

2025-2026 Smart Prosthetics CDR



ME 486A - Dr. Peter Bishay

9th Cohort Team Members:

Abdulrahman Al Dulaimi, Jorge Alvarez, Justin Brown, Cesar Flores Velasquez, Nathan Handal, Chris Lopez, Vanessa Montejano, Hao Phan, Matthew Portillo, Sergio Rivas, Kainen Shaw, Yaroslav Tretiak, Kurt Trocino, Katsuki Yasuda



Agenda

- Problem Statement
- Arm Design
 - History
 - Hand, Forearm/Actuation, Attachment Design
- Foot Controller System
 - History
 - Current design
 - Neural networks
- Haptic Feedback
 - History
 - M.I.D.A.S. Haptic system
- Q&A



Problem Statement

- Most prosthetics are made for amputees and can't be used by people with temporary arm or shoulder injuries.
- They are often expensive and not ideal for short-term use or rehab.
- They often rely on EMG control, which can be unreliable due to skin or muscle issues.
- Few provide real sensory feedback, and those that do give a limited response.
 - Vibrotactile (vibrations)
 - Electrotactile (electricity)

General Cohort Goals

- Create a lightweight, modular robotic arm that can be used as a:
 - Wearable Third Arm
 - Shoulder-and-Below Prosthesis
- Fast attach/swap: one-handed, tool-free connections
- Controlled by a user-friendly foot controller
- Provide users with haptic sensory feedback

What is currently on the market?



Kinova Assistive: Jaco Arm

- Third arm system targeted for wheelchair users
- Controlled with joystick

Jizai Arms

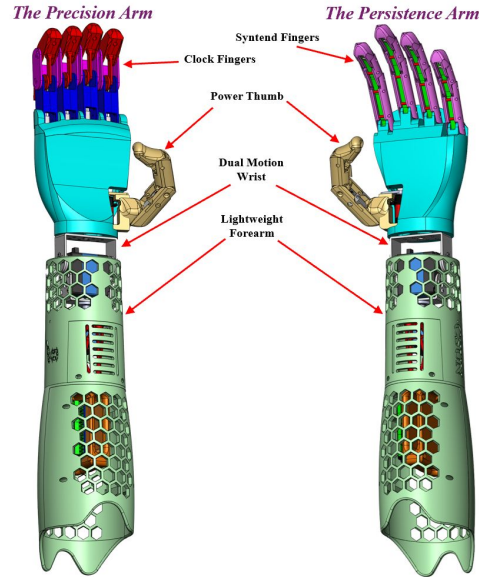
- Focused for Aesthetics
- Attach & Detach in multiple mounting points
- Controlled by external user

Arm Design

Team members:

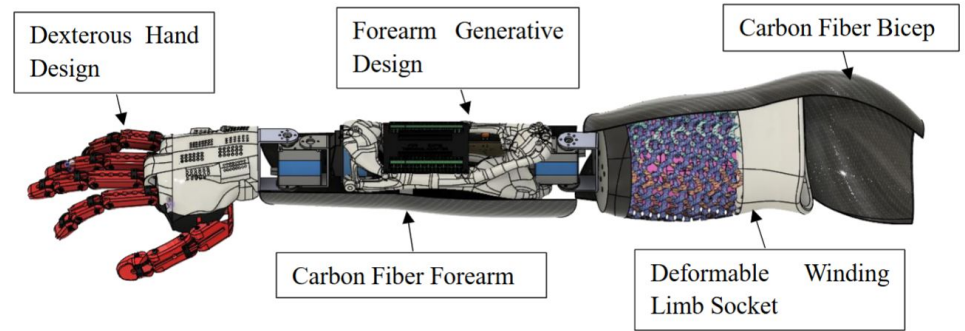
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History of Smart Prosthetics



