2 Camera	1	
Force Sensitive Resistor - Square	2	
Force Sensitive Resistor - Round	3	
Velleman VMA309: Microphone Sound Sensor Module for Arduino	1	
8Ω 0.5W Speaker	1	
Oiyagai 5PCS 200 Times Gain 5V-12V LM386 Audio Amplifier Module for Arduino EK1236	1	

5V Mini Solenoid	2	
LCD Display and Keypad	1	
TIP120 NPN Transistor	1	
1N4004GP Diodes (25 pack)	1	
220Ω Resistor	2	
10kΩ Resistor	7	

10kΩ Potentiometer	1	
Full 7in Long Breadboard	3	
22 AWG Wire for breadboarding (solid and in at least 2 different colors)	About 25ft or more	
Servo Extension Cable	19	
Jumper Wires (Male-to-Male, Male-to-Female, and Female-to-Female)	About 30 of each kind	
microSD card and adapter for the computer	1	
Computer	1	N/A

Chapter 2: Mechanical Assembly

This chapter will cover the mechanical components needed for H.A.L. S.M.I.T. and contains information on hardware, 3D printed components, and subsystem assembly.

2.1 Base and Neck Enclosure

This section will outline the construction of the base and neck enclosure. Both pieces use DWG and STL files to create the pieces between the two. Many wires and components are seated in or around these two subassemblies. For additional information on how to pass electronics through the assembly, please refer to Chapter 4.

2.1.1 Materials Needed

Table 6: Base and neck enclosure materials

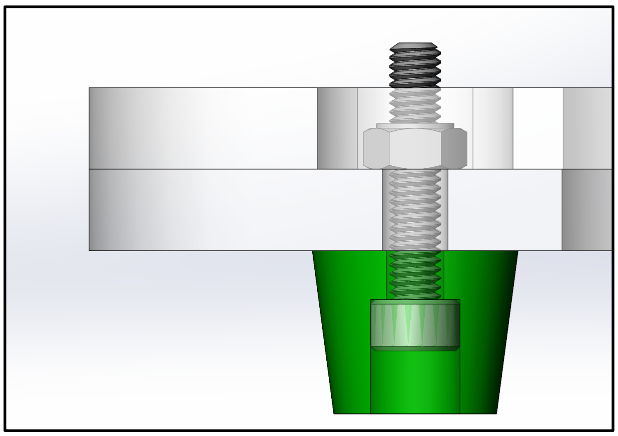
Components	Title of .stl / .dwg	Estimated Time (H:mm)	Infill / Layer Height (mm)	Quantity
Upper Base	Upper Base	0:05	N/A	1
Lower Base	Lower Base	0:05	N/A	1
Bottom Support	Bottom Support	0.02	N/A	1
PLA Feet	PLA Feet	0:10 each	15% / 0.15	6
Front Plate	Front Plate	0:03	N/A	1
Back Plate	Back Plate	0:03	N/A	1
Side Plates	Side Plates	0:02 each	N/A	2
Top Plate	Top and Top2	0:02	N/A	1
Left Shoulder	Shoulder Front Left and Back Right	3:00 each	15% / 0.15	2
Right Shoulder	Shoulder Front Right and Back Left	3:00 each	15% / 0.15	2
Brackets	Lattice Retainer	0:30 each	15% / 0.15	2
Cover	Cover	0:30	N/A	1

Hardware:

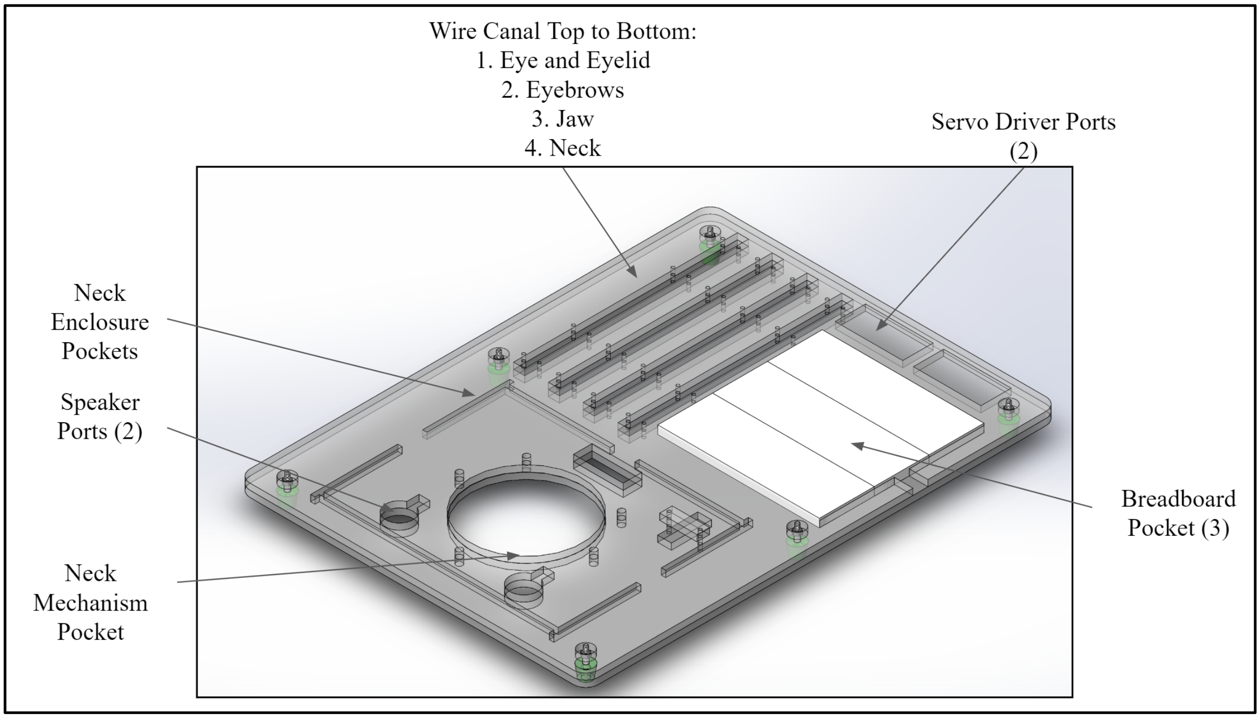
- 8 M4 20mm Socket Cap Screws link
- 8 M4 Hex Nuts link
- 3 7" Long breadboards (see Table 5)
- 12 6" Zip Ties link

2.1.2 Base and Neck Enclosure Assembly

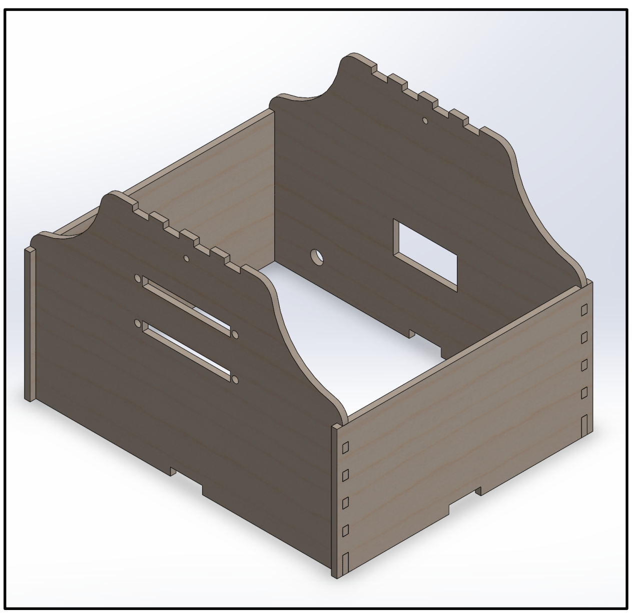
1. Place the ***Upper Base*** on top of the ***Lower Base*** so the large pockets in each align.
2. Insert ***M4 20mm Screws*** through the ***PLA Feet*** from the side as shown below.



3. Put the ***M4 20mm Screw*** through the ***Lower Base*** and ***Upper Base***, then tighten a ***M4 Hex Nut*** so the feet connect firmly to the ***Lower Base.***
4. Repeat five more times for the remaining holes around the perimeter of the combined base.
5. Insert the three breadboards into the ***Upper Base*** as shown below. The ***Bottom Support*** will be used in Section 2.2.2..

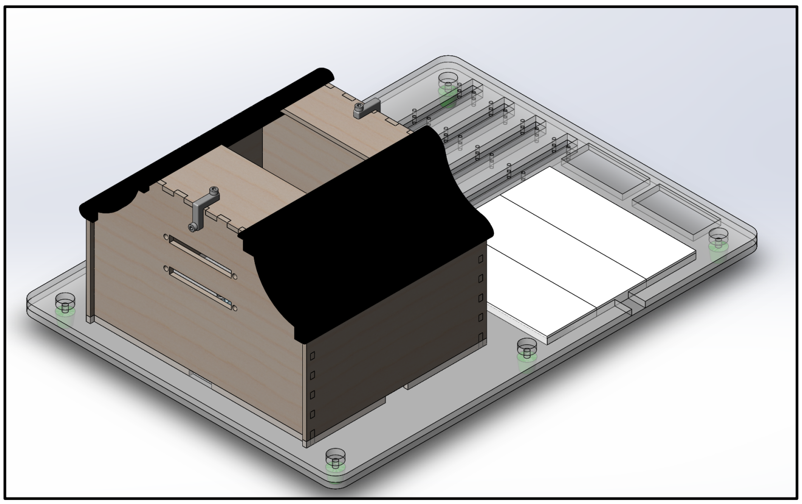


6. Take the ***Front Plate*** or **Back Plate** and slide the slots into the pockets of the ***Side Plate*** pockets. Be sure the parts are oriented as below.



7. Connect the ***Brackets*** to the ***Front Plate*** and ***Top Plate*** by inserting the remaining ***M4 Socket Cap Screws*** into the ***Bracket***.
8. Put this screw through the ***Top Plate*** and tighten with the ***M4 Hex Nut*** on the other side.

9. Repeat for the ***Top Plate*** and ***Back Plate*** bracket. Add the ***Left Shoulder*** and ***Right Shoulde***r pieces. These parts have a groove on the inside that connect with the curvature of the ***Front Plate*** and ***Back Plate***.
10. The assembly should be able to slip into the grooves on the ***Base Assembly***.
11. If it looks as below, take the neck enclosure off the base assembly, as that will be added after the neck mechanism is complete.
12. Loop ***Zip Ties*** through each of the holes that straddle the channels that hold the servo wires. Keep the zip ties loose enough so that about six sets of servo wires can be fed through comfortably and the ties can be cut loose if needed without damaging the wires.



2.2 Neck Mechanism

This section will discuss the construction of the neck mechanism. The neck employs the use of three ***DSS Servo Motors***, one (Y-Axis Servo) situated in the ***Stationary Base*** and two (XZ-Axis Servos) affixed to the ***Rotating Plate***. The maximum positions for these servos to be calibrated is shown in Step 16 below, with more exact instructions on calibration itself present in Section 3.2.3.

2.2.1 Materials Needed

Table 7: Neck mechanism materials

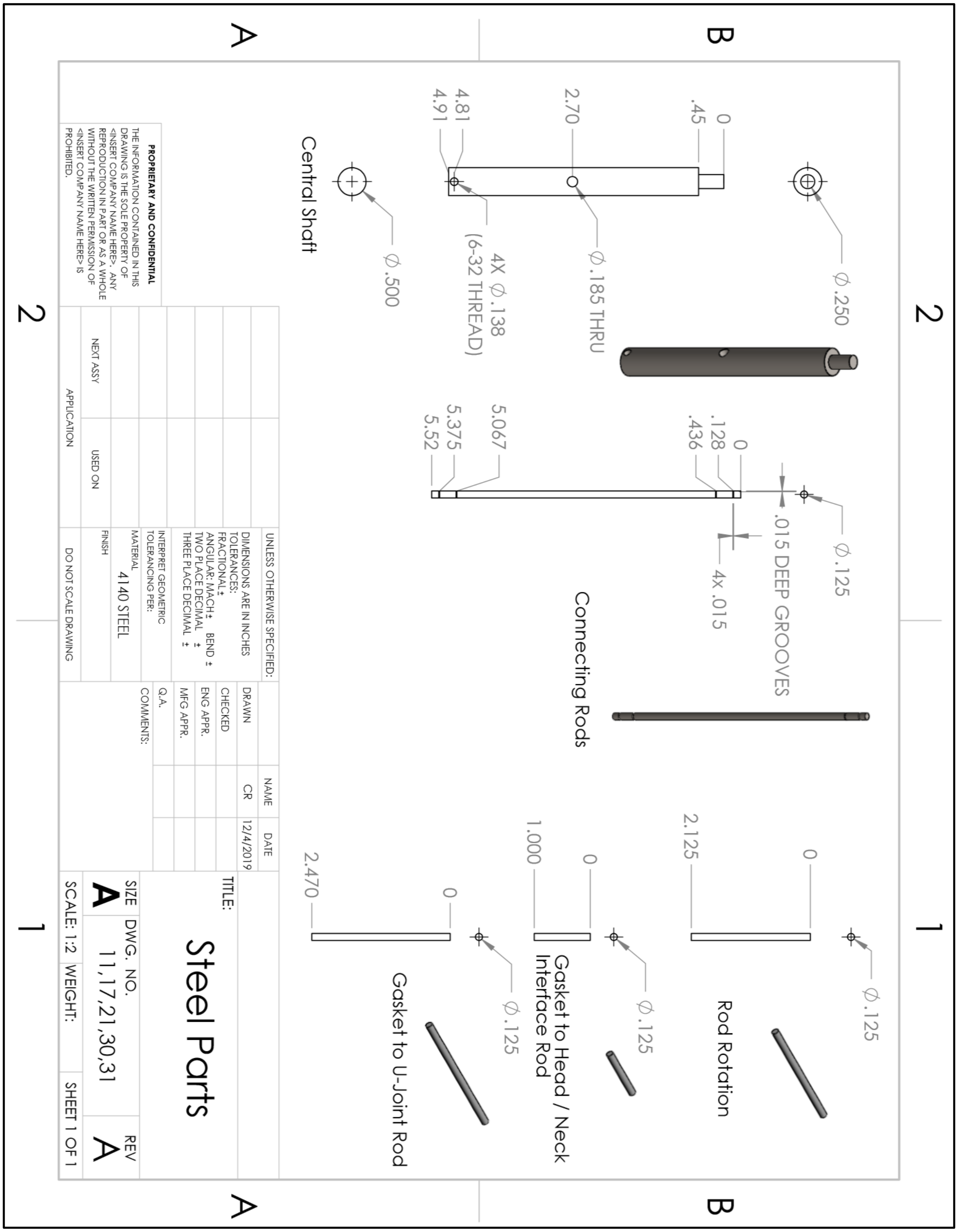
Components	Title of .stl	Estimated Time (H:mm)	Infill / Layer Height (mm)	Quantity
Rotating Plate (2)	Rotating Plate	7:00	10% / 0.15	1
Gasket Rod (7)	Gasket Rod	2:00	20% / 0.15	1
Servo Block (8)	Servo Block	0:30 each	20% / 0.15	4
Stationary Base Lid (9)	Stationary Base Lid	4:00	10% / 0.15	1
Stationary Base (10)	Stationary Base	8:00	10% / 0.15	1
Stationary Base Lid Ball Bearing (12)	Ball Bearing	0:15 each	30% / 0.15	3
Head/Neck Interface (15)	Head Neck Interface	2:30	20% / 0.15	1
Saver (18)	Saver	0:10 each	20% / 0.15	2
Rotational Saver (19)	Rotational Saver	0:45 each	20% / 0.15	2
Neck Servo Link (21)	Servo Link	0:45 each	20% / 0.15	2
Shaft Servo Interface (24)	Shaft Servo Interface	0:30	30% / 0.15	1

Hardware

- (2) ½” Ball Bearing (1) link
- (1) ¼” Universal Joint (3) link
- (2) 6-32 Female Ball Joints (4) link

- (3) DSS-M15S 270º with Feedback Servo Motors (5) link
- (2) 6-32 Male Ball Joints (6) link
- 3’ of ⅛” 4140 Steel Round Stock link cut into:
    - 3 Ball Rods (11)*
    - 2 Connecting Rods (16)*
    - 1 Rod Rotation (21)*
    - 1 Gasket to U-Joint Rod (30)*
    - 1 Gasket to Head/Neck Interface Rod (31)*
- (2) 6-32 Washers (13) link
- (2) 6-32 ½” Philips Flat Head Screw (14) link
- 1’ of ½” 4140 Steel Round Stock for Central Shaft (17)* link
- (3) ¼-20 1.5” Socket Cap Screws (22) link
- (4) 6-32 5/32” Set Screws (23) link
- (8) M4 20mm Socket Cap Screws (25) link
- (4) M4 30mm Socket Cap Screws (26) link
- (12) M4 Hex Nuts (27) link
- (2) 6-32 Hex Nuts (28) link
- (4) M4 50mm Socket Cap Screws (31) link
- (4) ¼-20 ¾” Socket Cap Screws (32) link
- (5) ¼-20 1” Socket Cap Screws link
- (5) ¼-20 Hex Nuts link
- (8) ⅛” OD Retaining Rings link

  **Drawings of dimensions seen on next page*


Ø.250
0
.45
2.70
4.81
4.91
Ø.185 THRU
4X Ø.138
(6-32 THREAD)
Ø.500
Central Shaft
Ø.125
0
.128
.436
5.067
5.375
5.52
.015 DEEP GROOVES
4x .015
Connecting Rods
Ø.125
0
2.125
Rod Rotation
Ø.125
0
1.000
Gasket to Head / Neck
Interface Rod
Ø.125
0
2.470
Gasket to U-Joint Rod
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
4140 STEEL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CR
12/4/2019
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Steel Parts
SIZE
A
DWG. NO.
11,17,21,30,31
REV
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
A
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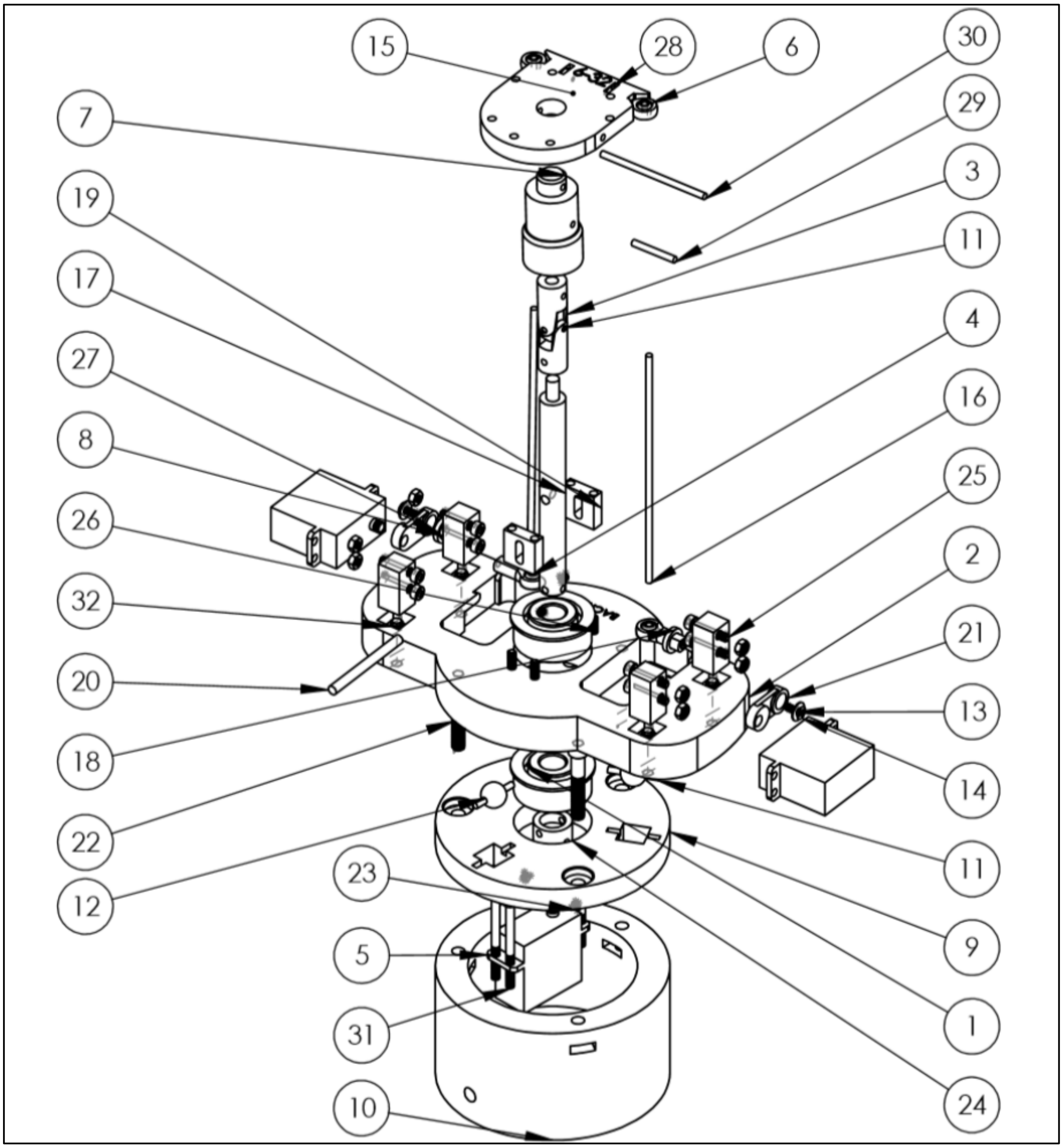
1
2


15
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23
5
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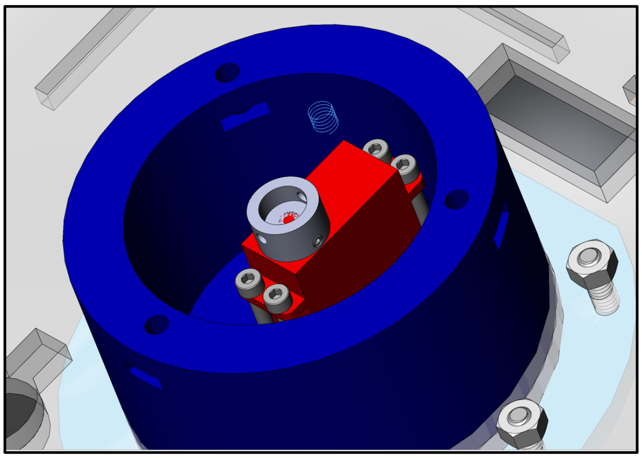
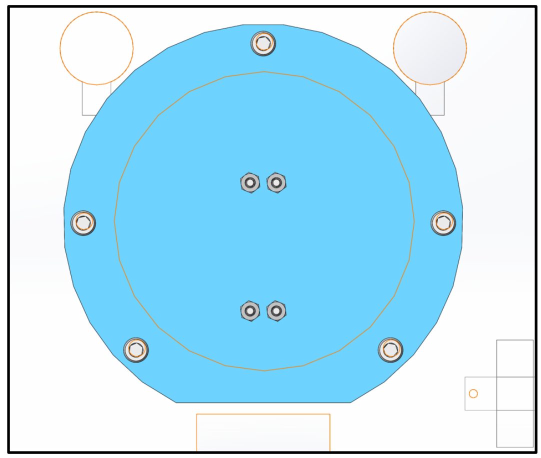
24

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	McMaster 6383K245	1/2" Ball Bearing	2
2	Rotating Plate	3D Printed PLA	1
3	McMaster 6445K1	1/4" U Joint	1
4	McMaster 60645K78	6-32 Female Ball Joint	2
5	Digikey SER0044	Servo Motor	3
6	McMaster 60645K61	6-32 Male Ball Joint	2
7	Gasket Rod	3D Printed PLA	1
8	Servo Block	3D Printed PLA	4
9	Stationary Base Lid	3D Printed PLA	1
10	Stationary Base	3D Printed PLA	1
11	Ball Rod	1/8" 4140 Steel Rod	3
12	Stationary Base Lid Ball Bearing	3D Printed PLA	3
13	McMaster 94589A200	6-32 Servo Link Washer	2
14	McMaster 91099A215	6-32 1/2" Screw	2
15	Head/Neck Interface	3D Printed PLA	1
16	Connecting Rod	1/8" 4140 Steel	2
17	Central Shaft	1/2" 4140 Steel	1
18	Saver	3D Printed PLA	2
19	Rotational Saver	3D Printed PLA	2
20	Rod Rotation	1/8" 4140 Steel Rod	1
21	Neck Servo Link	3D Printed PLA	2
22	McMaster 90128A251	1/4-20 1.5" Socket Cap	3
23	McMaster 94355A219	6-32 5/32" Set Screw	4
24	Shaft Servo Interface	3D Printed PLA	1
25	McMaster 90128A216	M4 20mm Socket Cap Screw	8
26	McMaster 91290A180	M4 30mm Socket Cap Screw	4
27	McMaster 90592A090	M4 Hex Nut	12
28	McMaster 90480A007	6-32 Hex Nut	2
29	Gasket to U-Joint Rod	1/8" 4140 Steel Rod	1
30	Gasket to Head/Neck Interface Rod	1/8" 4140 Steel Rod	1
31	McMaster 91290A186	M4 50mm Socket Cap Screw	4
32	McMaster 91251A540	1/4-20 3/4" Socket Cap Screw	4

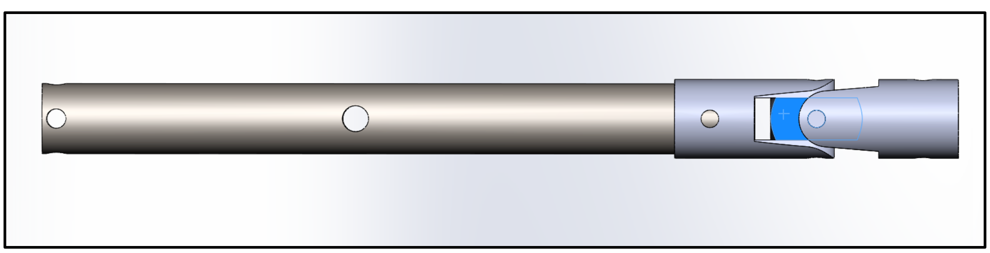
2.2.2 Neck Mechanism Assembly

1. Press-fit the smaller hole in the ***Shaft Servo Interface*** onto the ***DSS Y-axis Servo***
2. Screw in two ***6-32 5/32" Set Screws*** to further connect the ***Shaft Servo Interface*** with the ***DSS Y-axis Servo.***
3. Secure a ***DSS Y-Axis Servo*** to the stationary base with four ***M4 50mm Socket Cap Screws***.
4. Pass these screws through the holes in the ***Upper Base***, ***Lower Base***, and ***Bottom Support***.
5. Attach to ***Bottom Support*** with four ***M4 Hex Nuts***.