7th Cohort

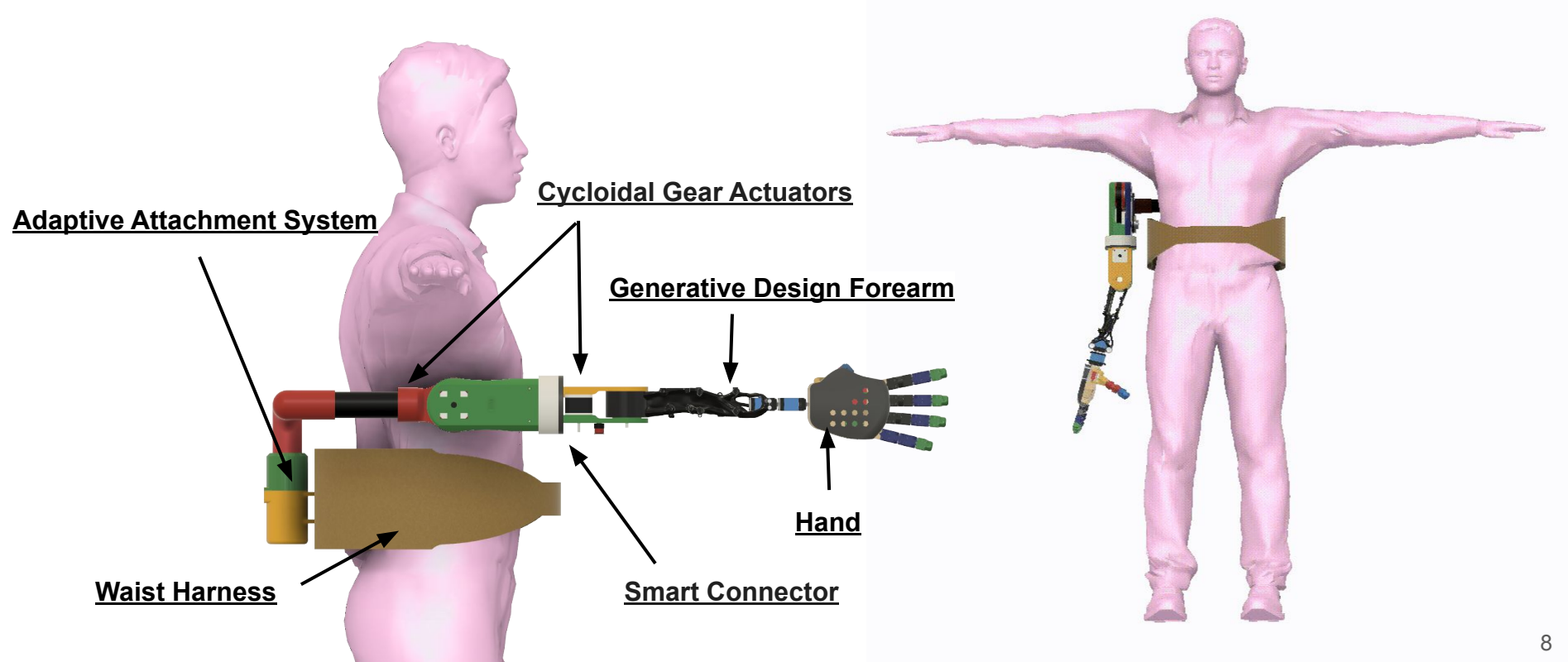
- Linkage and Tendon Driven
- Below the Elbow Prosthetic



8th Cohort

- Tendon Driven Rolling Contact Joints
- Forearm Generative Design
- Below the Shoulder Prosthetic

9th Cohort: Cerberus Modular Prosthesis/Wearable “Third Arm”



9th Cohort Arm Design Goals

- Incorporate Rolling Contact Joints
- Grip Strength > 40 [N]
- Experiment with Nylon CF
- FOS: 1.5
- Carry and lift a weight of 5 [kg] (11lb)
- Modularity for versatile use
- Comfort for user to reduce rejection

[Hand]

[Forearm]

[Actuation]

[Attachment]