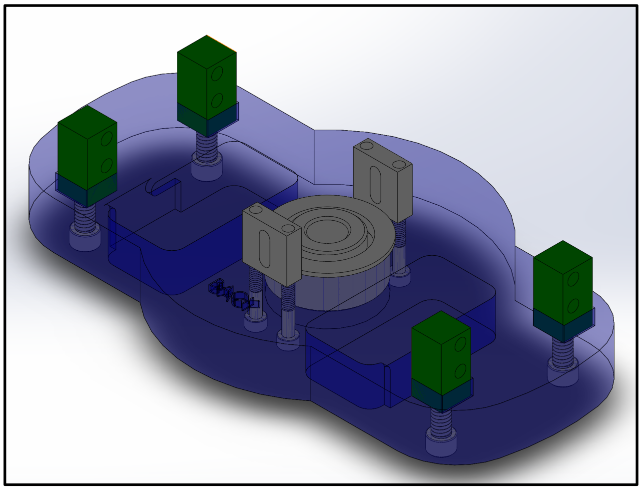




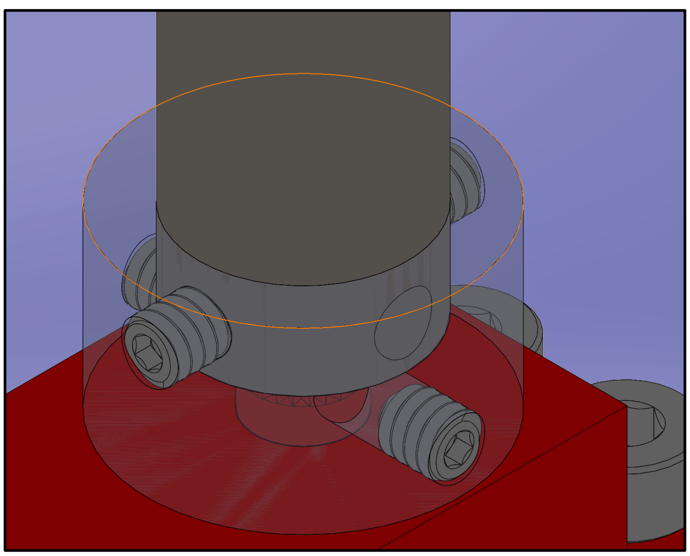
6. Press fit the ***¼" U-Joint*** onto the turned surface of the ***Central Shaft*** with the use of an arbor press. **Ensure the *U-Joint* is aligned as shown below, or else the mechanism will not function.**



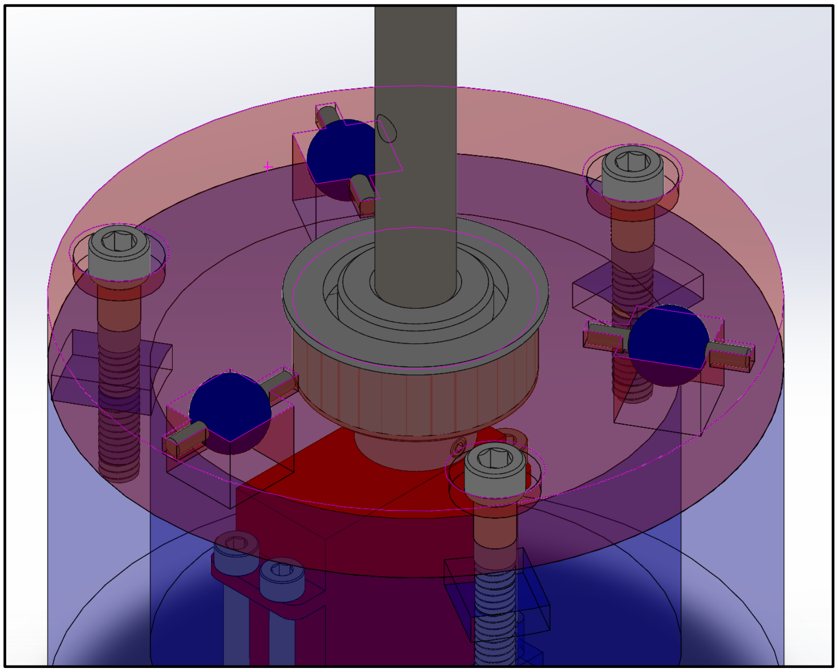
7. Insert ***½" Ball Bearings*** into the central holes of the ***Rotating Plate*** and ***Stationary Base Lid***.
8. Fasten the ***Servo Block*** and ***Rotational Savers*** to the ***Rotating Plate*** using ***¼-20 ¾" Socket Cap Screw***s and ***M4 30mm Socket Cap Screws*** respectively through the bottom of the ***Rotating Plate*** upwards.



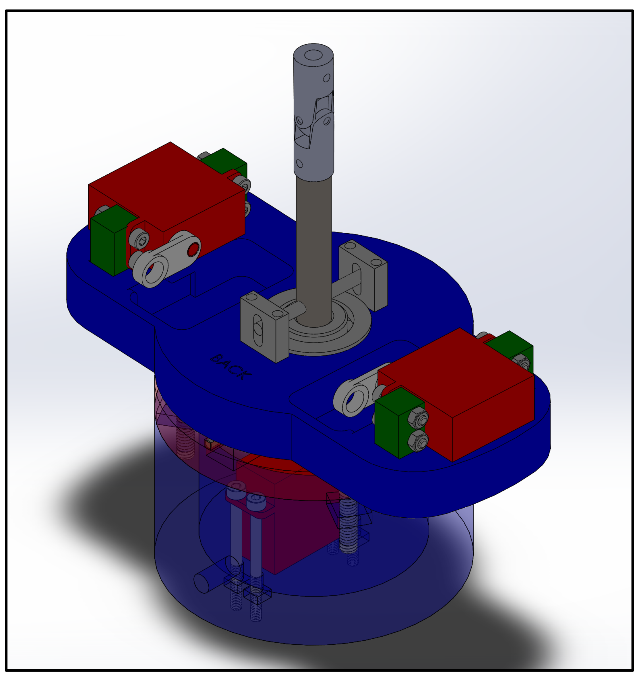
9. Pass the 3 ***Ball Rods*** through their respective ***Stationary Base Lid Ball Bearing*** and insert them into the top slots of the ***Stationary Base Lid***.
10. Insert ***Central Shaft*** thicker end first through the ***Rotating Plate*** and ***Stationary Base Lid*** in sequence.
11. Secure the ***Central Shaft*** to the ***Shaft Servo Interface*** using the remaining ***6-32 5/32" Set Screws***.



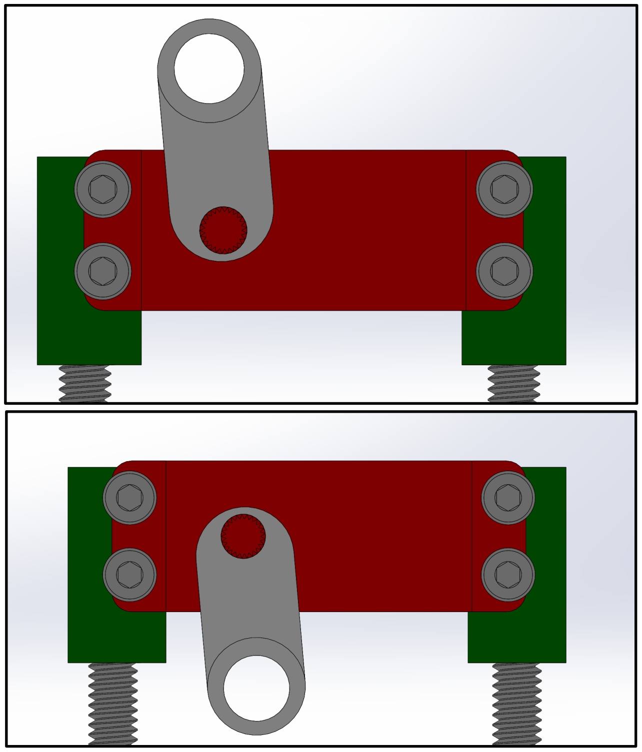
12. Insert three ***¼-20 1.5" Socket Cap Screws*** through the ***Stationary Base Lid*** into the ***Stationary Base*** and fasten these two bodies in place.



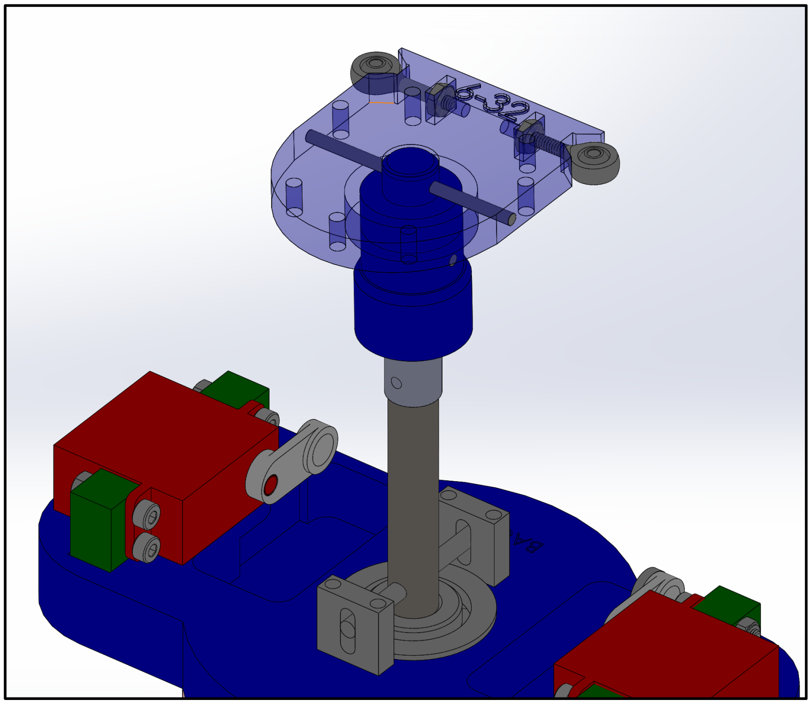
13. Pass the ***Rod Rotation*** piece through one ***Rotational Saver***, through the hole in the ***Central Shaft***, and through the second ***Rotational Saver***.
14. Press-fit the ***Servos Links*** onto the remaining two ***XZ-Axis DSS Servos***.
15. Connect the ***XZ-Axis DSS Servos*** to the ***Servo Blocks*** using 8 ***M4 20mm Socket Cap Screws*** and ***8 M4 Hex Nuts***.



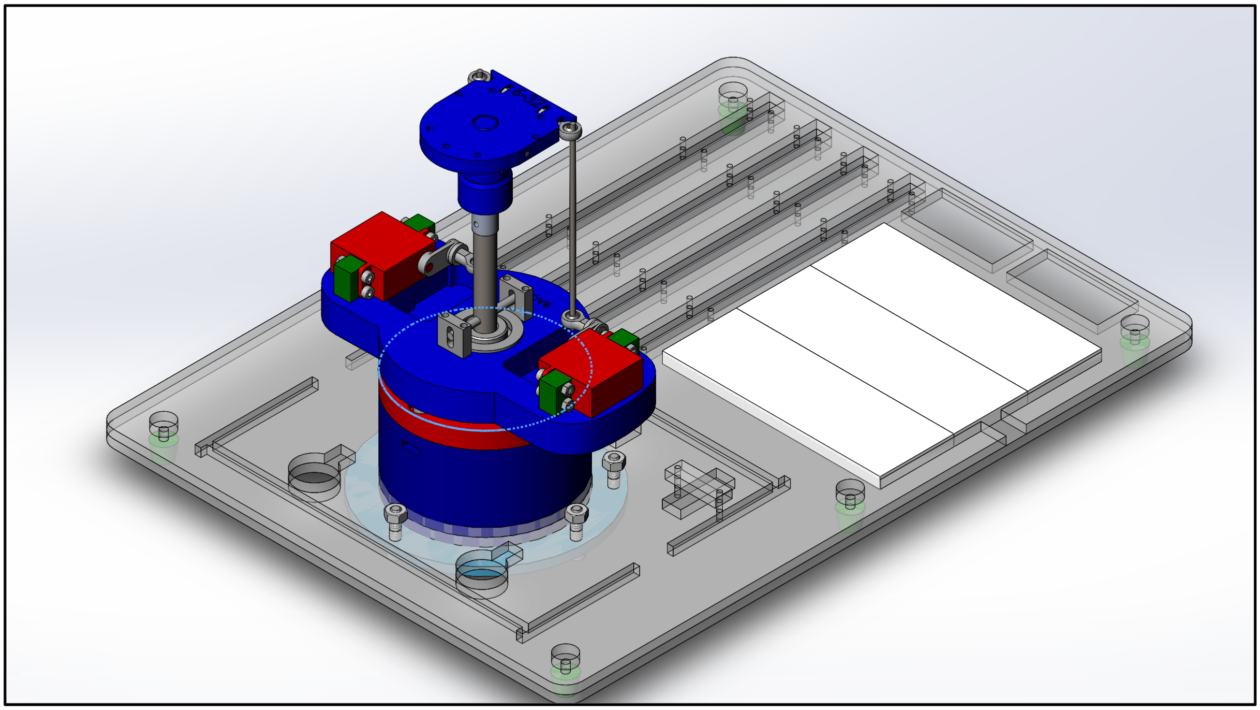
16. Take this time to calibrate the three ***DSS Servos***, so the servo's maximum positions when the neck mechanism is in motion reaches the extremes shown in the diagrams below.



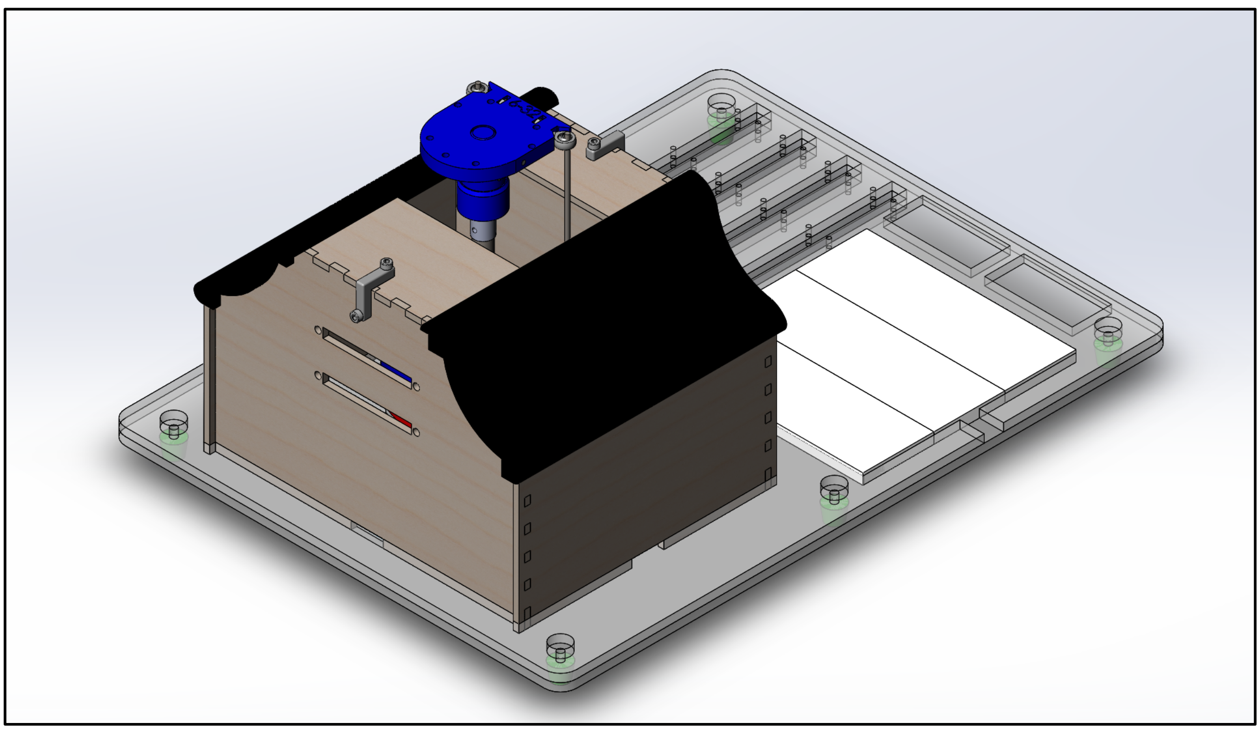
17. Insert two ***6-32 Hex Nuts*** into the smaller holes in the top of the ***Head/Neck Interface***.
18. Insert two ***Male Ball Joints*** through the holes in the side of the ***Head/Neck Interface*** and thread the ***Male Ball Joints*** through the ***6-32 Hex Nuts***. Ensure the ***Male Ball Joints*** are parallel with the top surface of the ***Head/Neck Interface*** when secured.
19. Press fit the ***Gasket Rod*** into the large hole in the ***Head/Neck Interface***. Connect these two pieces with the ***Gasket to Head/Neck Interface Rod*** so the rod doesn't protrude from either side of the ***Head/Neck Interface***.
20. Repeat process for the ***Gasket Rod to U-Joint Rod***. Be sure to not apply too much force securing the ***Gasket Rod*** to the ***U-Joint***, as the ***DSS Y-Axis Servo*** is supporting the force. If the press is too tight, sand the inner diameter of the ***Gasket Rod***.



21. Pass the ***Connecting Rods*** through the ***Female Ball Joints*** and ***Male Ball Joints*** on one side of the mechanism.
22. Attach 4 ***Retaining Rings*** to each side of both ***Male and Female Ball Joints***. The ***Connecting Rod*** should now not be able to slip past either ball joint.
23. Pass a ***6-32 Phillips Flat Head Screw*** through the ***6-32 Washer***, then into the other holes in the ***Servo Link*** towards the ***Central Shaft***.
24. Thread through the ***Saver***, and finally the ***Female Ball Joint***. Screw the ***Female Ball Joint*** into the ***6-32 Phillips Flat Head Screw*** until the ***Female Ball Joint*** is secured but able to rotate freely.
25. Repeat Steps 21-24 for the other ***Connecting Rod Linkage***.



26. Fit the ***Neck Enclosure*** into the slots of the base assembly to complete the construction of base, neck enclosure, and neck mechanism subsystem.



2.3 Jaw Mechanism

This section contains information on the jaw assembly including printing information and servo attachments. This section will refer to the hinge servo and the thrust servo. The hinge servo is the front servo which sits in the box of the right or left triangle link. The thrust servo is the back servo which is connected to the driving link. Right and left are determined as if looking from the manikin's point of view.

2.3.1 Materials Needed

Table 8: Jaw mechanism 3D prints

Components	Title of .stl	Estimated Time for Each (HH:mm)	Infill / Layer Height (mm)	Quantity	Additional Notes
Input Link	Input	0:30	30% / 0.1	2	Flat side down
Follower Link	Follower	0:30	30% / 0.1	2	Flat side down
Right Triangle Link	RightTriangle	1:15	30% / 0.1	1	Large flat face on bed. Supports everywhere
Left Triangle Link	LeftTriangle	1:15	30% / 0.1	1	Large flat face on bed. Supports everywhere

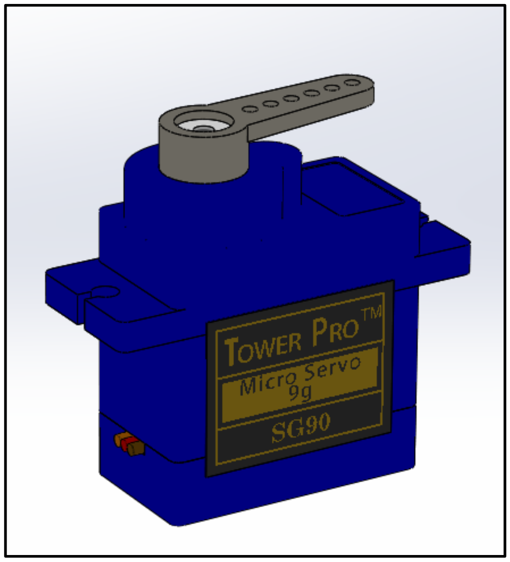
Hardware:

- (4) SG90 Tower Pro Micro Servos link
  - (2) "Hinge Servo"
  - (2) "Thrust Servo"
- (4) Single Arm Servo Horns (included with servo)
- (4) Servo Horn Screws (included with servo)
- (4) Nylon Plastic Washers link
- (4) 4-40 ¾" Button Head Hex Drive Screws link
- (4) 4-40 Nylon Insert Lock Nuts link
- (4) M2x0.4mm 10mm Button Head Hex Drive Screws link
- (4) M2x0.4mm Nylon Insert Lock Nuts link
- (4) ½" 18 Gauge Finishing Nails link
  - Or similar 0.05" diameter pins for servo horns

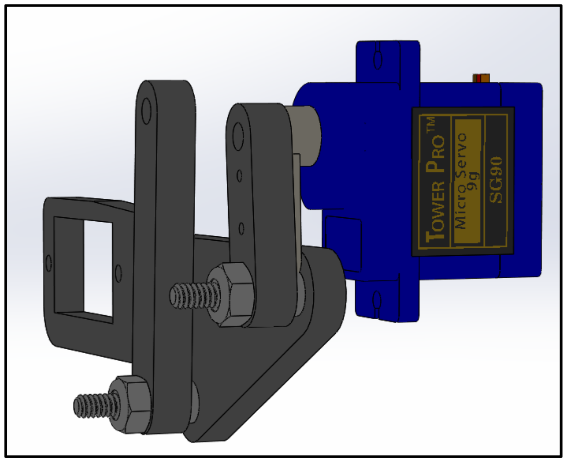
2.3.2 Jaw Mechanism Assembly

Note: This will need to be completed for both the right and left side jaw mechanism linkages.