Hand Design



- Rolling Contact Joints
- 1 DOF Fingers + 2 DOF Thumb



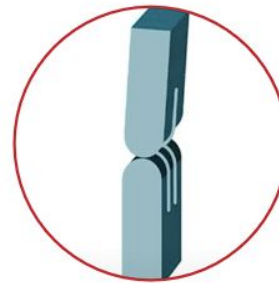
Hand Design: Joint Selection



Revolute Pins

- Simple
- Ease of manufacturing
- Predictable Kinematics (rotation)

- Frictional Wear
- Link Failure



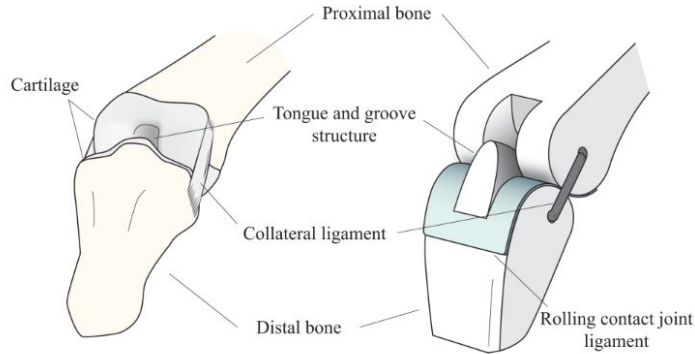
Rolling Contact Joints

- Biomimetic
- Dislocation*
- Low Friction
- Smooth Motion

- Complex design and manufacturing

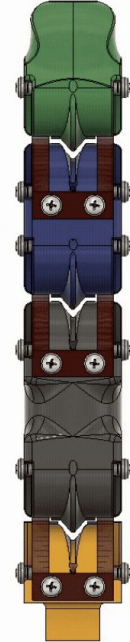
Hand Design: Finger

- Anthropomorphic Rolling Contact (ARC) Joints
 - Variable Torsional Stiffness
- Beadalon String Wire for Tendon
 - Stainless Steel Strands with Nylon Coating
- Passive extension with elastic wire