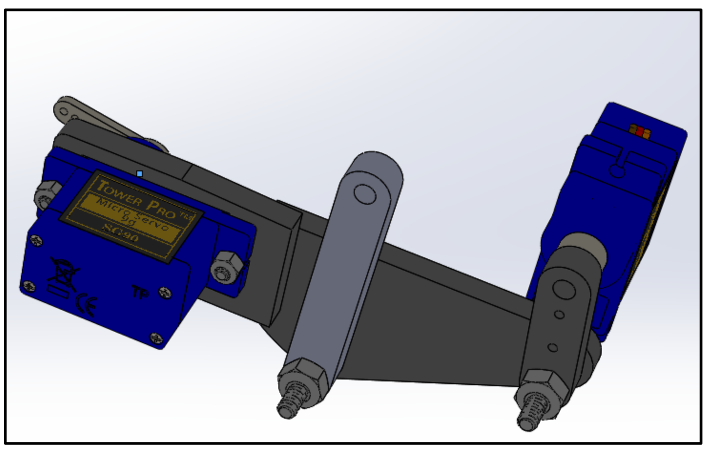
1. Attach a ***Single Arm Servo Horn*** to an ***SG90 Tower Pro Micro Servo***. Do not screw on yet.
2. Calibrate the thrust servo. See Section 3.2.3. Once this is complete, screw the ***Single Arm Servo Horn*** on.



3. Pin the ***Input Link*** to the thrust servo ***Single Arm Servo Horn*** using two ***½" 18 Gauge Finishing Nails***. The nails will have to be cut to length, and the ***Servo Horn*** will need to be trimmed so as to not interfere with Step 4.
4. Thread a ***¾" 4-40 Screw*** through the ***Triangle Link***, a ***Nylon Washer***, and the ***Input Link*** - the head of the screw should face away from the servo. Tighten a ***4-40 Nylon Insert Lock Nut*** on to reduce play, but not tight enough to restrict rotation.
5. Through the middle hole of the ***Triangle Link***, thread a ***¾" 4-40 Screw*** - this should be in the same orientation as the previous screw. On this, place a ***Nylon Washer***, thread it through either end of a ***Follower Link***, and again tighten with a ***4-40 Nylon Insert Lock Nut***. The image below shows the assembly up to this point.



6. Put the ***Hinge Servo*** in the box of the ***Triangle Link*** with the actuation side of the servo facing toward the ***Thrust Servo*** from Steps 1-5. The text "Tower Pro" text should face upward.
7. Attach the ***Hinge Servo*** to the ***Triangle Link*** using two ***M2x0.4mm 10mm Button Head Hex Drive Screws*** and two ***M2x0.4mm Nylon Insert Locknuts***. The final jaw left jaw mechanism assembly is shown below.



2.4 Oral Cavity

This section contains information on the oral cavity assembly. This section will refer to the hinge servo. The hinge servo is the front servo which sits in the box of the right or left triangle link, to be pinned to the oral cavity in Section 2.4.2.

2.4.1 Materials Needed

Table 9: Oral cavity 3D prints required

Components	Title of .stl	Estimated Time (HH:mm)	Infill / Layer Height (mm)	Quantity	Additional Notes
Soft Palate	Bottom Teeth CAO 4 Nov.stl	4:00	30% / 0.15	1	Bottom of piece face down. Supports everywhere
Hard Palate	TopOralAndTeeth.stl	7:00	30% / 0.15	1	Top of piece face down. Supports everywhere
Trachea	Trachea 2.stl	5:00	30% / 0.15	1	Supports everywhere
Jaw Piece	Jawbone 3.stl	6:00	30% / 0.15	1	Supports everywhere
Tongue Mold	Tongue Mold.stl	3:15	15% / 0.15	1	N/A

Tongue

The tongue component is cast in silicone using the 3D printed tongue mold component using Dragon Skin 10 Fast silicone rubber. The mold needs to be held upright to set after the silicone is poured in, and a popsicle stick needs to be inserted before the material hardens so that the tongue can be pulled out of the mold.

Lips

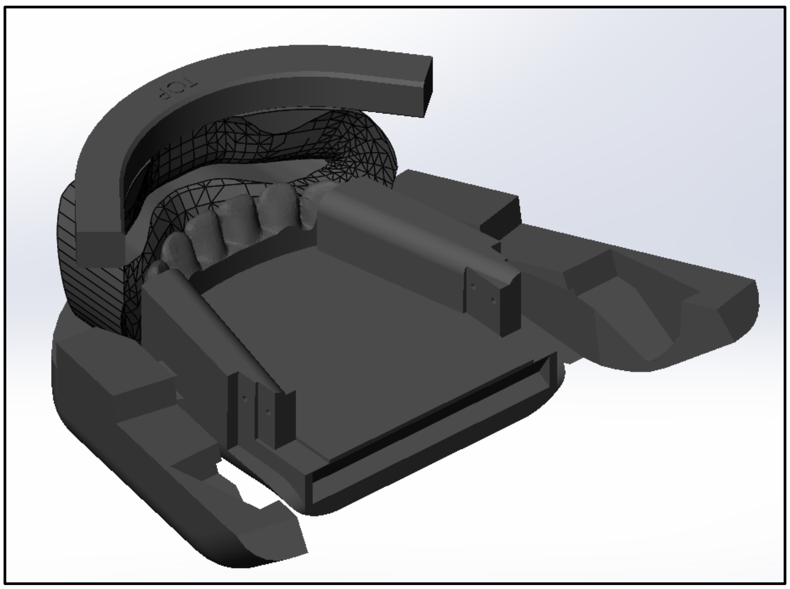
The lips are printed using the Objet260 Connex printer at the WPI Rapid Prototyping Lab. An STL file was made which overlaps the ledges and the lips by 0.0005”. The material for the ledges was set to VeroWhitePlus. The material for the lips was TangoBlackPlus. Another option for the lips is to print them using TPU. The filling setting for this should be concentric. This can be done without the use of special 3D printers, and at a lower cost.

Hardware:

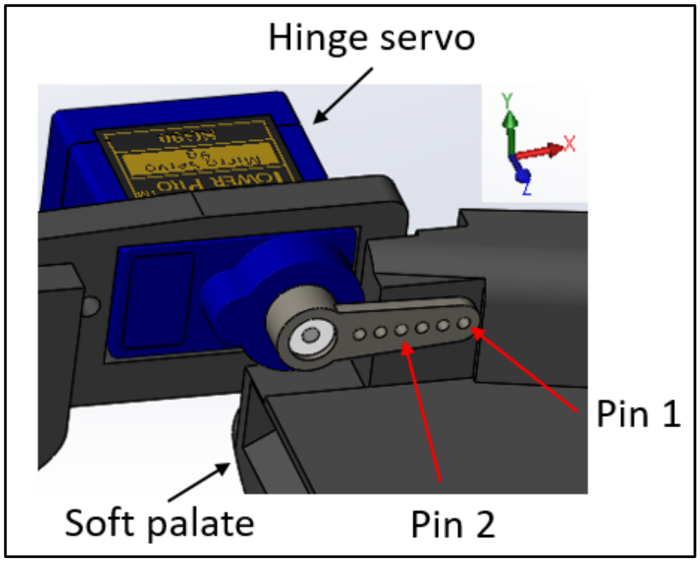
- (4) ½" 18 Gauge Finishing Nails link
    - Or similar 0.05" diameter pins for servo horns
- Super Glue

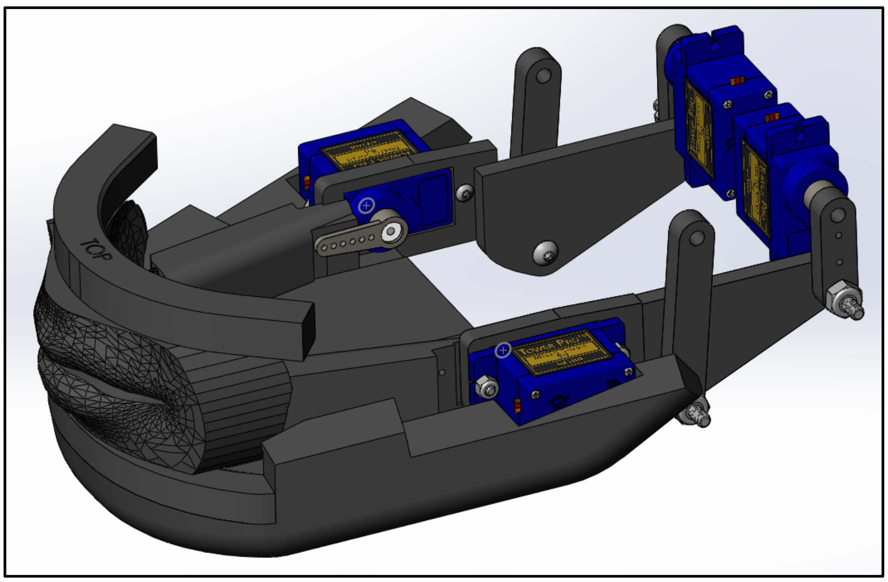
2.4.2 Oral Cavity Assembly

1. Snap the bottom ledge of the ***Lips*** into the snap fits on the soft palate.
    a. This may require filing down one or both of the pieces.
2. Superglue the flat part of the ***Jaw Piece*** to the bottom of the ***Soft Palate*** and allow time to dry.

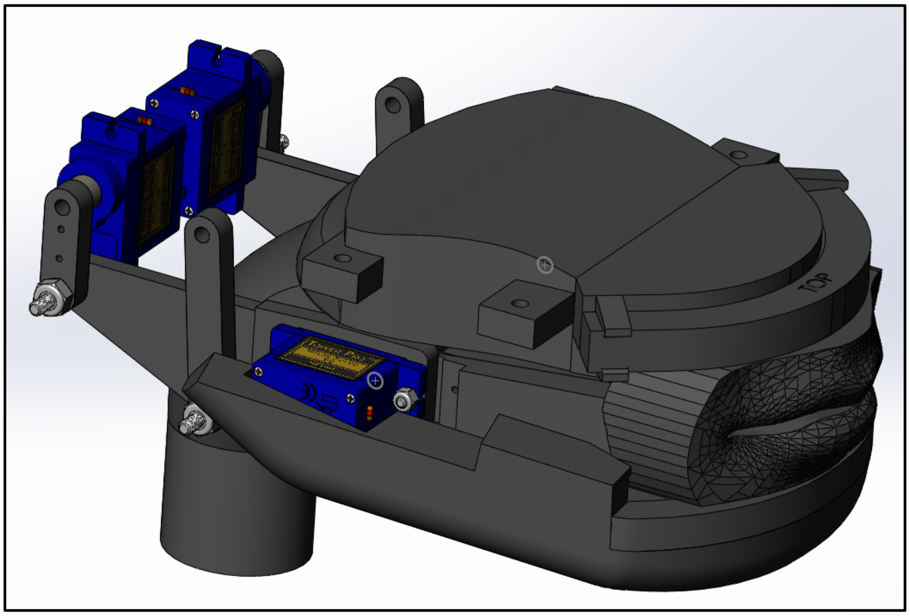


3. Calibrate the ***Hinge Servos*** to determine direction and range of rotation. See Section 3.2.3 for servo calibration.
4. Attach the ***Single Arm Servo Horns*** of the ***Hinge Servos*** to the cutouts in the back of the soft palate with two ***½" 18 Gauge Finishing Nails***. This attachment is shown below.





5. Superglue the ***Trachea*** to the ***Hard Palate,*** making sure to match the curves as precisely as possible. Allow the glue to dry.
6. Snap the top ledge of the ***Lips*** into the snap fits on the ***Hard Palate***. The final oral cavity and jaw mechanism assembly is shown below. This may require filing down one or both of the pieces.



2.5 Eyes

This section covers the assembly of the eye subsystem. The eyes are composed of a left and right eye module attached to a central platform which connects the eyes to the rest of the head. Details for the production and assembly of the eyes including fasteners are included. Note that some of the hardware in this section is described as a “substitute”. This means the hardware noted is an estimated substitute for hardware currently on the head that was previously used for which there is no record of the specification.

2.5.1 Materials Needed

Table 10: Eye mechanism materials

Components	Title of .stl / .dwg	Estimated Time (H:mm)	Infill / Layer Height (mm)	Quantity	Additional Notes
Eye holder (left)	final left eye holder final.stl	3:30	15% / 0.15	1	N/A
Eye holder (right)	final_eye_holder_V3.75_final.stl	3:30	15% / 0.15	1	N/A
Center Platform	platform_V3.stl	8:00	15% / 0.15	1	Vertical print orientation
Top Eyelid	final_clip on eyelid top rev3.stl	00:35	15% / 0.15	2	N/A
Bottom Eyelid	final_clip on eyelid rev3.stl	00:35	15% / 0.15	2	N/A
Butterfly Lid (Top Right)	final_eye clip butterfly top.stl	00:25	15% / 0.15	1	Print ball joint up
Butterfly Lid (Top Left)	final left butterfly top.stl	00:25	15% / 0.15	1	Print ball joint up
Butterfly Lid (Bottom Right)	final_eye clip butterfly bottom.stl	00:25	15% / 0.15	1	Print ball joint up
Butterfly Lid	final left butterfly	00:25	15% / 0.15	1	Print ball

(Bottom Left)	bottom.stl				joint up
Servo Adapter 1 (Left)	final left servo ball joint link 1.stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 1 (Right)	final_servo_ball_joint_link 1.stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 2 (Left)	final left servo ball joint link 2. stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 2 (Right)	final_servo_ball_joint_link 2.stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 3 (Left)	final left ball joint link 2.stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 3 (Right)	final_servo_ball_joint_link 3.stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 4 (Left)	final_servo_ball_joint_link 4.stl	00:30	15% / 0.15	1	Print ball joint up
Servo Adapter 4 (Right)	final_servo_ball_joint_link 4.stl	00:30	15% / 0.15	1	Print ball joint up
Ball-ended Link 1	final_link 1.stl	00:15	15% / 0.10	2	N/A
Ball-ended Link 2	final_link 2.stl	00:15	15% / 0.10	2	N/A
Ball-ended Link 3	final_link3.stl	00:15	15% / 0.10	2	N/A
Ball-ended Link 4	final_link4.stl	00:10	15% / 0.10	2	N/A

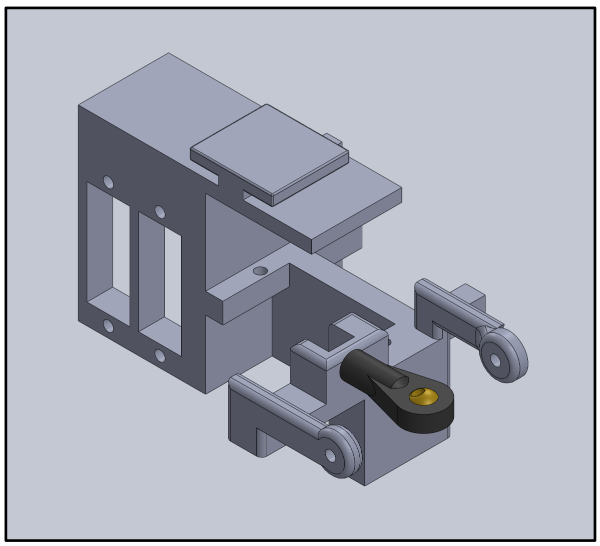
Hardware:

- (8) KS HD47MG servos link
- (8) KS HD47MG Servo horns (supplied with servos)
- (8) KS HD47MG Servo screws (supplied with servos)
- (10) Black-Oxide Alloy Steel Socket Head Screw, 0-80 Thread Size, 3/8" Long, McMaster-Carr link
- (10) 18-8 Stainless Steel Hex Nut, 0-80 Thread Size, McMaster-Carr link

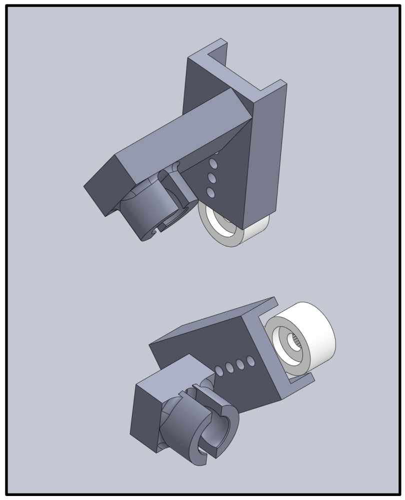
- (4) Narrow Fillister Head Slotted Screw 18-8 Stainless Steel, High-Profile, 000-120 Thread, 1/4" Long link [substitution]
- (2) Ball Joint Rod End M3 x 0.5mm Thread, Right Hand link [substitution]
- (2) Painted Steel Pan Head Torx Screws with Black Head, M3 Thread, 13 mm Long link [substitution]
- (4) Zinc-Plated Steel Hex Nut Medium-Strength, Class 8, M3 x 0.5 mm Thread link [substitution]

2.5.2 Assembly

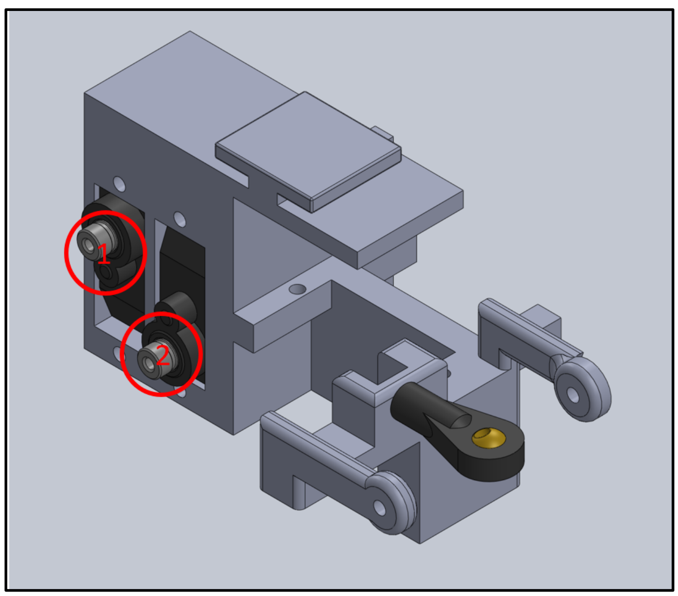
1. Attach the ***Ball Joint*** to the ***Eye Holder*** using (1) ***M3 Steel Pan Head Screw*** through the central post and (1) ***M3 Nut*** to secure.



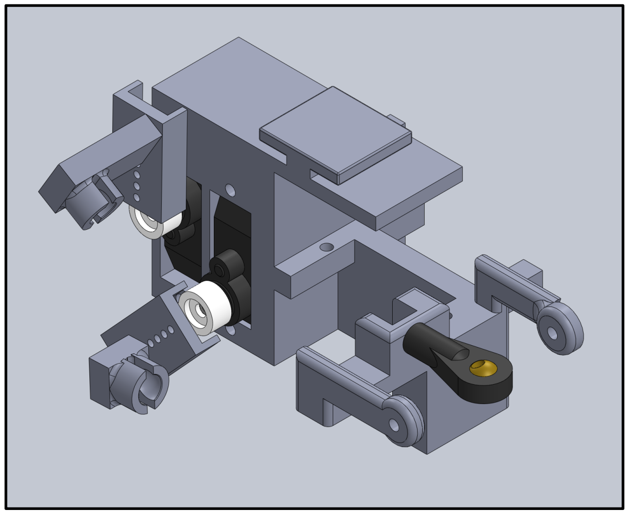
2. Secure the (4) ***Servo Horns*** to the (4) corresponding ***Ball-Joint Adapters*** using (1) ***000-120 Stainless Steel Fillister Head Screw*** aligning the length of holes with one another in a suitable position.



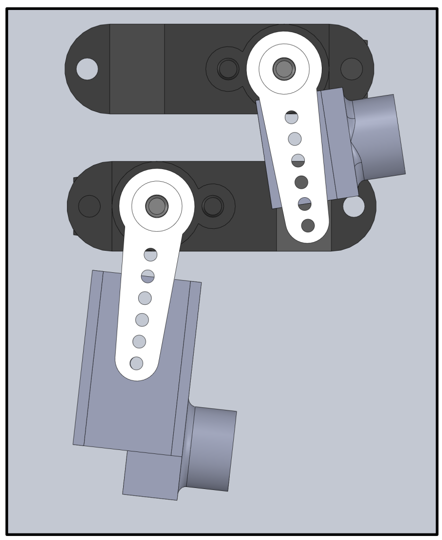
3. For linkages 1 and 2, the servos should be pinned to the eye holder using (2) ***0-80 Steel Socket Head Screw*** and (2) ***0-80 Stainless Steel Hex Nut***.



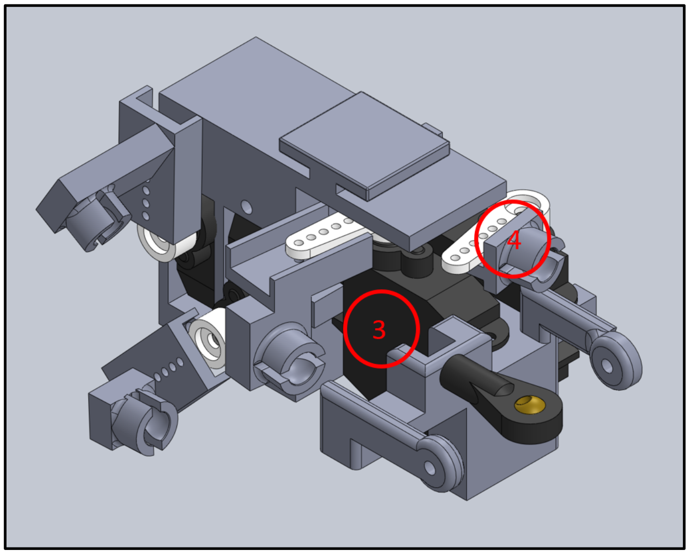
4. Bolt the horn assemblies for linkages 1 and 2 to the ***Servos*** using the provided ***Servo Screw***.

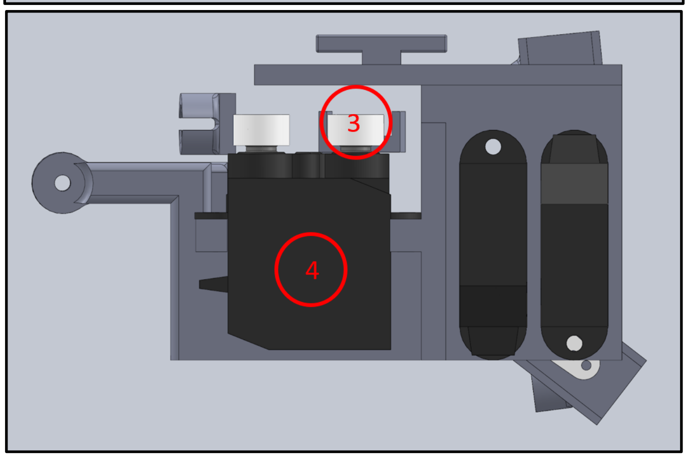


5. For linkages 3 and 4, the horn assembly should first be bolted to their corresponding ***Servos*** using the provided ***Servo Screws***.

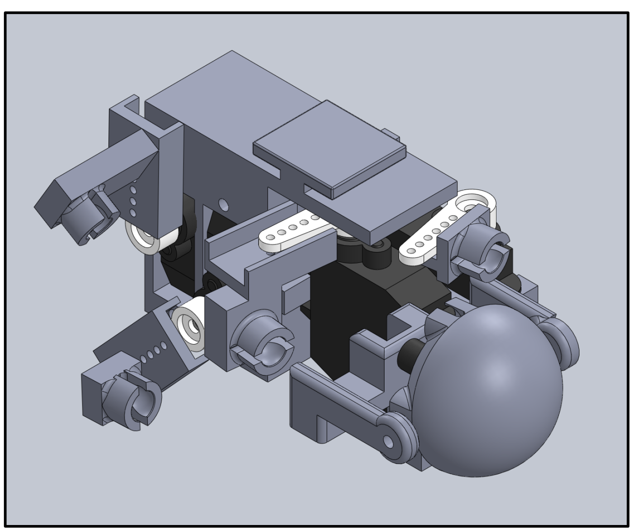


6. Then the 3 and 4 servo assemblies should be subsequently installed to the eye holder using (2) ***0-80 Steel Socket Head Screw*** and (2) ***0-80 Stainless Steel Hex Nut***.

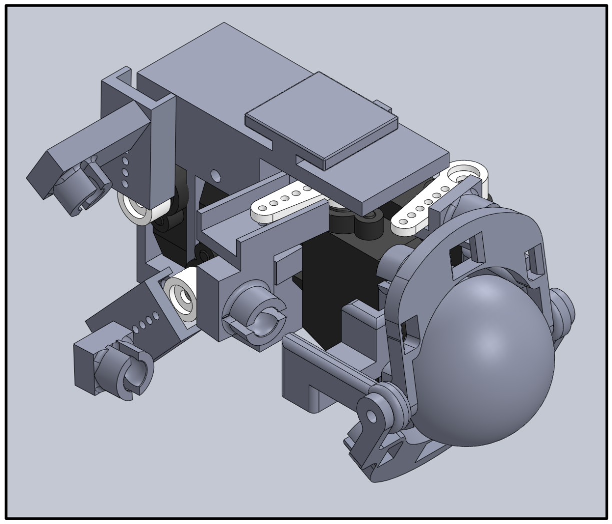




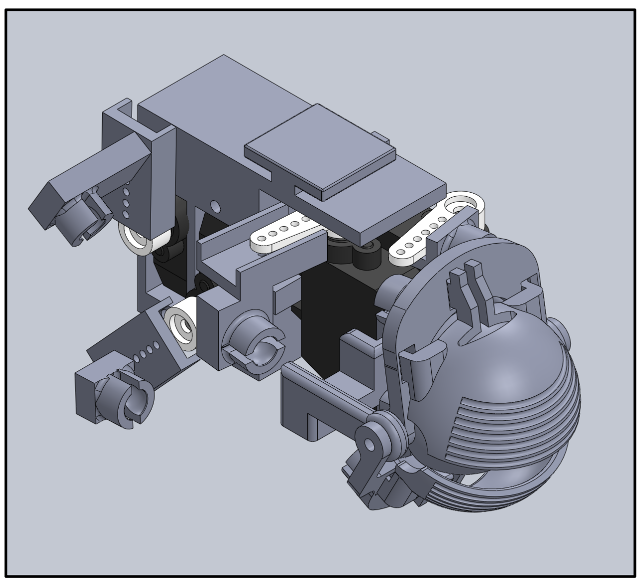
7. Attach the printed ***Eyeball*** to the ***Ball Joint*** using (1) ***M3 Steel Pan Head Screw*** through the central ball and (1) ***M3 Nut*** to secure.



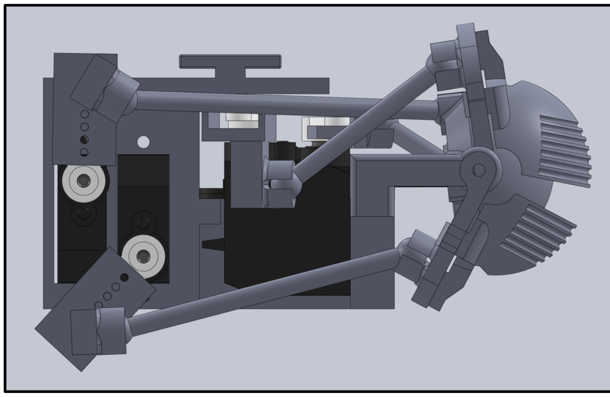
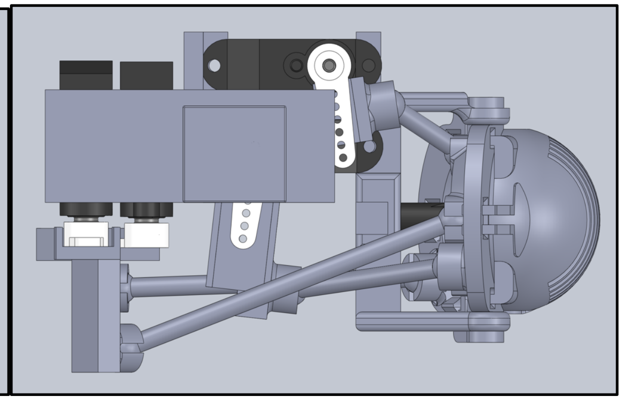
8. Bolt the ***Upper Butterfly Lid*** and ***Lower Butterfly Lid*** through the hands of the ***Eye Holder*** using (2) ***0-80 Steel Socket Head Screw*** and (2) ***0-80 Stainless Steel Hex Nut***.



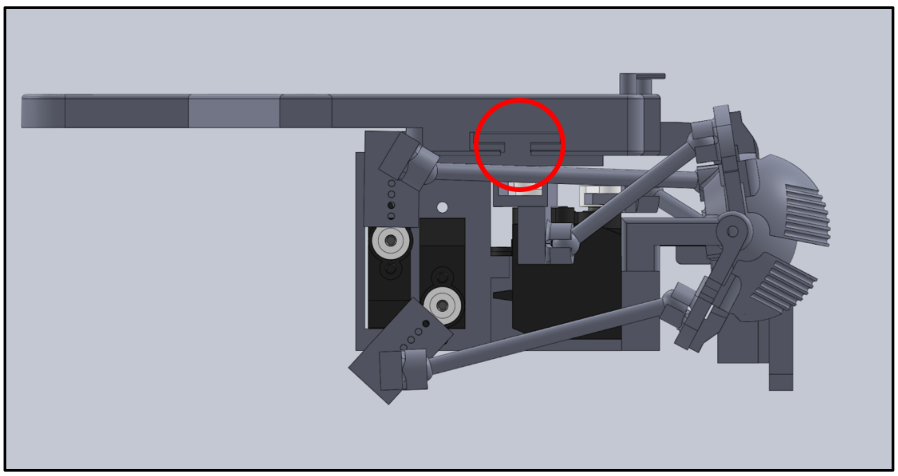
9. Clip the ***Upper Eyelid*** and ***Lower Eyelid*** into the corresponding ***Butterfly Lids***.



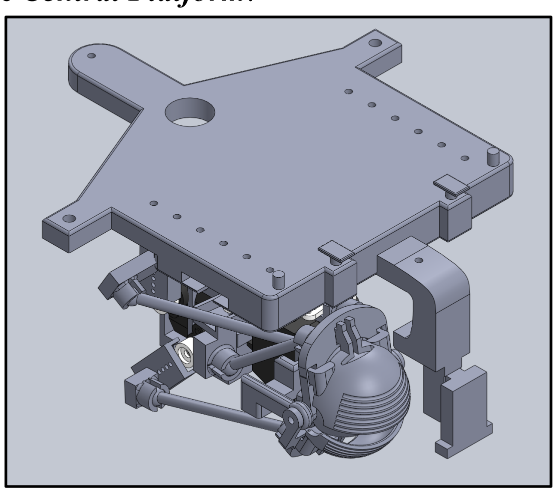
10. Insert the ***Ball-ended Links***, into the ***Servo Adapters*** and eye mechanism.



11. Attach the assembled eye module to the ***Central Platform*** sliding the top post of the ***Eye Holder*** into the canal structure.



12. Repeat the process above for the opposite eye module. The picture below shows the right eye assembled to the ***Central Platform***.



2.6 Eyebrows

This section covers the assembly of the eyebrow subsystem. The eyebrows are composed of a left and right eyebrow module attached to the central platform that connects the eyes to the rest of the head. Note that some of the hardware in this section is described as a "substitute". This means the hardware noted is an estimated substitute for hardware currently on the head that was previously used for which there is no record of the specification.

2.6.1 Materials Needed

Table 11: Eyebrow mechanism materials

Components	Title of .stl / .dwg	Estimated Time (H:mm)	Infill / Layer Height (mm)	Quantity	Additional Notes
Dual link (left)	middle link eyebrow v2.stl	00:20	15% / 0.15	1	Print ball joint up
Adapter (left)	20mm extension link.stl	00:15	15% / 0.15	1	N/A
Bar link (left)	brow link v2.stl	00:20	15% / 0.15	1	N/A
Eyebrow base (left)	v9 eyebrowbaseleft.stl	00:45	15% / 0.15	1	Print ball joint up
Dual link (right)	R_middle link eyebrow.stl	00:20	15% / 0.15	1	Print ball joint up
Adapter (right)	R_20mm extension link.stl	00:15	15% / 0.15	1	N/A
Bar link (right)	R_brow link v2.stl	00:20	15% / 0.15	1	Print ball joint up
Eyebrow base (right)	R_v9 eyebrowbaseleft.stl	00:45	15% / 0.15	1	N/A

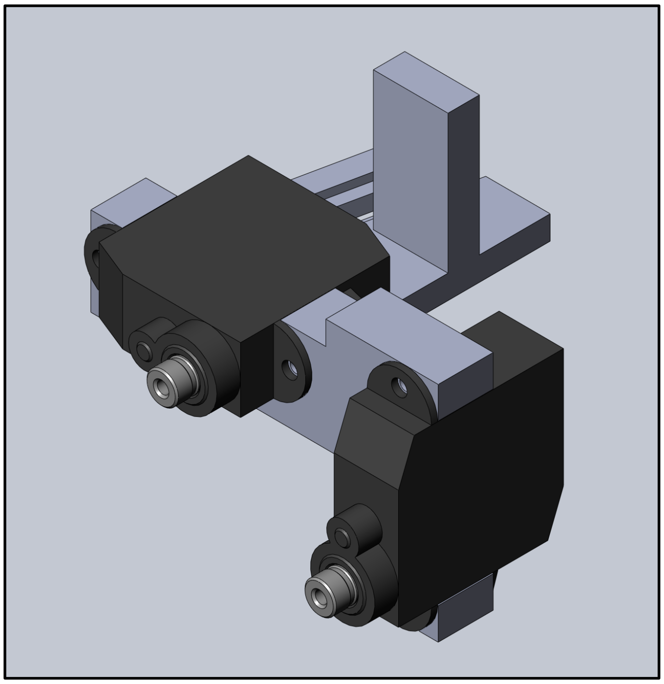
Hardware:

- (4) KS HD47MG Servos link
- (4) KS HD47MG Servo Horns (supplied with servos)
- (4) KS HD47MG Servo screws (supplied with servos)

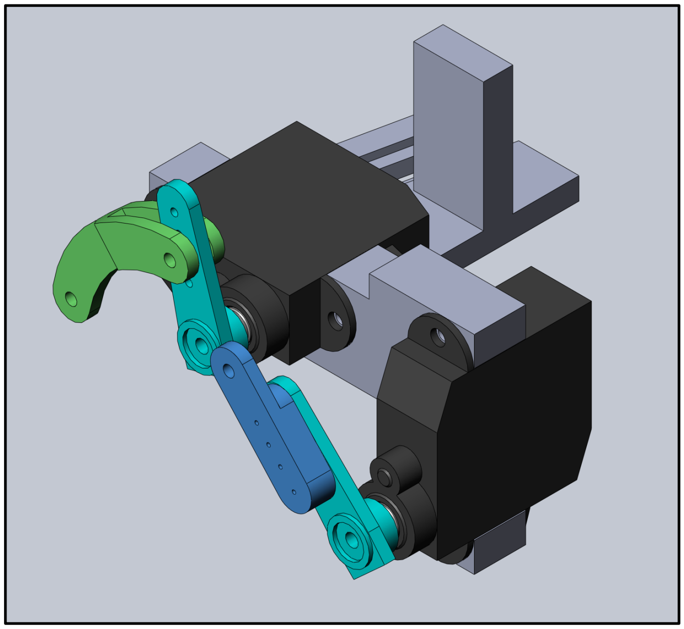
- (10) Black-Oxide Alloy Steel Socket Head Screw, 0-80 Thread Size, 3/8" Long, McMaster-Carr link
- (10) 18-8 Stainless Steel Hex Nut, 0-80 Thread Size, McMaster-Carr link
- (2) Narrow Fillister Head Slotted Screw 18-8 Stainless Steel, High-Profile, 000-120 Thread, 1/4" Long link [substitution]

2.6.2 Assembly

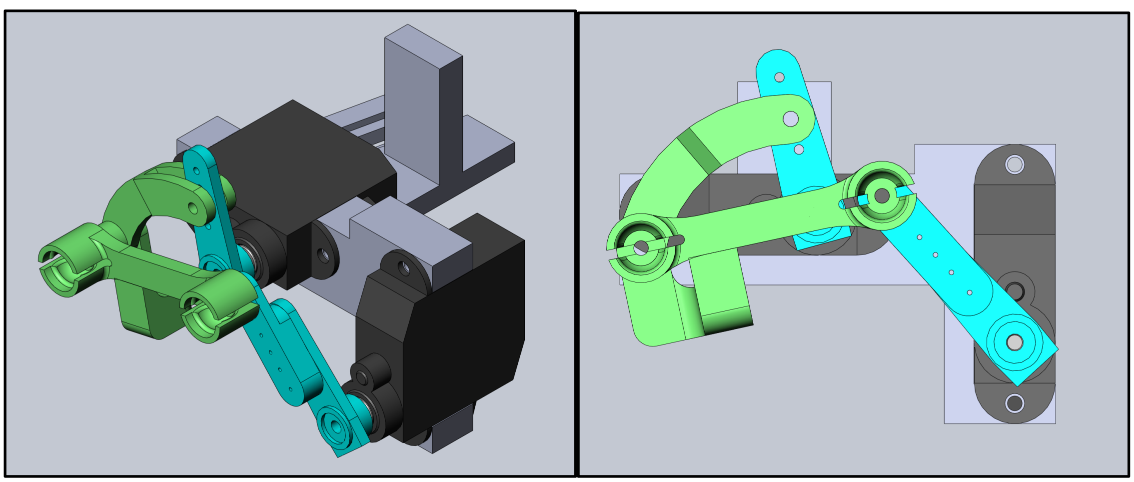
1. Bolt the ***Servos*** to the ***Eyebrow Base*** using (4) ***0-80 Steel Socket Head Screw*** and (4) ***0-80 Stainless Steel Hex Nut***.



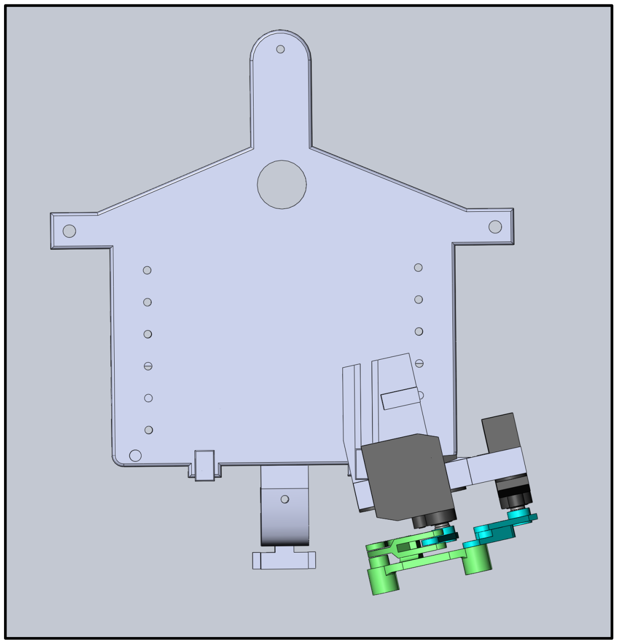
2. Attach the ***Dual Link*** and ***Adapter*** to the given ***Servo Horns*** using the (2) ***000-120 Stainless Steel Fillister Head Screw***.
3. Attach the horn assemblies to the ***Servos*** using the (2) **Servo Screws**.



4. Bolt the ***Central Link*** to the two servo assemblies using (2) ***0-80 Steel Socket Head Screw*** and (2) ***0-80 Stainless Steel Hex Nut***, linking them and completing the eyebrow module.



5. Attach the eyebrow to the ***Central Platform*** using the attachment post of the platform and attachment canal of the eyebrow base.



2.7 Lattice

This section will cover only the printing of the head lattice pieces, to include the two neck pieces, the two side head pieces, the eye/nose piece, and the top head piece.

2.7.1 Materials Needed

Table 12: List of 3D printed parts for the lattice

Components	Title of .stl	Estimated Time (HH:mm)	Infill / Layer Height(mm)	Quantity	Additional Notes
Left Neck	NeckLattice Left	14:00	20% / 0.15	1	Neck connection tabs down. Supports everywhere
Right Neck	NeckLattice Right	14:00	20% / 0.15	1	Neck connection tabs down. Supports everywhere
Left Head	LeftHeadLattice	14:00	30% / 0.15	1	Top up. Supports everywhere
Right Head	RightHeadLattice	14:00	30% / 0.15	1	Top up. Supports everywhere
Top Head	TopHeadLattice	18:00	20% / 0.15	1	Skull up
Eye/Nose	EyeAndNoseLatticePiece	8:00	30% / 0.10	1	Nose face up. Supports everywhere

Hardware:

- None

2.7.2 Lattice Assembly

The assembly of the lattice is detailed in Chapter 4.

2.8 Skin

This section will cover only the printing details and information for the skin pieces. The skin assembly is listed as part of the full assembly in Chapter 4.

2.8.1 Materials Needed

Table 13: Skin shell materials

Components	Title of .stl / .dwg	Estimated Time (H:mm)	Infill / Layer Height (mm)	Quantity	Additional Notes
Neck (left)	left neck skin no window.stl OR left neck skin.stl	14:00	10% / 0.10	1	Concentric infill
Neck (right)	right neck skin no window.stl OR right neck skin.stl	14:00	10% / 0.10	1	Concentric infill
Face	corrected face skin.stl	20:00	10% / 0.10	1	Concentric infill
Crown	top of head skin.stl	20:00	10% / 0.10	1	Concentric infill
Ear (left)	left back of head skin.stl	20:00	10% / 0.10	1	Concentric infill
Ear (right)	right back of head skin.stl	20:00	10% / 0.10	1	Concentric infill
Eyebrow (left)	left eyebrow.stl	6:00	15% / 0.10	1	Cubic infill
Eyebrow (right)	right eyebrow.stl	6:00	15% / 0.10	1	Cubic infill
Jaw	jaw skin.stl	14:00	10% / 0.10	1	Concentric infill

Hardware:

- (1) Velcro Coins, Pack of 75 link

Printing Notes:

1. 10% concentric infill
2. Print speed 25-40%
3. Print settings- PLA then increase temp to 230^{o}C

2.8.2 Skin Assembly

The assembly of the skin is detailed in Chapter 4, after the full assembly of the animatronic.

Chapter 3: Software and Electrical Assembly

This chapter describes how to set up the software, programs, and the electrical circuits required to run H.A.L. The first section will step you through how to download the necessary software, including the different libraries used in the program. Steps on how to compile and upload the program to the animatronic are listed as well. Finally, the steps on building the circuits for sensors and other electronics are listed as well. Be sure to complete the preliminary tests for each component to ensure the circuit was constructed properly before integrating it with the rest of the system.

3.1 Software Downloads

Make sure the latest version of the various software listed in Chapter 1 Table 1 are downloaded onto the computer. Follow the download and installation instructions on each of the websites unless otherwise specified in this manual. Table 14 lists the components and total time needed to complete this section.

Table 14: Materials needed and estimated time - software downloads

Component	**Quantity**
Computer	1
Total Time	1:00

Files and Libraries:

Download the GitHub Repository linked here. The folder "MQPOOPv1" contains the code pertaining to the most recent animatronic. Install the libraries listed below. Several Teensy and Arduino libraries overlap and often conflict with one another. All of libraries used the Teensy version except those with an asterisk (*) next to the name. You may need to delete, rename, or move the Arduino version of the library.

- Arduino.h*
- Wire.h
- Adafruit_PWMServoDriver.h (*download instruction available here)
- Adafruit_RGBLCDShield.h (*download instruction available here)
- utility/Adafruit_MCP23017.h
- Audio.h

- SPI.h
- SD.h
- SerialFlash.h
- Pixy2I2C.h (*available for download at here)
-

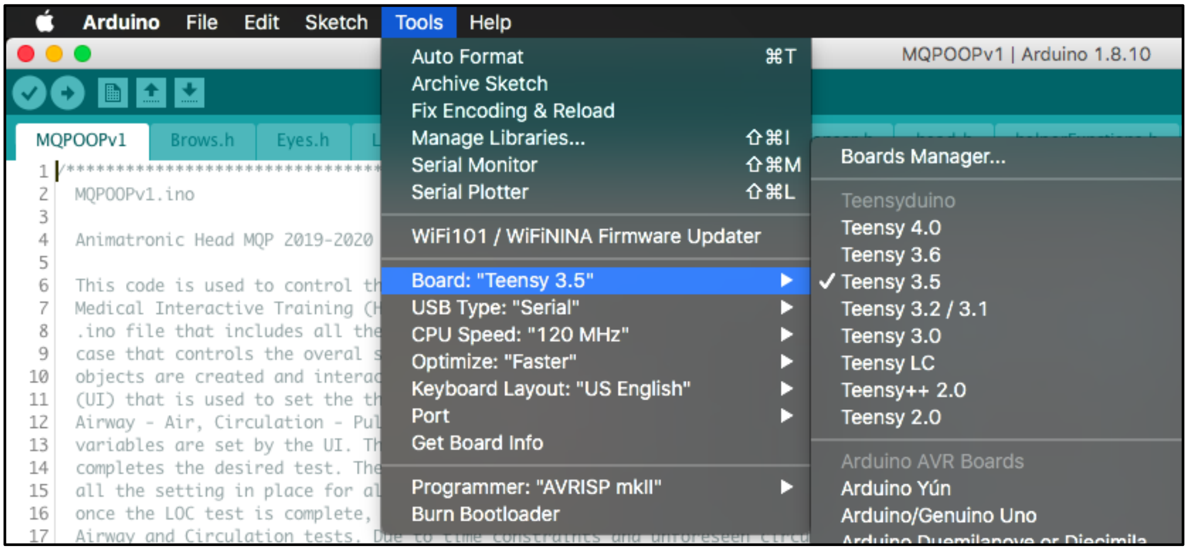
The console should output the lines shown below when the full code is compiled without any conflicts.

```
Opening Teensy Loader...
Multiple libraries were found for "SPI.h"
 Used: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/SPI
Multiple libraries were found for "SD.h"
 Used: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/SD
 Not used: /Applications/Arduino.app/Contents/Java/libraries/SD
Multiple libraries were found for "SerialFlash.h"
 Used: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/SerialFlash
Multiple libraries were found for "Pixy2I2C.h"
 Used: /Users/EthanLauer/Documents/Arduino/libraries/Pixy2
Multiple libraries were found for "Wire.h"
 Used: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/Wire
Multiple libraries were found for "Adafruit_PWMServoDriver.h"
 Used: /Users/EthanLauer/Documents/Arduino/libraries/Adafruit_PWM_Servo_Driver_Library
Multiple libraries were found for "Adafruit_RGBLCDShield.h"
 Used: /Users/EthanLauer/Documents/Arduino/libraries/Adafruit_RGB_LCD_Shield_Library
Multiple libraries were found for "Audio.h"
 Used: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/Audio
Using library Wire at version 1.0 in folder: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/Wire
Using library Adafruit_PWM_Servo_Driver_Library at version 1.0.2 in folder: /Users/EthanLauer/Documents/Arduino/libraries/Adafruit_PWM_Servo_Driver_Library
Using library Adafruit_RGB_LCD_Shield_Library at version 1.0.3 in folder: /Users/EthanLauer/Documents/Arduino/libraries/Adafruit_RGB_LCD_Shield_Library
Using library Audio at version 1.3 in folder: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/Audio
Using library SPI at version 1.0 in folder: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/SPI
Using library SD at version 1.2.2 in folder: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/SD
Using library SerialFlash at version 0.5 in folder: /Applications/Arduino.app/Contents/Java/hardware/teensy/avr/libraries/SerialFlash
Using library Pixy2 in folder: /Users/EthanLauer/Documents/Arduino/libraries/Pixy2 (legacy)
```

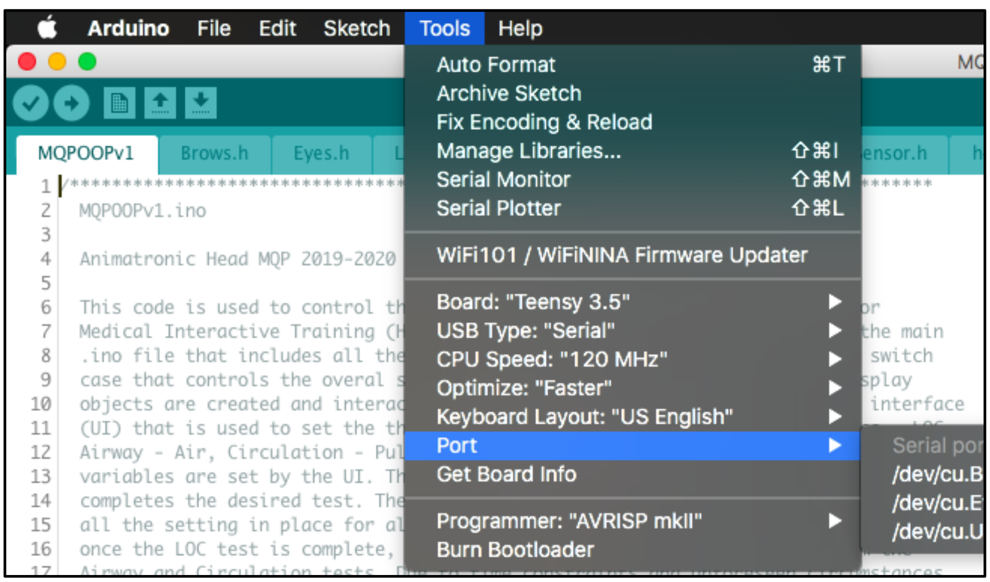
Steps in Running the Program

Below are some steps for uploading programs to the Teensy. More information on using the Teensy Loader can be found here. When testing each component individually, make sure to comment out the code currently in the main loop. Do not delete the code!