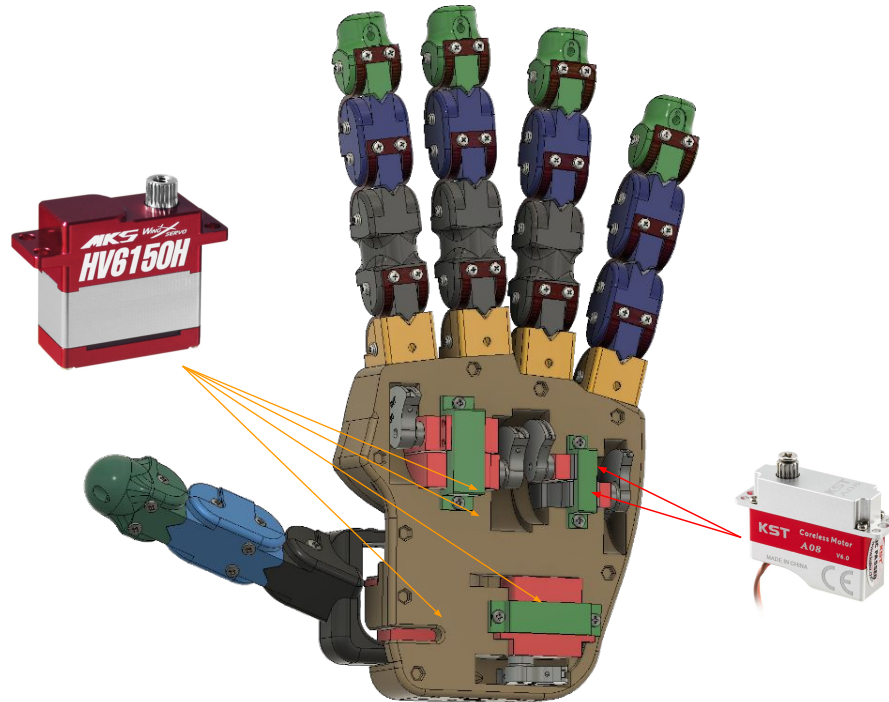
Human finger

Robotic finger with ARC joint



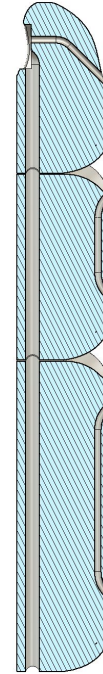
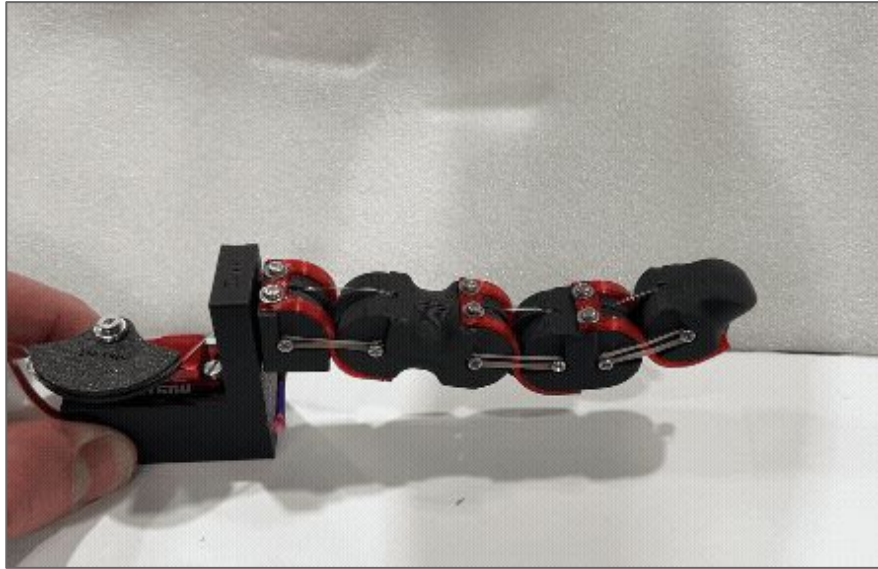
Hand Design: Servo Selection

Theoretical Finger Strength				
Voltage	KST A08		MKS HV6150	
	[kg]	[N]	[kg]	[N]
5.0	0.95	10.76	4.26	41.76
6.0	1.49	11.30	5.54	54.35
7.4	1.89	11.70	6.62	64.96
8.4	2.16	11.97	7.36	72.25



- MKS HV6150 QTY 4
- KST A08 QTY 2
- Brackets to secure servo

Hand Design: Finger Actuation



Finger Actuation Test using both **KST A08** and **MKS HV6150** Servos

Hand Design: Finger Strength

KST A08 at 5 V : 1.4 kgf.cm		
Theoretical	Vertical Pulling Test	Grip Test
	Experimental [kg]	Experimental [kg]
0.945946	0.775	0.9
	0.850	1
	0.770	1
AVG	0.798	0.967



- “Dr. Meter ES-PS01” for Pulling Test
 - **Old equipment with possible errors** of +/- 15 g with zero offset of 70 g
- “Baseline Evaluation Instruments” for Grip Test
- KST A08 Servo Test: **Finger Slippage**
- MKS HV 6150H Servo Test: **Spool Slippage**