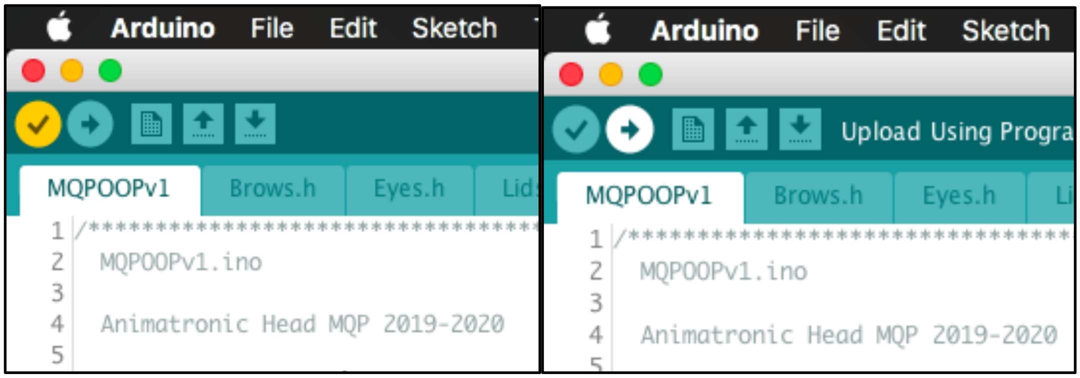
1. Set up the IDE for the correct board by selecting the Teensy 3.5 board under the “Tools” menu. Make sure the fields are defined as follows:
    - Board: Teensy 3.5
    - USB Type: Serial
    - CPU Speed: 120 MHz
    - Optimize: Faster



2. Connect to the Teensy by selecting the Port the Teensy is connected to under the "Tools" menu (not shown in the picture below). If the Teensy Board does not show up, try a different port or simple reconnect it.



3. Use the provided code or write code (depending on what stage the project is in).
4. Compile and Download.

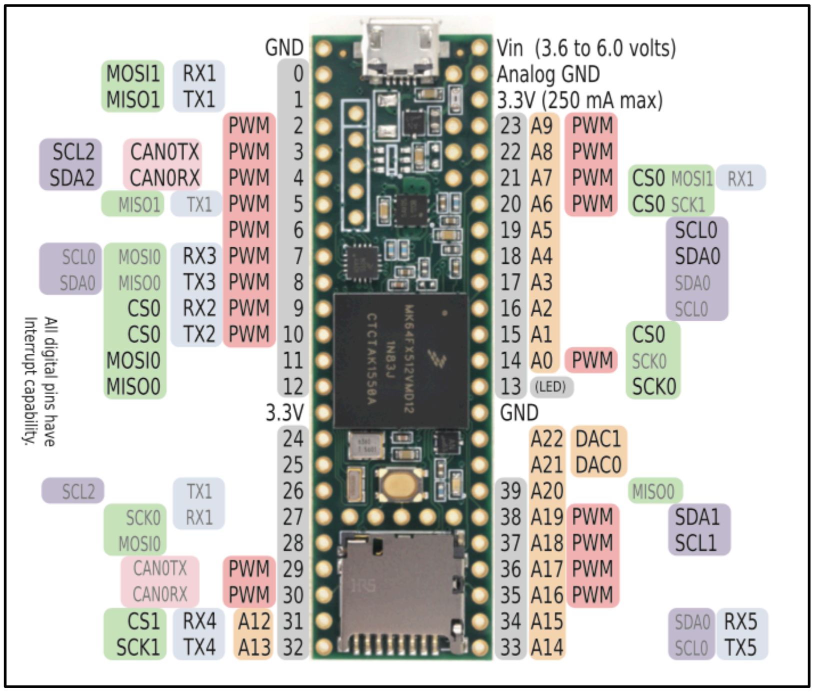


5. Wait for the program to finish uploading and for the Teensy Loader to open. When the Teensy Loader does not work, press the reset button on the microcontroller.
6. Open the Serial Monitor to view any data being printed.
7. To stop the program, simply unplug the USB cable connecting the Teensy to the microcontroller.
8. Restart the program by pressing the reset button on the microcontroller

3.2 Electrical

This section instructs you how to construct all of the circuits and set up the sensors necessary to the animatronic's operation. This entire Section 3.2 will take about 12 hours to assemble and test assuming the parts are readily available and there are no major issues. The estimated time for each individual part includes the circuit construction, soldering time, calibration, and testing. These times may vary by one hour. All steps require the power supply and a computer. A completed circuit diagram is shown in the Appendix.

The animatronic runs on the Teensy 3.5 microcontroller. This controller has a high processing speed of 120MHz compared to the Arduino Mega's 16MHz and a significant number of I/O pins. It supports I^2C communication for other electronics and the code can be developed in the Arduino IDE, giving access to the many Arduino and Teensy libraries. Programs are loaded onto the board by a USB cable. The pinout for the Teensy 3.5 is shown below and additional information can be found at Teensy's website.



The animatronic is powered by a variable power supply with two separate channels: 7.2V 1A and 5V 1A. The 7.2V channel (Ch. 1) is used to power the servo drivers while the 5V channel (Ch. 2) is used to power the solenoids. Any of the components that use 3.3V are connected to the microcontroller. The exact connections are discussed later in the respective sections. Make sure to connect the alligator clips or banana plugs to the correct channels.

3.2.1 Breadboard and Microcontroller Placement

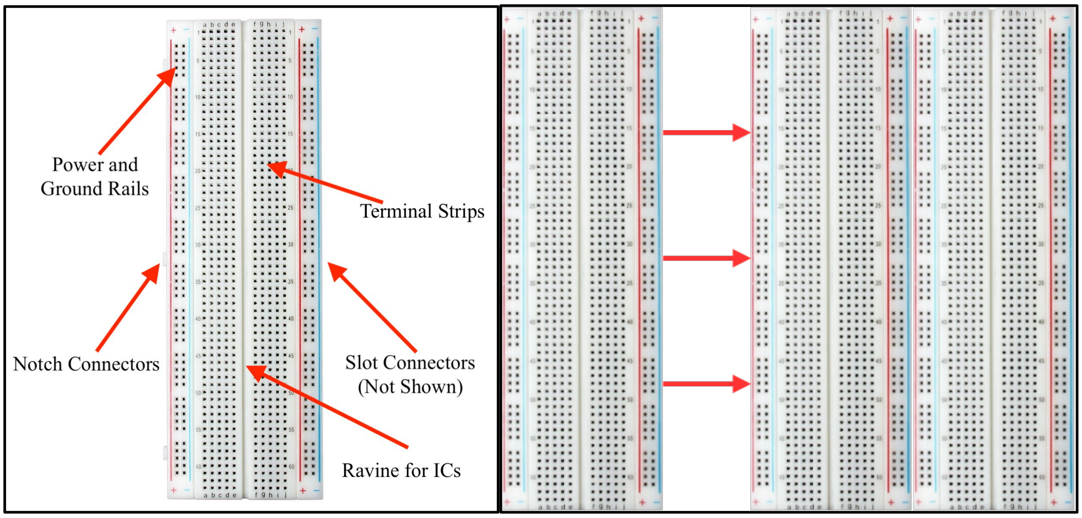
Table 15 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 15: Materials needed and estimated time - breadboard and microcontroller placement

Component	**Quantity**
Teensy 3.5 Microcontroller	1
Full 7in Long Breadboard	3
10 kΩ Resistors	2
22 AWG Wire	About 25ft or more
Jumper Wires	About 30 of each kind

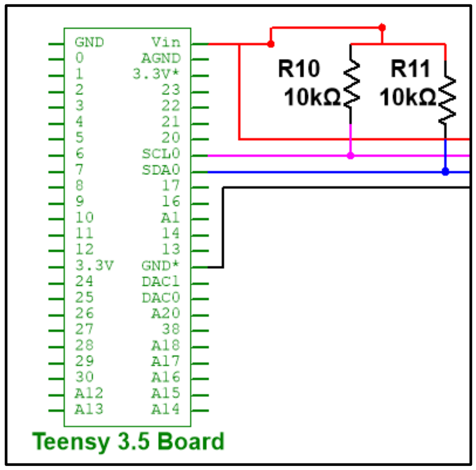
Total Time	0:10

Each of the ***Breadboards*** have notch and slot connectors located on the long edges as shown below.



Follow the steps listed below for the initial breadboard placement.

1. Connect the three full ***Breadboards*** together using the notches on the sides so the three ***Breadboards*** create a one large "square" breadboard. The numbers and letters on the edges should all be facing the same direction.
2. The side power and ground strips (red + and blue -) will be used for different voltage sources (3.3V, 5V, and 7.2V). Add a label at the top of each strip so there is a clear distinction between the different voltage supplies. This reminder will ensure the components are connected to the correct voltage source and reduce the chance of a burnout.
3. Place the three ***Breadboards*** in its designated slot in the acrylic base.
4. Place the ***Teensy 3.5 Microcontroller*** in the center ***Breadboard*** so the two rows of pins are straddling the center ravine. The microcontroller should be a few terminal strips away from the edge of the board for easy access to the microUSB port. The microSD card port should be easily accessible as well.
5. Add the two ***10kΩ*** pull-up ***Resistors*** to circuit as shown below so the ***Teensy*** can use I^2C to communicate with the Servo Drivers, Camera, and LCD.



Since the SDA and SCL lines are shared by multiple components, the resistors will be shown in circuit diagrams later on. Please note, these are all referring to the same resistors (i.e. there are only two ***10kΩ Resistors*** connected to the SDA and SCL ports). See the Teensy Website for pinout details.

For each component, make sure the wires are long enough to reach from the component's location in the head (neck, jaw, forehead, etc.), through the ***Neck Enclosure***, and to the ***Breadboard***. The wires should not come loose from the ***Breadboard*** or be under much tension regardless of any movements in the system. The servo wires should be organized in their respective channels in the acrylic ***Base*** and any other wires originating from the head should be taped neatly to the inside of the ***Neck Enclosure***. Use the many terminal strips on the ***Breadboards*** to organize the wires and create clean circuits.

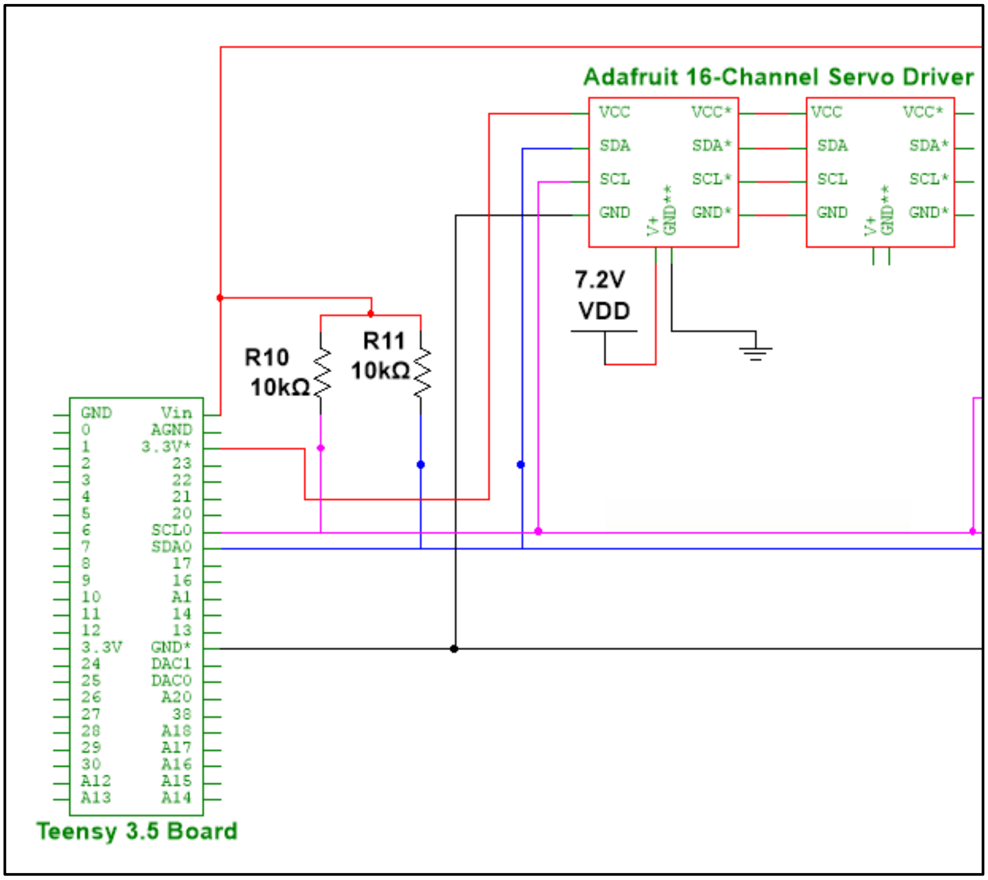
3.2.2 Servo Drivers

Table 16 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 16: Materials needed and estimated time - breadboard and microcontroller placement

Component	Quantity
Adafruit Servo Drivers	2
22 AWG Wire	About 25ft or more
Jumper Wires	About 30 of each kind
Total Time	0:10

The two ***Adafruit Servo Drivers*** are used to control all the servos. The two drivers are daisy chained together to accommodate the many servos and use I^2C to communicate with the ***Teensy***. Construct the following circuit using the steps below.



1. Connect the ***first driver's VCC port*** to the ***3.3V port*** on the ***Teensy***
2. Connect the ***first driver's SDA port*** to the terminal strip corresponding with the ***Teensy*** SDA port.
3. Connect the ***first driver's SCL port*** to the terminal strip corresponding with the ***Teensy*** SCL port.
4. Connect the ***first driver's GND pin*** to the active breadboard ground strip.
5. Connect the ***right side VCC, SDA, SCL, and GND ports*** to the corresponding ports on the left side of the second ***Servo Driver***.
6. Connect the first ***Servo Driver's*** additional power ports to the 7.2V rail supply and the respective ground.

3.2.3 Servo Connections and Calibration

Table 17 lists the components and total time needed to complete this section. Servo calibration may take longer than indicated.

Table 17: Materials needed and estimated time - servo connections and calibration

Component	Quantity
Adafruit Servo Drivers	2
Servo Extension Cables	19
Turnigy TGY-D56MG Servo	12
Tower Pro Servo	4
DSS-M15S 270º with Feedback Servo	3
Servo Extension Cable	19
22 AWG Wire	About 25ft or more
Jumper Wires	About 30 of each kind
10kΩ Potentiometer	1
Total Time (including each servo calibration)	2:00

Note: This section is assuming the servos are already set in their respective mechanical components, but full assembly has not occurred.

A total of 19 servos are used in the animatronic and three different servos are used: ***Turnigy***, ***Tower Pro***, and ***DSS servos***. Different servo types control different features in the animatronic. Each type of servo has three wires: power (red), signal (white or orange), and ground (black). Note: The ***DSS servo***s used for the neck have four wires (power (red), signal (orange), ground (black), and feedback (white). It is very important to connect the servos to the drivers in the correct direction. Failure to have the pins connected in the proper locations will result in a damaged or broken servo.

1. Connect each servo to a ***Servo Extension Cable*** so there is a strong connection between the servos nested in the head and neck and the servo drivers on the base.
2. Label each wire set indicating the mechanical part the servo is controlling. Both the set directly connected to the servo and the corresponding ***Extension Cable*** should be labeled. This will help with establishing the correct connections during troubleshooting.
3. ***DSS Servos*** only: Connect the white feedback wires to their respective ports on the ***Teensy***.

Connections

Each servo driver has labeled pins for servo connections with indexing starting at 0. The first ***Servo Driver*** has pins 0-15. The second, ***Right-side Driver*** that was added to the right side of the first, contains pins 16-31. Although not all 31 servo pins are used, both ***Servo Drivers*** are required. Use Table 18 to connect the respective servo to the correct pin on the drivers. This can also be found in the pinSetUp.h header file. The labeled servo wires should be threaded through the designated channels on the acrylic ***Base*** towards the ***Servo Drivers***. Be sure to double check the wires are connected to the correct pins and in the proper orientation so the servos do not break when you run the code!

Table 18: Servo pin connections

Component/Servo	Pin Number	Servo Type
Eyelids		
Eyelid Left Bottom Servo	0	Turnigy
Eyelid Left Top Servo	1	Turnigy
Eyelid Right Bottom Servo	2	Turnigy
Eyelid Right Top Servo	3	Turnigy
Eyeballs		
Eyeball Left Horizontal Servo	4	Turnigy
Eyeball Left Vertical Servo	5	Turnigy
Eyeball Right Horizontal Servo	6	Turnigy
Eyeball Right Vertical Servo	7	Turnigy
Eyebrows		
Eyebrow Left Medial Servo	8	Turnigy
Eyebrow Left Lateral Servo	9	Turnigy
Eyebrow Right Medial Servo	10	Turnigy
Eyebrow Right Lateral Servo	11	Turnigy

Jaw		
Jaw Left Vertical Motion Servo	12	Tower Pro
Jaw Right Vertical Motion Servo	13	Tower Pro
Jaw Left Horizontal Motion Servo	14	Tower Pro
Jaw Right Horizontal Motion Servo	15	Tower Pro
Neck		
Neck Right Servo	16	DSS
Neck Left Servo	17	DSS
Neck Rotation Servo	18	DSS
Neck Right Servo Feedback (connect directly to Teensy)	A13	Feedback
Neck Left Servo Feedback (connect directly to Teensy)	A12	Feedback
Neck Rotation Servo Feedback (connect directly to Teensy)	A1	Feedback

Calibration

If the servos are connected exactly as it was in March 2020, you can use the servo setpoint positions defined in provided code without any changes. If the servos are connected differently than as it was in March 2020, the setpoints for each servo will need to be adjusted using the steps listed below.

1. Make sure the servo is connected to the correct pin.
2. Connect a basic ***Potentiometer*** to the Teensy A19 pin (***Potentiometer*** center pin to A19, left pin to 3.3V, and rightmost pin to ground).
3. Open the main "MQPOOPv1.ino" file.
4. Comment out the content currently in the main loop. DO NOT DELETE!
5. Compile and Run the "manualAdjustServo()" function* found in helperFunctions.h header file with the respective pin information found in the pinSetUp header file. (*Note:

for the ***DSS servos***, simply run the calibration function in the neck class. Be sure to disconnect the servos from the mechanism to prevent damaging the linkages or servos).

6. Turn on the power supply.
7. Open the Serial Monitor to view the angle values.
8. Record the minimum and maximum values for the servo and use these results for the servo positions in the respective header file.
9. If the servo could not achieve the desired range of motion, adjust the servo horn attachment or the connection to its mechanical component.
10. Repeat steps 1-9 for any of the servos that were reinstalled since March 2020.

3.2.4 Camera

Table 19 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 19: Materials needed and estimated time - camera

Component	Quantity
Pixy2 Camera	2
22 AWG Wire	About 25ft or more
Jumper Wires	About 30 of each kind
Blue Latex Glove	1
Total Time	1:45

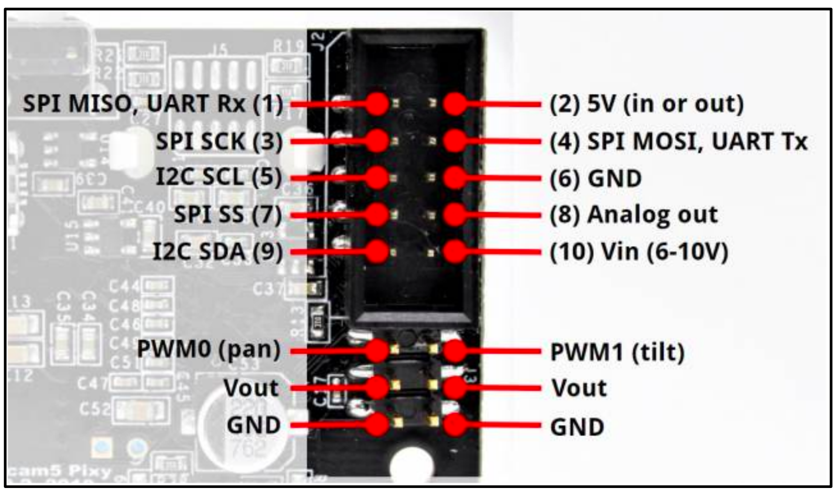
First, the ***Pixy2*** must be set up using the PixyMon software. Visit the PixyMon website to better understand the different elements and settings of the software. Make sure you are in a well-lit environment with a reasonably blank scene in front of the camera.

1. Connect the ***Camera*** to the computer using the provided USB cable and open PixyMon.
2. Put the ***Blue Latex Glove*** on and move it in front of the lens so it is clearly in the ***Camera's*** field of view. Be sure the entire ***Glove*** is in view and also not too far away.
3. Under the Action table, select "Run/Stop" which will freeze the frame with the ***Glove*** in view.
4. Follow the instructions for setting and tuning the signature at Pixy website however several other steps must be taken before confirming the signature.

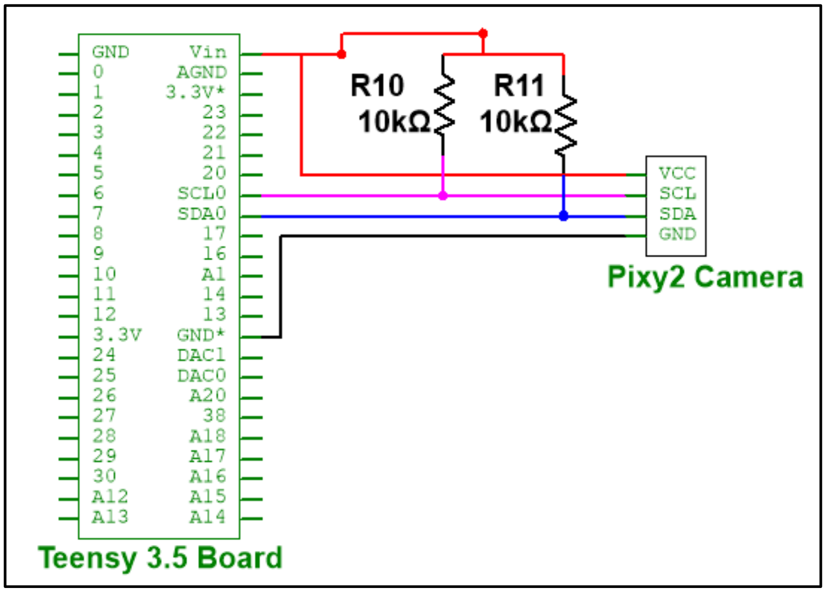
a. First, under the "Expert" tab, set both "Max blocks" and "Max blocks per signature" to 1. This ensures that only one object (the user's hand) is being detected at a time.
b. Next, under the "Tuning" tab, increase the brightness to the maximum value. Then slowly decrease it until you can see the full blue glove. This reduces the chance of other objects of the similar signature from being detected. Make sure to give the signature a label that you will remember (ex. "Blue Object" or "Blue Glove").
c. Apply the settings and select "OK".

5. Test the ***Camera's*** detection capabilities using PixyMon and adjust the settings accordingly until the camera can consistently detect and track the ***Blue Glove***. The LED on the camera should be a strong shade of blue when the camera has detected the glove. All of the settings will be saved to the camera itself.

Now the ***Camera*** works when linked to the computer, it must be connected to the ***Microcontroller*** and the rest of the system. The animatronic will be using I^2C communication so use the I^2C SCL and SDA pins (numbers 5 and 9) as well as the 5V input and GND pins (numbers 2 and 6).



Use ***Female-To-Female Jumper Wires*** to connect the camera to ***22AWG Wire*** that is long enough to reach from the H.A.L.'s forehead, through the ***Neck Enclosure***, to the ***Breadboard*** without the wires coming loose. Note: The current model of the lattice does not feature a slot in the forehead for the ***Camera***. Instead, mount the ***Camera*** to the top of the ***Base Enclosure*** as indicated in Section 2.1.2. Construct the circuit below using the information posted on the PixyCam website and the pinout shown above as a reference.



Once this is set up, run the "cc_i2c_uart" example provided in the Pixy2 library to test the ***Camera's*** settings and capabilities. The LED on the ***Camera*** should light up when it is successfully connected to power. Once the ***Camera*** is working on its own, use the code provided in the "camera.h" header file.

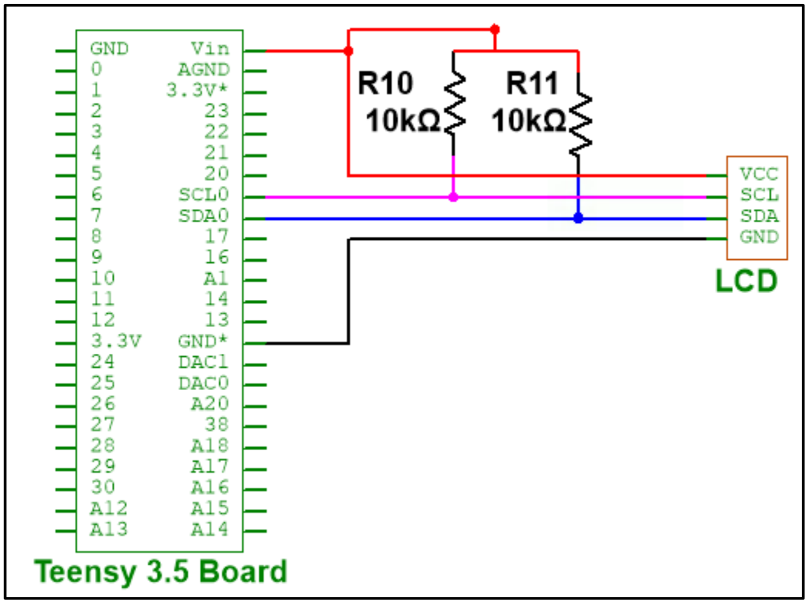
3.2.5 LCD

Table 20 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 20: Materials needed and estimated time - LCD

Component	Quantity
LCD Display and Keypad	1
22 AWG Wire	About 25ft or more
Jumper Wires	About 30 of each kind
Total Time (including kit construction)	1:30

The ***RGB LCD and keypad*** is the basic user interface of the animatronic and the final component that uses I^2C. If the Adafruit kit is not assembled, follow the kit assembly instructions found on the Adafruit website. Once the ***kit*** is fully assembled, install the ***LCD*** on the front of the ***Neck Enclosure*** using the fasteners discussed in Section 2.1 and construct the circuit illustrated below. Use ***Female-To-Female Jumper Wires*** to connect the ***LCD*** to 22AWG wire that is long enough to reach from the front plate, through the ***Neck Enclosure***, to the ***Breadboard*** without the wires coming loose.



With the circuit above assembled, first, run the "HelloWorld" example provided by the Adafruit RGB LCD library to ensure the kit is working properly. Once the ***LCD*** is working on its own, the code in the userInterface.h file can be run.

3.2.6 Force Sensor (FSR)

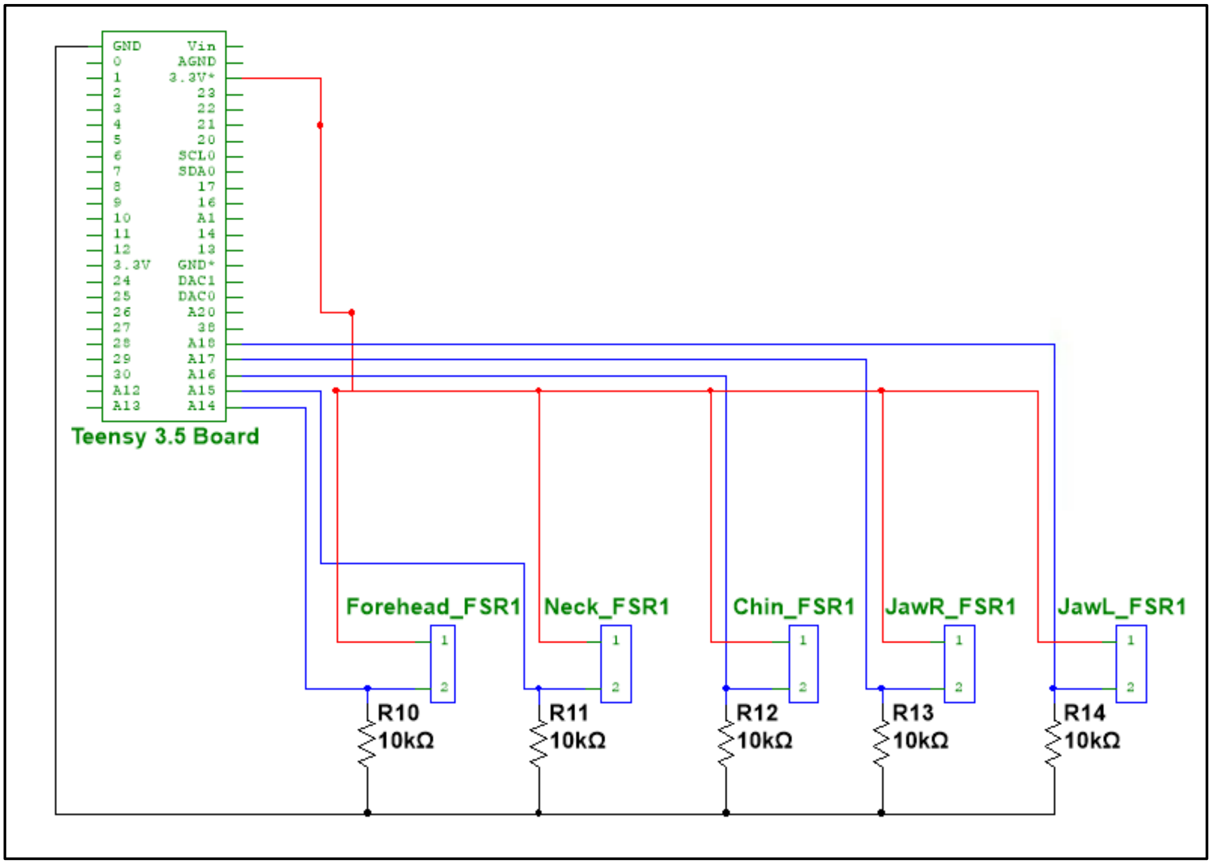
Table 21 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 21: Materials needed and estimated time - FSR

Component	Quantity
Force Sensitive Resistor - Square	2
Force Sensitive Resistor - Round	3
22 AWG Wire	About 25ft or more
10 kΩ Resistors	5
Total Time	1:30

Five ***FSRs*** are used in the animatronic and each change their resistance value depending on the amount of force applied. Each ***10kΩ Resistor*** is placed in a voltage divider circuit to change the voltage read from the ***Teensy's*** analog pins.

1. Solder a wire to each lead of the ***FSR***. The wires should be long enough to reach from the head, through the neck enclosure, to the breadboard without straining any of the parts. Make sure the soldered leads and wires do not touch.
2. Use heat shrink or electrical tape to isolate and protect each connection.
3. Construct the circuit shown below where the two ***Square FSRs*** are for the sides of the neck and the three, ***Round FSRs*** are for the chin and jaw (Helpful tip: these are five different voltage divider circuits with the ***FSR*** as a variable resistor).



Once the circuit is constructed, the ***FSRs*** can be read just like any other analog sensor using Arduino's "analogRead()" function. Set up and test each of the ***FSRs*** using the functions developed in the forceSensor.h file. The sensor outputs values in a range of about 0 - 1000 where the 0 is no force and 1000 is a very large force. The values from 0 - 800 are fairly sensitive. The forehead can be used for the other side of the neck. Rename the variables as needed. One can also use this ***FSR*** in the forehead for the "head-tilt-chin-lift test".

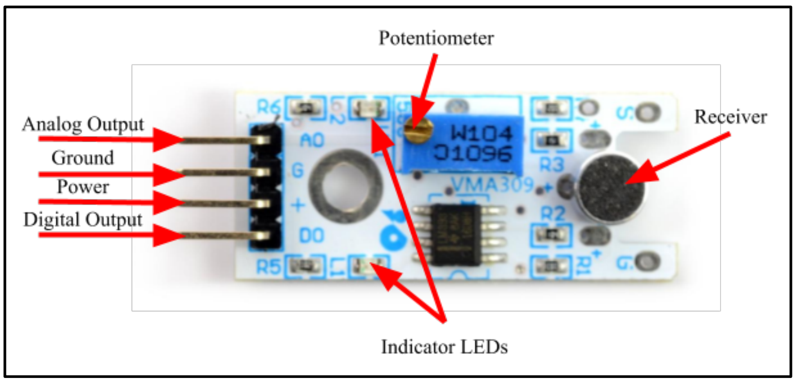
3.2.7 Microphone

Table 22 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

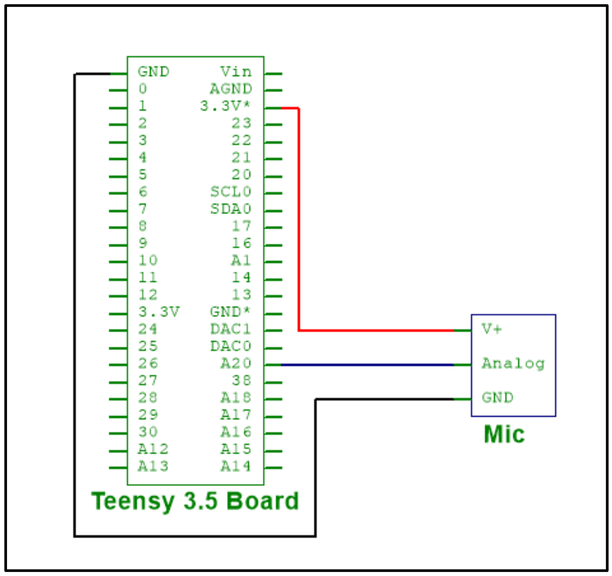
Table 22: Materials needed and estimated time - microphone

Component	Quantity
Microphone	1
Jumper Wires	About 30 of each kind
22 AWG Wire	About 25ft or more
Total Time	1:15

There are four pins used for the ***Microphone Module*** including pins for +5V power, ground, analog output, and digital output as shown below.



The ***Microphone*** has an onboard comparator that compares the voltage from the receiver to an adjusted input voltage set by a built-in potentiometer. The threshold of the comparator's digital output is also adjusted by the potentiometer. The analog output is the voltage as a result of the waveform being passed into the microphone, but the range of raw values are adjusted using the same potentiometer. The digital output pin is not used due to its high sensitivity. Construct the circuit below. Be sure to use relatively long wires when constructing the circuit below because the ***Microphone*** has from the ***Breadboard*** to reach to the user's hand. Place the ***Microphone*** on the table for now.



Once the circuit is completed, manually adjust the potentiometer (use a flathead screwdriver or tweezers) until the comparator output LED blinks on as soon as a person speaks into the ***Microphone***. Open the Serial Monitor in Arduino during this test. The sensor value during should remain about 560 in a silent environment when the calibration is completed. Now, the ***Microphone*** is ready to be used with the rest of the system.

3.2.8 Speaker System

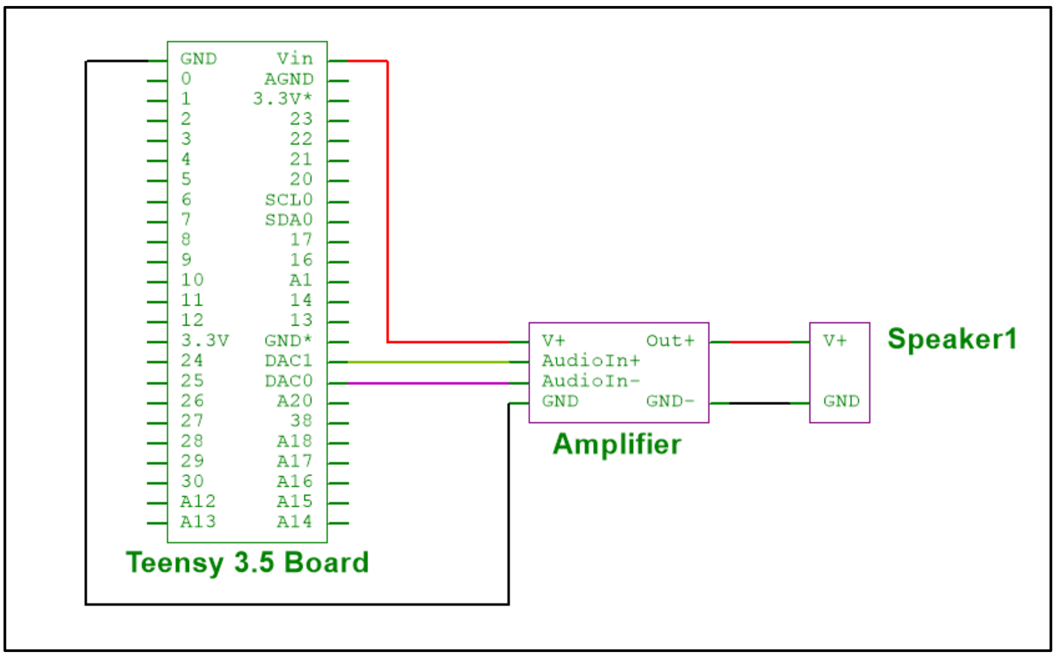
Table 23 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 23: Materials needed and estimated time - speaker system

Component	**Quantity**
8Ω 0.5W Speaker	1
Oiyagai Audio Amplifier Module	1
22 AWG Wire	About 25ft or more
microSD card	1
Total Time	1:15

The ***Speaker*** and ***Amplifier Module*** are used to provide H.A.L. with a voice. The primary component of the ***Amplifier Module*** is the LM386 operational amplifier (op-amp) for amplifying the voltage to the ***8Ω Speaker***. It features an on-board potentiometer to adjust the volume as well.

1. First, cut two wires that are about a foot long. The wire should be long enough to connect the ***Speaker*** and the ***Amplifier*** while both in their respective locations in the acrylic base (see Section 2.1 for details).
2. Solder one end of a wire to the ***Speaker's*** positive terminal and the end of another wire to the ***Speaker's*** ground terminal. Make sure the wires do not touch or you will short the circuit!
3. Construct the circuit illustrated below, making sure the wires can reach the ***Breadboard*** ports.



The Teensy Audio Library is used to play audio files saved on a microSD card through the DAC pins. The audio files follow the requirements below.

- Format: .wav
- Resolution: 16-bit
- Sampling rate: 44.1kHz
- Audio channels: Stereo (two channels)
- File names: All capital letters (ex. "HELLO.WAV")

Many free audio converters can be found online, or other software can be used. [This website] was reliable during the time of this project. The current audio files were for testing purposes only and more advanced, clear and concise recordings should be created. The audio files should be created so it is easier to sync the movements and audio together. Other recordings for added realism such as agonal gasps and or coughing should be developed as well. However, the current files can be used to test the audio.

1. Save the files directly onto the ***microSD Card*** (used adapter for computer if needed). Do not put the files in a subfolder on the card.
2. Download the WavFilePlayerV1.ino folder from the GitHub repository. This is a modified version of the WavFilePlayer example provided by the Teensy Audio Library that can be used with the current configuration.
3. Run this test file.
4. Turn the ***Amplifier's*** potentiometer as needed to adjust the volume and clarity of the audio. The ***Speaker*** is now ready to be integrated with the rest of the system.

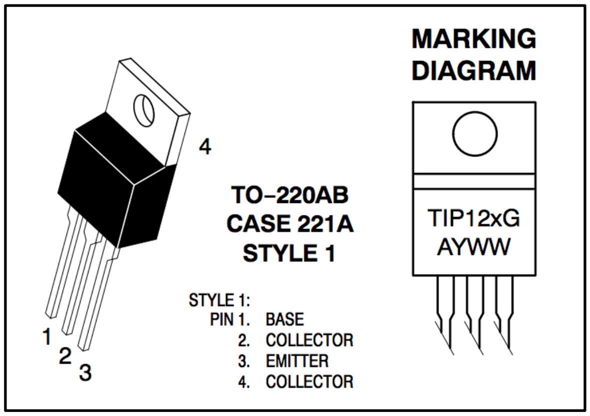
3.2.9 Solenoid

Table 24 lists the components and total time needed to complete this section. Testing may take longer than the indicated time.

Table 24: Materials needed and estimated time - solenoid

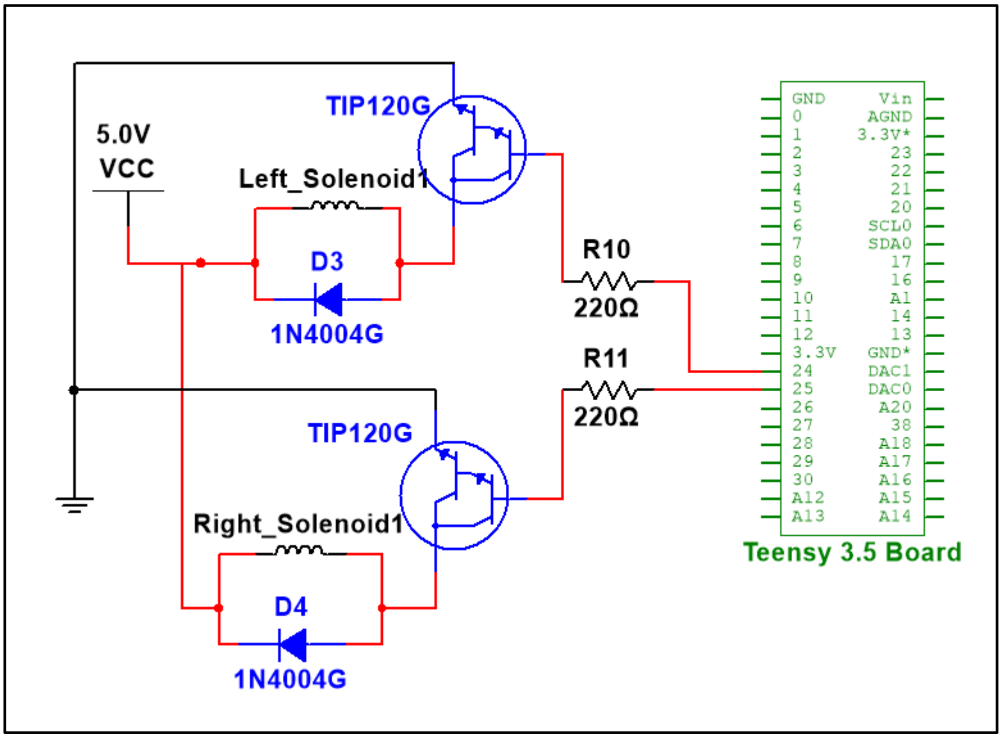
Component	**Quantity**
5V Mini Solenoid	2
TIP120 NPN Transistor	1
1N4004GP Diode	1
220Ω Resistor	2
22 AWG Wire	About 25ft or more
Total Time	1:30

Two ***5V Mini Push-Pull Solenoids*** are used to act as the animatronic's pulse. Each ***Solenoid*** draws 0.5A which is more than the 10mA output from the ***Teensy***. Directly connecting them to the microcontroller would cause the board to malfunction and all other operations to cease. Instead, use Ch. 2 on the variable power supply to provide a separate 5V 1A supply for just the ***Solenoids***. The Base, Collector, and Emitter for the ***TIP120 Transistor*** are labeled below.



Construct the circuit shown below by carefully the following steps. The longer wires in this circuit should only be the two wires originating from the ***Solenoid***. All of the other components should be completely connected to the ***Breadboard***.

1. Connect one of the ***Solenoid's*** wires to the 5V power supply and one to the supply's ground
2. Use the ***Diode*** to connect the two ends of the ***Solenoid*** together (prevents any back EMF from damaging the rest of the circuit!)
3. Connect the digital output pin (either pin 24 or 25) to a ***220Ω Resistor***.
4. Connect the other end of the ***Resistor*** to the base of the ***Transistor.***
5. Connect the emitter of the ***Transistor*** to ground
6. Connect the collector to the anode of the ***Diode***
7. Repeat steps 1-6 for the second ***Solenoid***



Triple check the circuit above to make sure none of the components break. Once the circuit is set, the ***Solenoids*** can be tested using the basic "digitalWrite" Arduino function in the main loop as shown in the pseudocode below.

```
void loop() {
   digitalWrite(solenoidPin,HIGH);
   delay(1000);
   digitalWrite(solenoidPin,LOW);
   delay(1000);
  }
```

The code above is essentially the Arduino Blink example that is modified for a ***Solenoid***. If the ***Solenoid's*** are acting in opposite directions, simply switch the ***Solenoid*** wires to correct the polarity. Once the basic test is completed, test the circuit using the code in the pulse.h file. The pulse is now ready to be integrated with the full system.

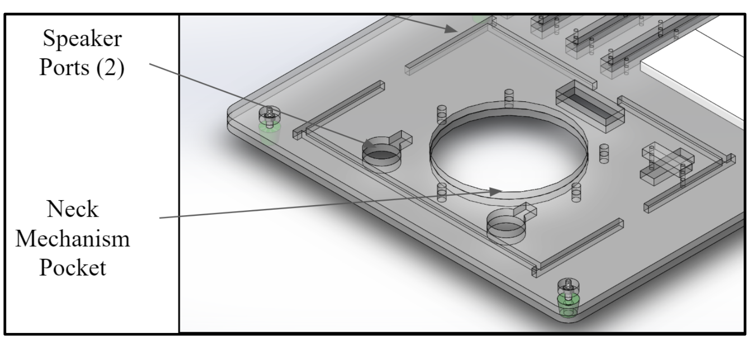
Chapter 4: Complete Assembly

This chapter will cover the full assembly of the animatronic including previously made mechanical and electrical subcomponents. The assembly pictures in this section do not include sensors or electrical components. Please refer to Section 3.2 for the circuit diagrams and pin numbers. Servo wires should be fed through the respective holes in the lattice, through the top of the neck enclosure and the rectangular hole designated in the base, through the respective labeled channels, and to the servo drivers. Exceptions include the neck servos (***DSS servos***) which can be fed directly out the hole in the back plate to the labeled channels. All other wires for the ***LCD***, ***Speaker System***, ***FSRs***, and ***Camera***, must be fed out the hole in the back plate to the breadboard. Use tape to organize each set of wires and to secure them to the insides of the neck enclosure.