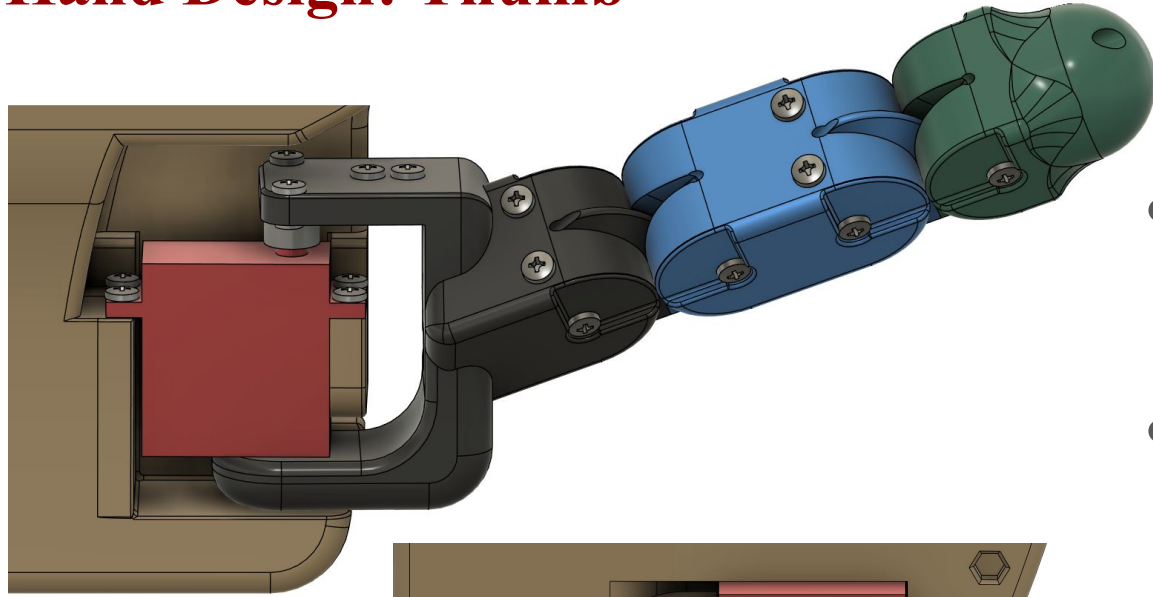
Hand Design: Weight

- Total weight of hand to be roughly **257 grams** (including servos)
- Weight of Finger: **4% decrease** compared to 8th Cohort
 - **12% decrease** without heat inserts
- **54% weight reduction** of palm from 7th Cohort (Using PLA 15% Gyroid)

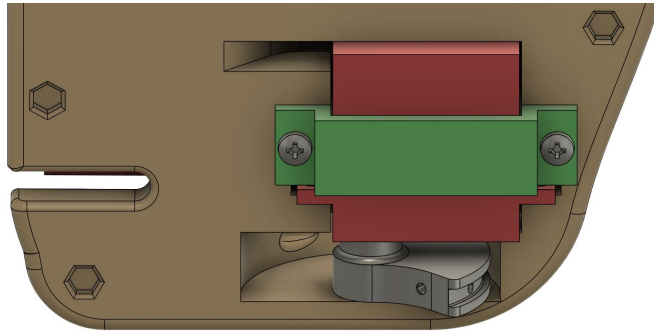


Hand Weight Breakdown			
Description	QTY	Weight [g] / ea.	Weight [g] / total
MKS Servos	4	17.4	69.6
KST Servos	2	7	14
Fingers	4	24	96
Thumb	1	18.4	18.4
Palm	1	59	59
TOTAL			257