Hardware Required:

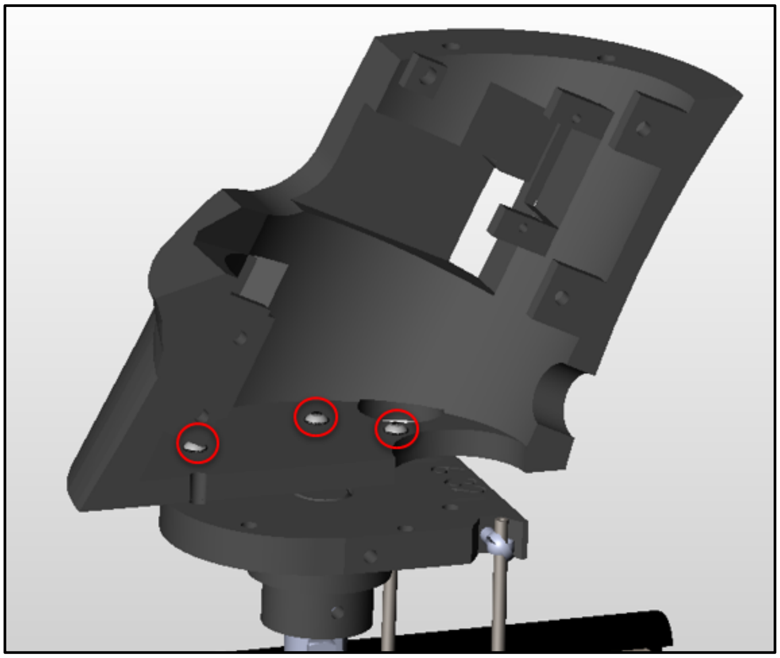
- (25) 4-40 ¾” Button Head Hex Drive Screws [link]
- (2) 4-40 ⅜” Button Head Hex Drive Screws [link]
- (17) 4-40 Nylon Insert Lock Nuts [link]
- (4) M2x0.4mm 10mm Button Head Hex Drive Screws [link]
- (4) M2x0.4mm Nylon Insert Lock Nuts [link]
- (10) 4-40 0.188” Brass Screw-to-Expand Inserts [link]

1. Connect the ***LCD Display*** to the designated mounting holes in the front plate using four ***4-40 1” Socket Cap Screws***. Make sure the header pins can fit through the thin rectangular slots without any interference. Complete the circuit listed in Section 3.2.5 while keeping the wires secure and organized.
2. Place the ***Speaker*** in its designated slot on the left side of the ***Acrylic Base***.
3. Place the ***Amplifier Module*** in its rectangular cutout in the base. Use ***4-40 1” Socket Cap Screws*** and the ***Rectangular Acrylic Piece*** to secure the module.

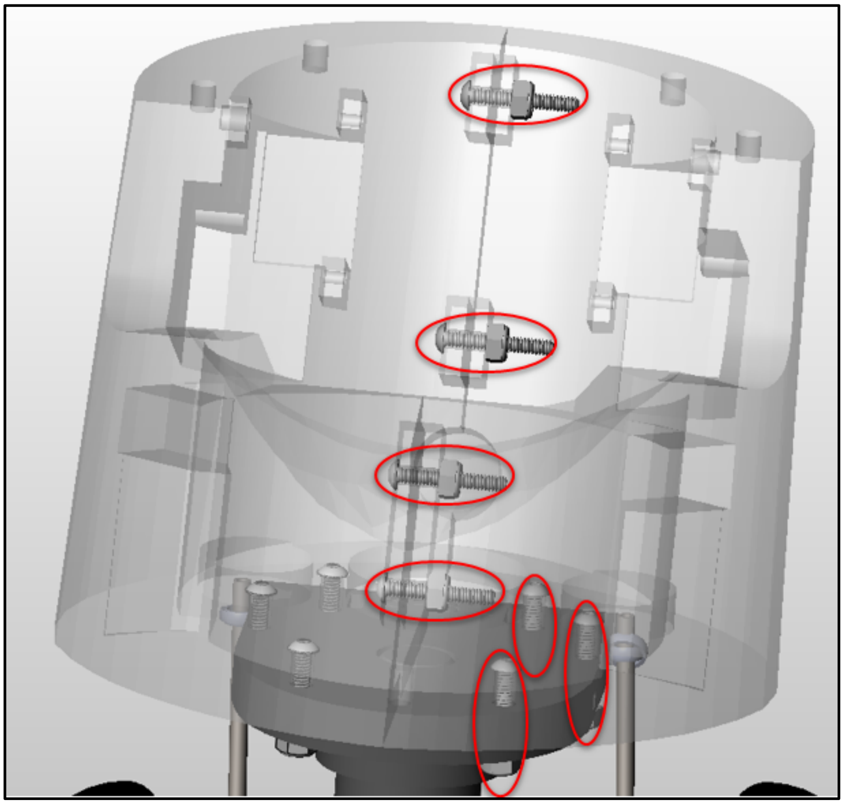


4. Complete the ***Speaker*** circuit listed in Section 3.2.8 while keeping the wires secure and organized.

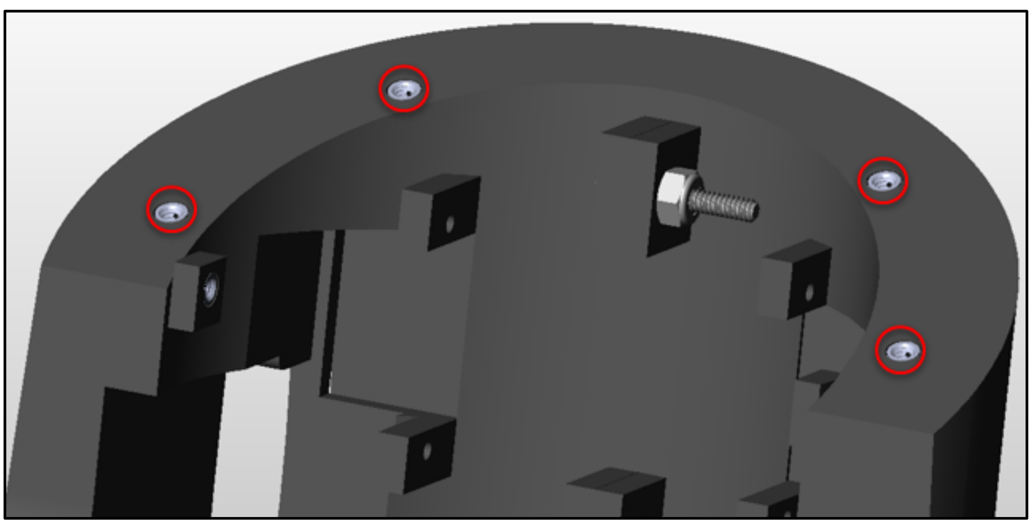
5. Attach the ***Right Neck*** lattice piece to the ***Head/Neck Interface*** using three ***¾" 4-40 Screws*** and three ***4-40 Nylon Lock Nuts***. Face the threaded portion of the screw downward. The circular hole cut out on the bottom of the neck lattice should be nearest the straight edge of the head/neck interface. This is shown below.



6. Place one of the ***Solenoids*** in the designated mounting cutout in the ***Right Neck*** lattice piece.
7. Feed the two long wires from the ***Solenoid*** to the ***Breadboard*** and to create the circuit found shown in Section 3.2.9.
8. Place one ***Square*** neck ***FSR*** in the mounting location in the ***Right Neck*** lattice.
9. Feed the two long wires from the ***FSR*** to the ***Breadboard*** using the circuit in Section 3.2.6 as a reference.
10. Attach the ***Left Neck*** lattice piece to the ***Right Neck*** lattice piece using four ***¾" 4-40 Screws*** and four ***4-40 Nylon Lock Nuts***. At the same time, attach the ***Left Neck*** lattice piece to the ***Head/Neck Interface*** with three ***¾" 4-40 Screws*** and three ***4-40 Nylon Lock Nuts*** using the same process as Step 1.

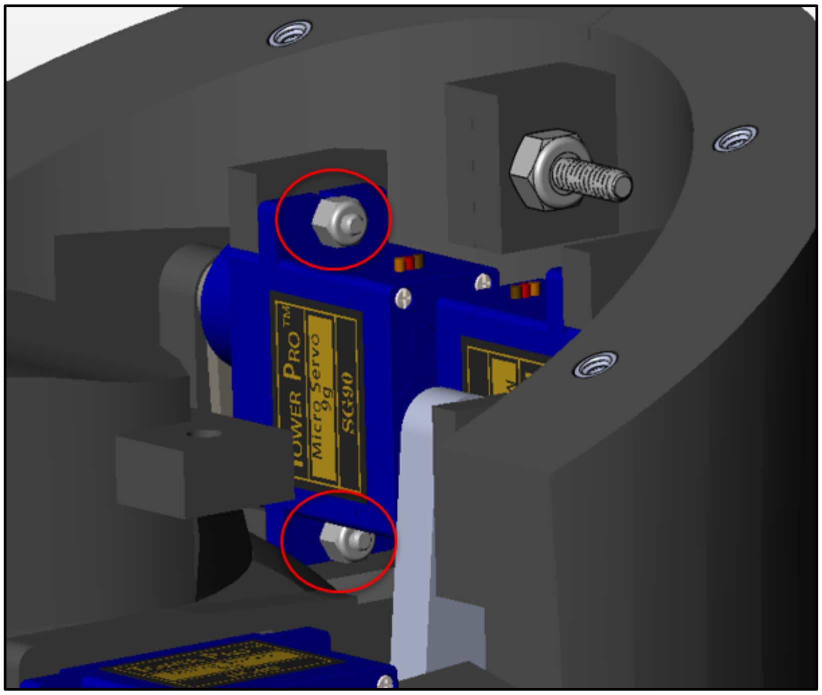


11. Insert six ***0.188" 4-40 Brass Screw-to-Expand Inserts*** to the ***Right Neck*** and ***Left Neck*** lattice pieces in the positions designated in the figure below.

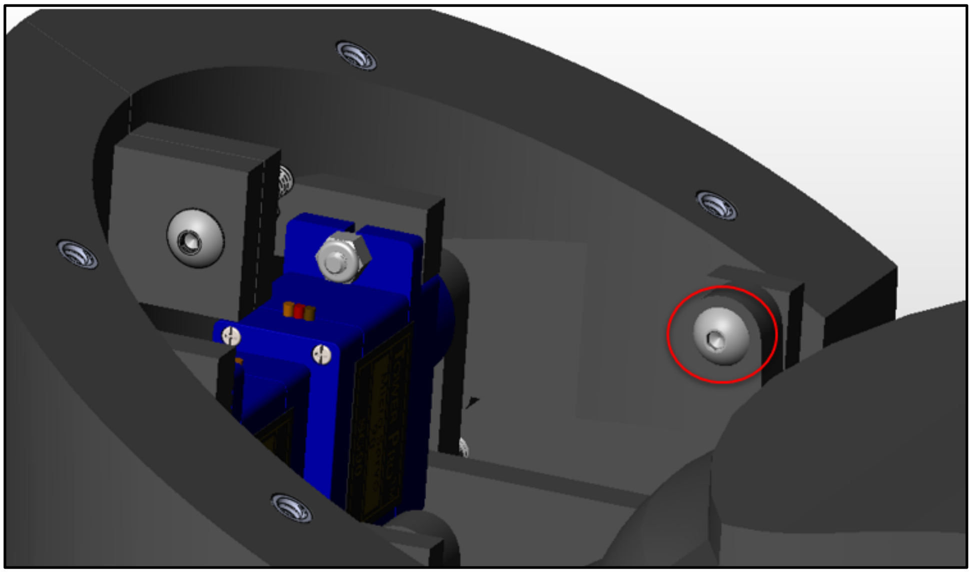


12. Place the second ***Solenoid*** in the designated location in the ***Left Neck*** lattice piece.
13. Feed the two long wires from the ***Solenoid*** to the ***Breadboard*** and to create the circuit found shown in Section 3.2.9.
14. Place the other square neck ***FSR*** in the mounting location in the ***Left Neck*** lattice.

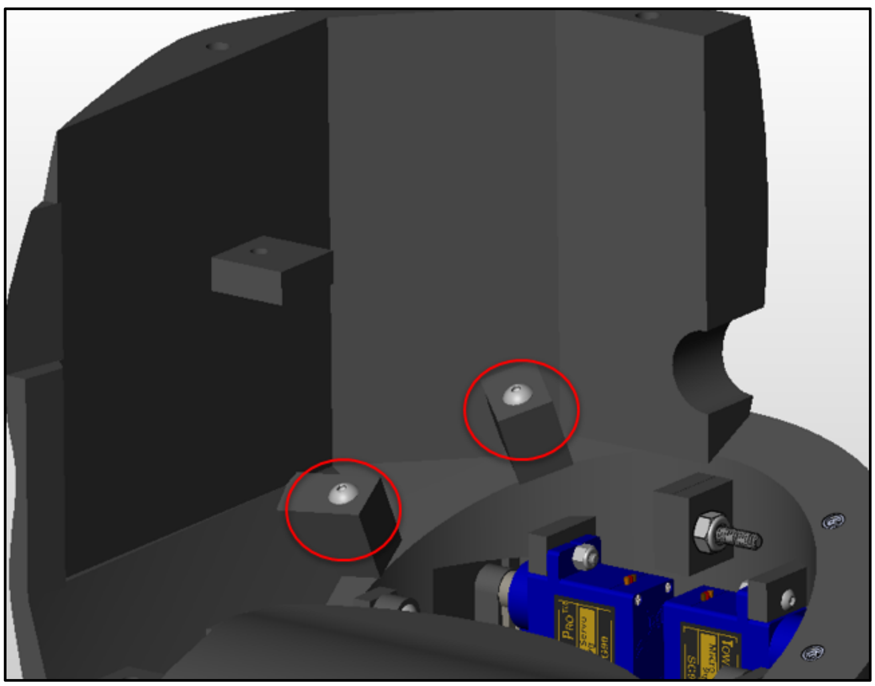
15. Feed the two long wires from the ***FSR*** to the ***Breadboard*** using the circuit in Section 3.2.6 as a reference.
16. Attach the already assembled ***Oral Cavity*** from Section 2.4.2
    a. Using four **M2x0.4mm 10mm Screws** and four ***M2x0.4mm Nylon Lock Nuts***, attach the thrust servos to the neck lattice servo tabs. Face the screws inward. The right-side servo attachment is shown below. The left side must also be fastened.



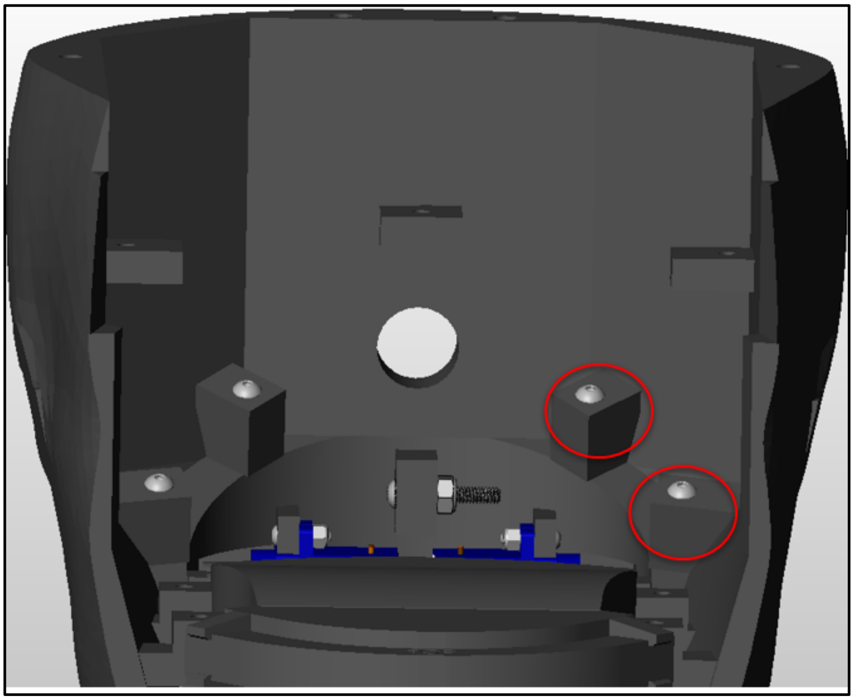
    b. With two ***⅜" 4-40 Hex Screws***, pin the ***Follower Links*** to the **Neck Lattice**. This is shown for the left link below. Feed the oral cavity wires through the hole at the bottom of the back side of the neck lattice.



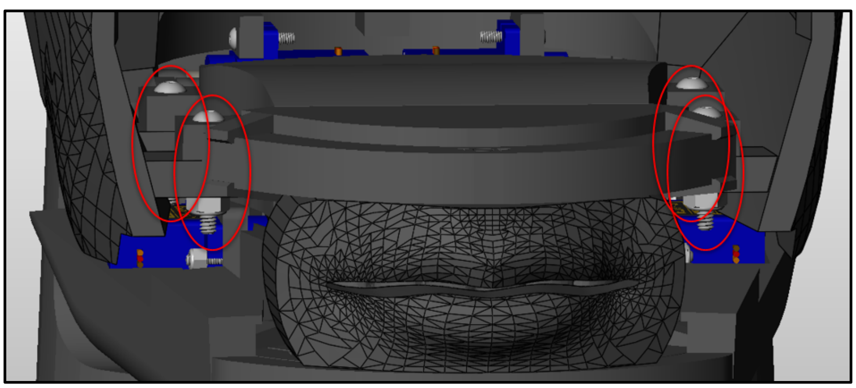
17. With two ¾” **4-40 Hex Screws**, attach the ***Right Head*** lattice piece to the ***Right Neck*** lattice through the head lattice tabs. The screws are driven into the previously installed threaded inserts on the top of the neck lattice. This is shown below.



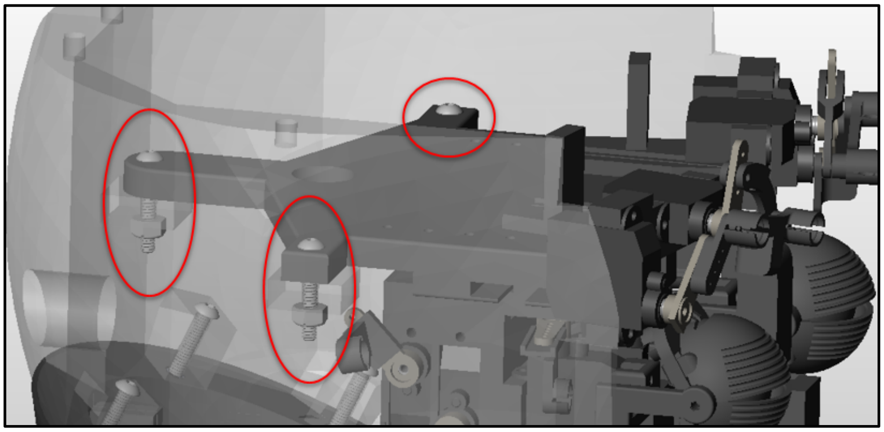
18. Using the same procedure and hardware as Step 18, attach the ***Left Head Lattice*** to the ***Left Neck Lattice***.



19. Now that the head lattice is in place, attach the ***Hard Palate*** to the lattice using four ***¾” 4-40 Hex Screws*** and four ***4-40 Nylon Lock Nuts*** through the four hard palate tabs. This is shown below.

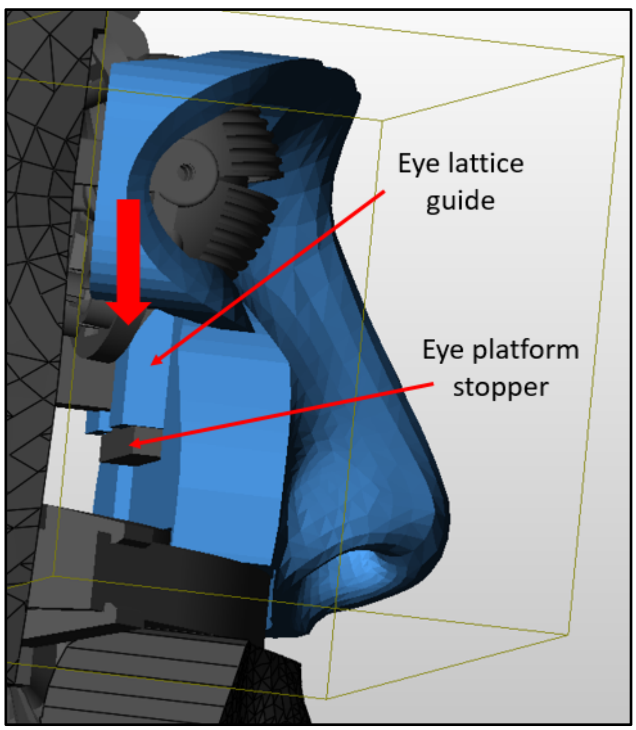


20. Lower the completed ***Eye and Eyebrow Assembly*** from Section 2.6.2 into the head and attach it to the head lattice using three ***¾” 4-40 Hex Screws*** and three ***4-40 Nylon Lock Nuts***. This is shown below.

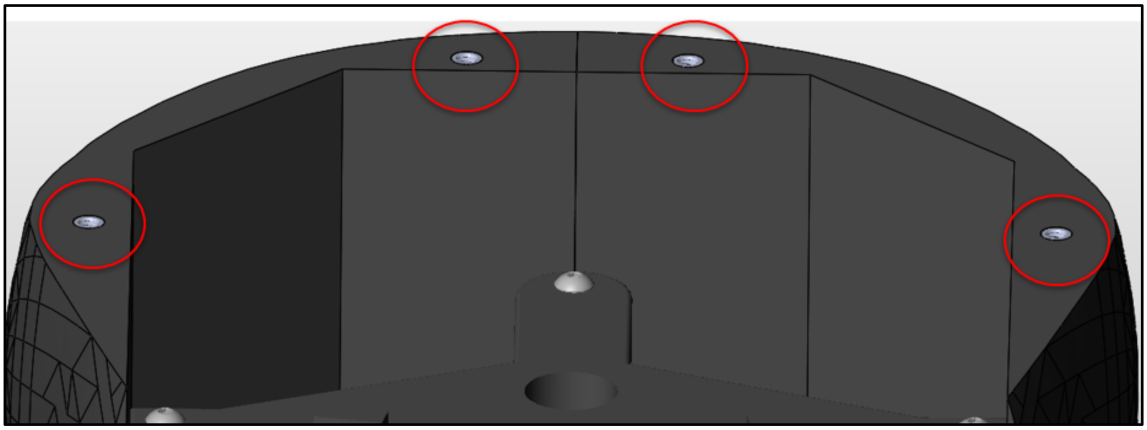


Thread the eyebrow wires through the hole on the ***Central Platform*** and then through the hole in the back of the head lattice. Thread the eye wires though the hole in the back of the head lattice.

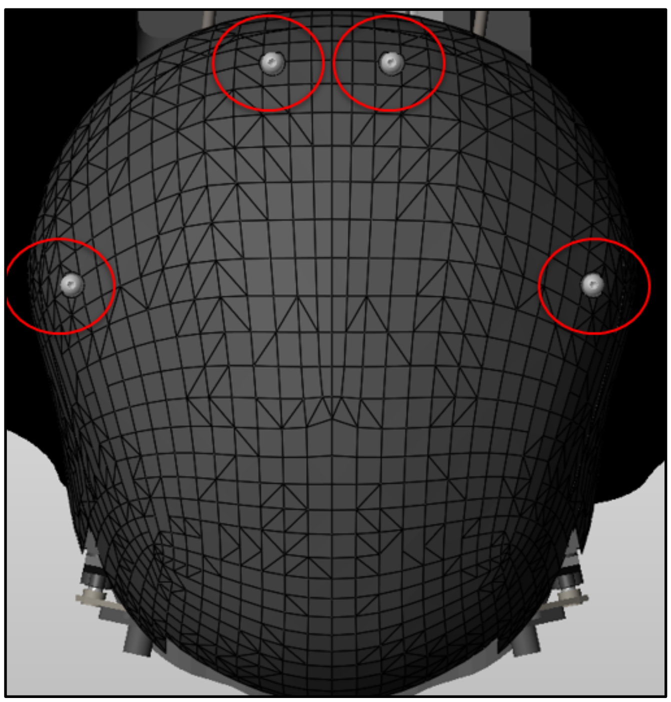
21. Slide the ***Eye/Nose*** lattice piece onto the eye and eyebrow ***Central Platform*** as shown below.



22. Install four ***0.188" 4-40 Brass Screw-to-Expand Inserts*** to the top of the head lattice as shown below.

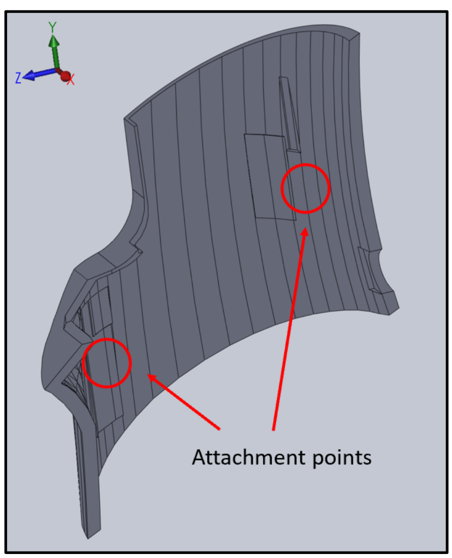


23. Using four ***¾" 4-40 Hex Screws***, attach the ***Top Head*** lattice piece to the screw-to-expand inserts from Step 23. This is shown below.

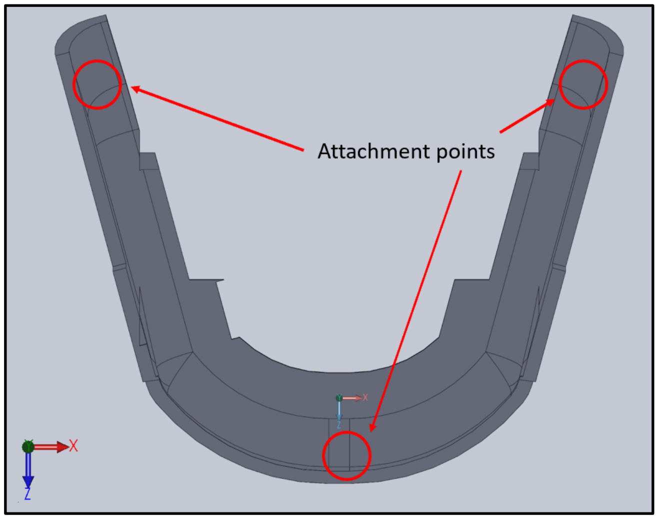


The final CAD assembly of Steps 1-24 is shown below, excluding any electronics and sensors.

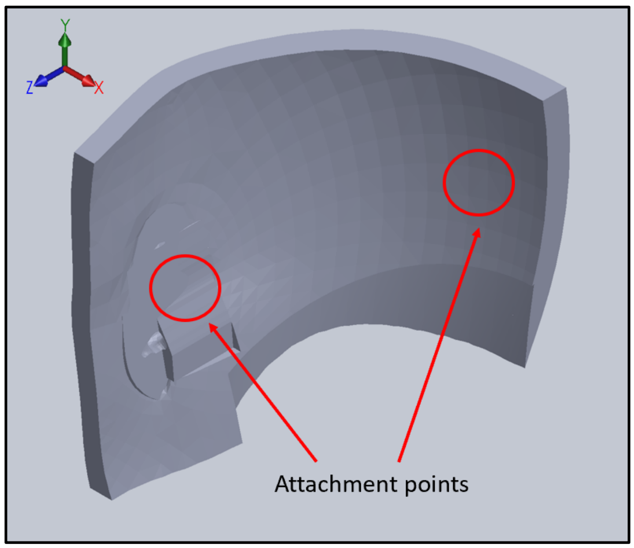
24. Connect the ***Camera*** to this location as well using the brackets in the Pixy2 package to help. Feed the wires connected to the ***Camera*** through the opening in the ***Neck Enclosure*** and out the hole in the back plate (see Section 3.2.4 for camera details). Complete the circuit while keeping the wires secure and organized.
25. Connect the ***Microphone*** by following the steps in Section 3.2.7.
26. Attach the skin in the order and manner shown to the underlying lattice using Velcro.



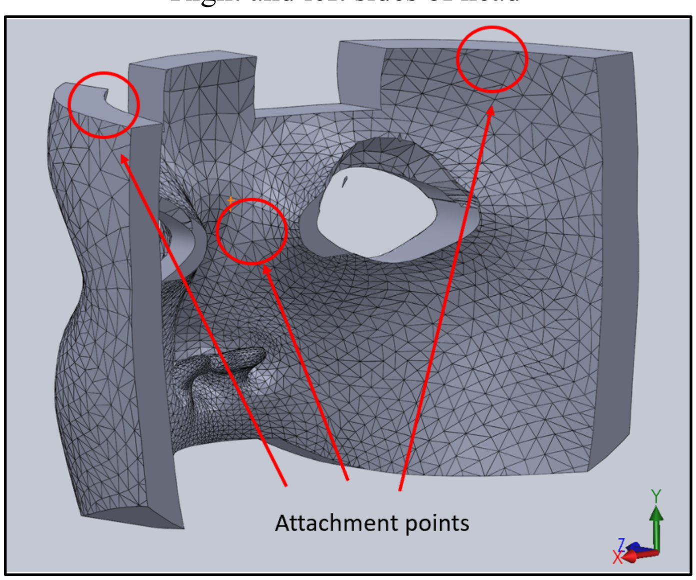
Right and left neck skin



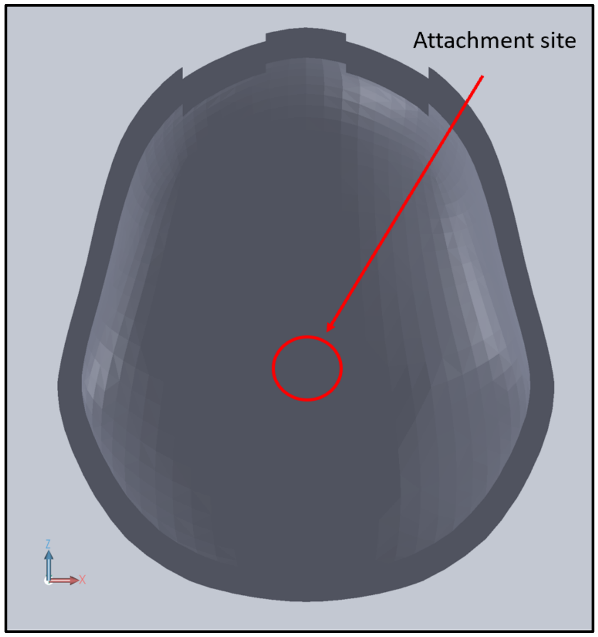
Jaw skin



Right and left sides of head



Face skin



Crown skin

Chapter 5: Operation

This chapter describes how to operate H.A.L. once the entire system is assembled. Before running any tests, double check the circuit diagrams listed in Chapter 3 to ensure the power is connected to the system correctly. Check that all mechanisms are secured as described in Chapters 2 and 4. Make sure there are no obstacles in front of any of the parts or sensors.

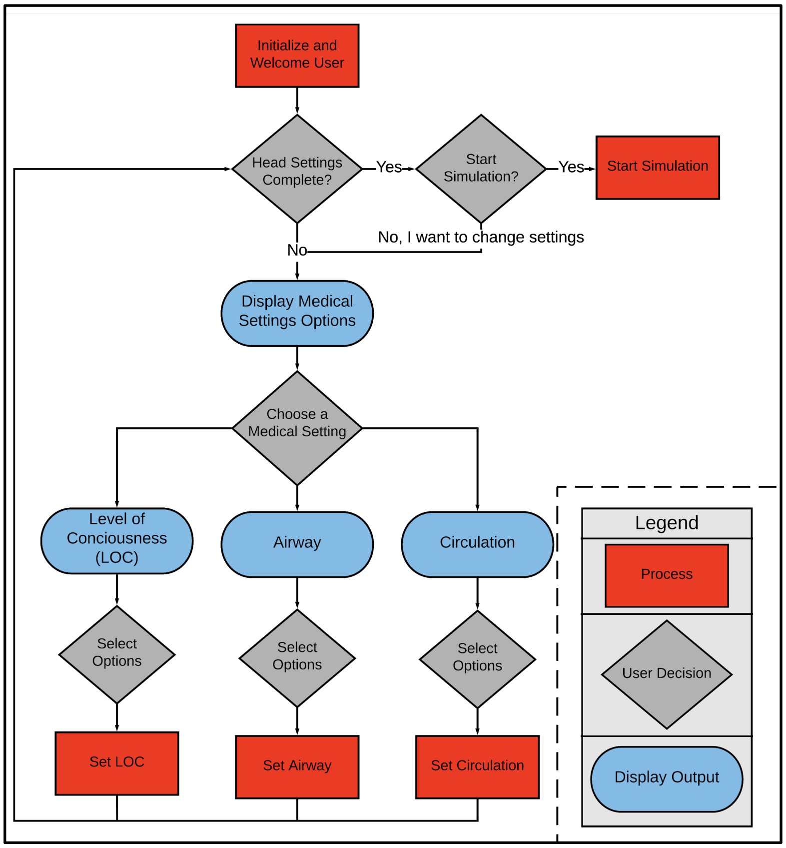
5.1 Powering On

1. Turn on the power supply (make sure the output is OFF).
2. Use the respective dials to set Ch. 1 to 7.2V with 1A and Ch. 2 to 5V with 1A.
3. Connect the banana plugs or alligator clips to the power supply and make the respective connections to the breadboard (ex. Ch. 1 to the 7.2V strip).
4. Turn the output to (ON).
5. As the operation proceeds, occasionally check the power supply's voltage and current readings for any problems.

5.2 Inputting Settings

Below are some notes to keep in mind when using the user interface. The flow chart below shows the different menus in the UI.

- If you cannot see the screen, first check the wiring connections. Then, turn the built-in potentiometer to adjust the contrast until you can view the options.
- Use the arrow keys to move the cursor.
- Move the cursor over the first letter of an option you wish to select.
- Press the select button to confirm the choice.
- Be careful when pressing each button to avoid the button being read multiple times. Button debouncing is built into the LCD library but it is not perfect.
- Select "Y" for yes, and "N" for no.



As shown above, the UI "main menu" consists of the three settings options: LOC, Airway, and Pulse.

1. Set the level of consciousness by selecting "LOC". This displays the different letters corresponding with each level of the AVPU scale as shown below.
2. Select "A" to set the LOC to the alert, "V" for verbal, "P" for pain, or "U" for unresponsive.
3. Set the irregular pulse by selecting the "Pain" LOC. This will override any pulse setting.

The screen displays a message informing the user the LOC is set (shown on the right above) and then returns back to the main menu since there are still some settings that are incomplete. Select an airway state based on the available options listed below (the general format is shown below on the left).

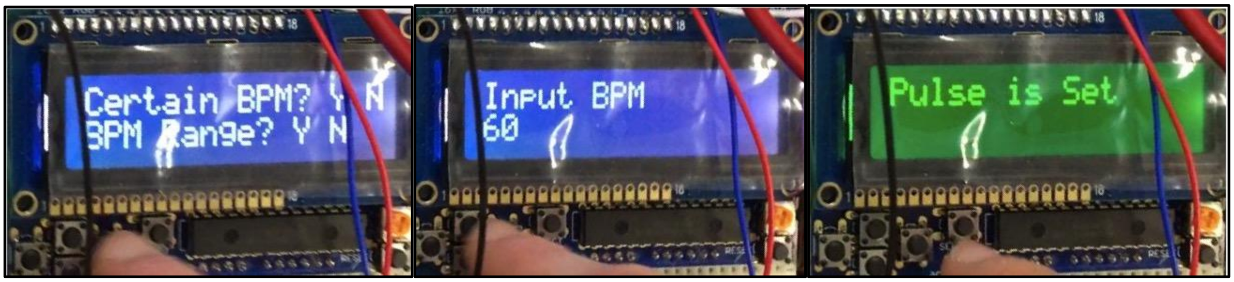
- Normal airway
- Lock jaw
- Agonal gasps
- Irregular Breathing
- Stridor Breaths

Once the options are chosen, the screen displays the confirmation, shown below on the right, and returns to the main menu.

The final setting is for the circulation assessment which involves setting the pulse's rate as shown in the figures below.

1. Set the pulse by selecting a specific BPM value or by a general range

2. If setting for a specific BPM press the up or down arrows to increase or decrease the rate by 1BPM.
3. If setting for a general range, select slow, normal, or fast.
4. Note: Even if irregular pulse was chosen by selecting the "Pain" LOC, the UI still requires a pulse input. This will be overridden by the LOC so just choose any selection.



Once all settings are configured, the user is asked if they want to start the simulation as indicated below on the far left.

1. If you don't want to start the simulation, select no.
2. Select the medical setting (LOC, Air, or Pulse) to change.
3. Select yes to confirm you want to change the settings or no if there was a mistake.
4. If you want to start the simulation, select yes. The screen will signal that the simulation has begun.

5.3 Run Simulation

The current simulation is a combination of all three tests: level of consciousness (LOC), airway, and circulation. The LOC test is completed first by following a defined script (see details in Section 5.4). Once the test is completed, the animatronic will be in "idle mode", meaning the animatronic will exhibit the same responses and movements until it is unplugged from the power source. During this time, the airway test and circulation tests can take place since the system will still be using the settings inputted by the user.

5.4 Level of Consciousness (LOC) Test

Given the sensor capabilities, the LOC test is conducted by following a defined script. This can be adjusted in future iterations to allow for more verbal communication, additional responses, and a more detailed test. The code provided runs through the steps listed below before ending the LOC test. Be sure to read Section 5.4.1 and 5.4.2 for details on how to best use the microphone and camera during the LOC test.

1. Input the settings and start the simulation (see Section 5.2).
2. Use the microphone to introduce yourself to the patient and ask how they are doing (H.A.L is listening for there to be input into the microphone).
3. Once H.A.L. hears the input, he will wait until you are done speaking to respond.
4. H.A.L. will respond based on the LOC that was set.
5. Use the microphone to ask H.A.L. to follow your hand.
6. H.A.L. will respond and follow the glove based on the LOC that was set.
7. Once the hand is out of frame long enough, H.A.L. will be in “idle” mode.
8. Complete the airway and circulation tests.

5.4.1 Using the Microphone

1. Carefully pick up the microphone from the table or the acrylic base before the simulation starts. The microphone might detect excess noise as it is lifted off the table or if it is bumped on its way off the table.
2. Hold the microphone carefully by the edges of the module board (do not touch the circuit board itself) or at the connection from the female-to-female jumper wires and the module header pins.
3. Do not touch the potentiometer. Once the microphone is calibrated (see Section 3.2.7), the potentiometer should not move otherwise the readings will be wrong and the test will not work.
4. Watch the wires! If a wire is unplugged, the device will not work properly. Make sure the wires are not shorting the circuit.
5. Hold the microphone about five inches away from your mouth to detect your entire dialog and speak at a normal volume. If the microphone is too far away, it may stop detecting your speech too early and the H.A.L. may respond prematurely. If the microphone is too close or you are speaking too loudly, the device may be damaged.
6. When you are done, carefully place the microphone back on the acrylic base so the sensor is not damaged.

5.4.2 Using the Camera

1. Make sure the connections from the jumper wires to the camera and the wires to the breadboard are secure. Loose wires will cause the camera to lose its connection.
2. Do not wear clothes that have a strong blue color on them. Otherwise, the camera may detect the clothes the eyes will jump between following the hand and the other clothes. Wear a white lab coat if possible.
3. Check the surrounding environment that the camera will be able to see and remove any objects that have a strong bluish hue. This further reduces the chance of the camera detecting other objects instead of the hand.
4. Make sure there is nothing interfering with the camera's field of view (ex. lattice parts, loose wires, etc.).
5. Keep the glove about three or four feet away from the camera. If the glove is too far away, there is risk the camera may no longer detect it. If the glove is too close, the blue color may appear darker to the camera and it will not be detected. The camera may also detect the object is multiple locations of the screen and the eyes may jump around between these points. It may also make the patient feel uncomfortable.
6. Make sure to move the glove completely out of the field of view to complete the "follow the hand" test. H.A.L. will keep tracking the glove until it has left the field of view. Use the PixyMon software to see the camera's view (see Section 3.2.4 for details).

5.5 Airway Test

Note: The reactions for this specific test have not been completely developed. Further addition to the existing code must take place for this test is to be completed as desired. Not all airway features have been integrated into the current system.

The airway can be tested by trying to perform the "head-tilt-chin-lift" and jaw thrust maneuvers. This will ensure the airway can be opened. Head-tilt-chin-lift is performed by placing one hand on the chin and one hand on the forehead. The head is tilted back while the chin is lifted. The jaw thrust maneuver is performed by hooking fingers under the curved part of the jaw beneath the ears on both sides and pushing forward. Once the airway has been opened, an oropharyngeal airway (OPA) can be inserted to test simulation capabilities. Further airway testing can be performed by attempting to ventilate the head with a bag-valve mask and checking for equal, bilateral rise of the simulated lungs.

5.6 Circulation Test

Note: While the solenoid was successfully tested on its own, the pulse has not been tested through the TPU skin at the time of this manual's completion. This must be completed before conducting final circulation tests.

The pulse can be tested by checking if the solenoid is palpable through the skin in the neck. The solenoid will actuate at the rate that was previously set (see Section 5.2). This can be either an exact BPM or a rate within one of the ranges listed below.

- Slow (10BPM - 60BPM)
- Normal (60BPM - 100BPM)
- Fast (101BPM - 220BPM)

As discussed in Section 5.2, the irregular pulse is set by selecting the "Pain" LOC, which overrides any other pulse setting. This will actuate the solenoid in a random pattern that can be felt through the skin.

5.7 Powering Off

Once the LOC test has been completed, the system will be in an "idle" state. If you wish to complete airway or circulation assessments, those can be completed as well. Once all the tests are done, the output from the power supply can be turned off which will shut off the servos, and solenoids. The sensors are still powered by the Teensy, which can be shut off by disconnecting the USB cable from the computer. Make sure to turn off the power supply before disconnecting the microcontroller.

Chapter 6: Troubleshooting

Below is a list of common problems you may come across while working with H.A.L. and the corresponding solutions that will make him work again. Remember to follow safe circuit debugging protocols if you are adjusting an electrical part by turning off the output from the power supply before changing the circuit.

Table 25: Troubleshooting problems and solutions

Problem	Solution
The Teensy board is not displayed in the “Port” menu in the Arduino IDE.	Make sure the Teensy Loader is correctly installed on the computer. If so, press the reset button on the Teensy. If the Teensy is still not registering, power cycle the microcontroller (unplug it and plug it back in).
There is a compile error saying there is a conflict in the libraries, and it won’t fix itself.	Move, rename, or delete the conflicting Arduino libraries so only the Teensy libraries are used.
The program compiles but won’t load properly.	Press the reset button on the Teensy to “manually program” the Teensy. If the Teensy is still not registering, power cycle the microcontroller (unplug it and plug it back in).
The backlight is on but nothing displayed on the LCD.	Double check the circuit. If the circuit is complete, slowly turn the built-in potentiometer to adjust the screen contrast.
The LCD is flashing on and off with the solenoid actuation.	Turn off the power! Make sure to have the LCD powered by the Teensy 5V output not the power supply. The 5V power supply is only used for the solenoids.
The LCD said a setting “is set” but I didn’t see the options.	Make sure you press the “Select” button only once and confidently, so the button press is not detected twice. If this is a recurring problem, add an additional function for button debouncing.

Nothing at all is moving.	Check that everything is connected to the correct power source and the power is on. The correct power connections are: ● 7.2V power supply connect to servo drivers ● 5V power supply connects to solenoids. ● 3.3V generated from the Teensy port. ● Power the Teensy via USB to the computer.
The servos are not moving and are not trying to move.	Check to make sure the wires are connected in the appropriate orientation. If they still do not move, check to make sure none of the extension cables came loose. Check for any frayed wires and replace them with new cables. Finally, check the code you are running to see if it's actually commanding the servos to move.
The servos are not moving but sound like they are trying to move.	Turn off the power. Check the component to see if there is any interference with another mechanism. Check the voltage and current settings on the power supply channel connected to the Servo Drivers. Check the servos are connected to the correct pins on the driver. The wrong servo is being told to move to a position. Check the code to make sure the correct servo type is being used and the pin numbers are correct as well.
The LED on the camera is not on.	Check the wiring in the circuit diagram from Section 3.2.4 as a reference. The camera should be receiving 5V from the Teensy.
The camera is on but the eyes are not following the glove.	Remove any obstructions that are in front of the camera lens. Check the surrounding area and remove any objects of a blue color that the camera might detect. Check the camera is using the settings listed in Section 3.2.4.

The eyes are jumping around when I try to have them follow my hand.	Check the camera is using the settings listed in Section 3.2.4. If the eyeball servo positions have changed since March 2020, check the conversion from “pixel” to “head” coordinates.
The microphone indicator LED is not turning on.	Run the “micTest()” function in the main loop and adjust the potentiometer as described in Section 3.2.7.
H.A.L. is reacting to my voice before I finish talking.	Run the “micTest()” function in the main loop and adjust the potentiometer as described in Section 3.2.7. Make sure you do not pause longer than 3.5 seconds between your sentences. If you are a slow speaker, adjust the 3.5 seconds in the code (see comments in the code for details).
I am testing the FSR on its own and it's not detecting any force.	Check to see if there is a strong soldered connection. Make sure the FSR is not disconnected from the breadboard. Check the circuit diagram shown in Section 3.2.6 and make sure the resistors are connected correctly. Make sure the pinMode is “INPUT” in the code.
The FSR works during the tests but the linkages keep getting stuck as H.A.L. moves between motions.	If there is not one already, add an intermediate state in the FSR test code that moves the mechanism into an intermediate position so there are no mechanical collisions.
The solenoids are not actuating.	Turn off the power. Make sure the wires have not come loose from the breadboard. Check the instructions and circuit diagrams in Section 3.2.9.
The solenoids are very hot.	Turn off the power! Check the power settings on the supply is at 5V, 1A for the solenoids. Make sure the diode is in the correct orientation

	to prevent any back EMF.
I cannot hear the audio recording coming from the speaker.	Check the circuit diagram shown in Section 3.2.8. Turn the built-in potentiometer on the amplifier to adjust the volume. Try swapping the wires connected to the DAC0 and the DAC1 pins.
The audio has a lot of noise.	Check the circuit diagram shown in Section 3.2.8. Turn the built-in potentiometer on the amplifier until there is a clearer output. Check the recording is in the proper format (see Section 3.2.8). Make the recording again in a less noisy environment.
3D Prints are not printing as they should.	Slow print speed to recommended values (outlined through Chapter 3).
The through holes in 3D printed parts are too small.	Apply force using an arbor press or vice to have parts press-fit through. If mate should be somewhat flexible, make hole larger in modelling software. 3D printers make holes about 0.012” below nominal.
Screws are not securing 3D printed parts	Reprint the part with a slightly smaller hole (-0.005”)
The lip snap joints do not fit.	File down the beveled ledges on the lips and remove any extraneous accidental PLA on the cantilever snap fit beams.
The lips provide too much resistance.	Cut the inside of the lips down to make them thinner. Cut along the attachment point between the lips and the ledges to allow for more “free material” to stretch with the jaw.
The servo horns interfere with the connection between the input link and the triangle link.	Cut the servo horns to a length that still allows them to be pinned.

Appendix: Full Circuit Diagram