Hand Design: Thumb



Front View-
1st DOF

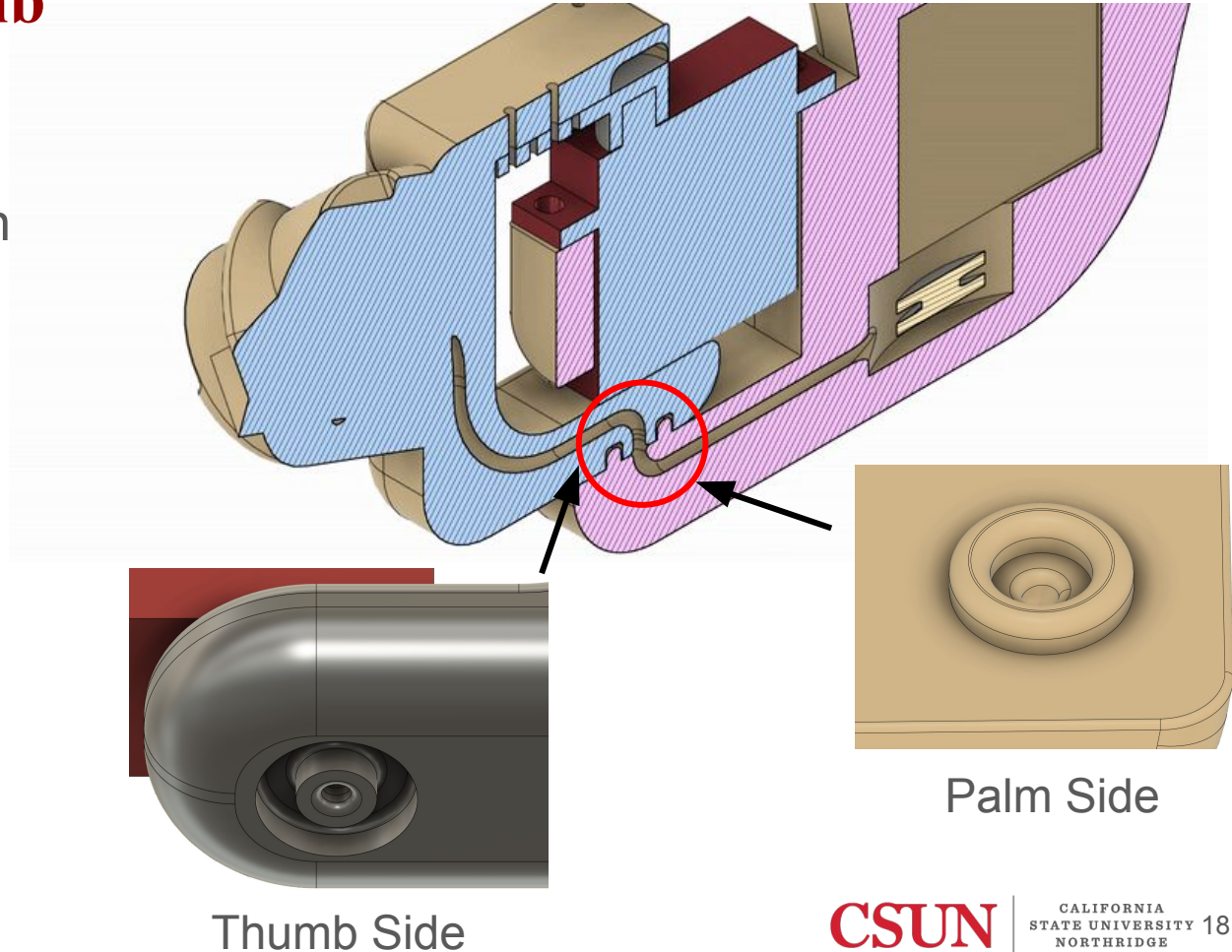


Back View- 2nd DOF

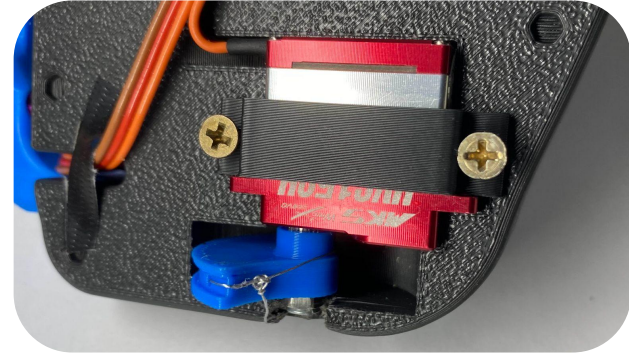
- Combination of tendon activation and direct rotation
- 2 DOFs
 1. Rotation
 2. Flexion/ extension
- Anthropomorphic rolling contact joints
- Splay set to 70°

Hand Design: Thumb

- Tendon runs through axis of rotation, making rotation mechanically independent from flexion/ extension
- Range of rotation: 120 °

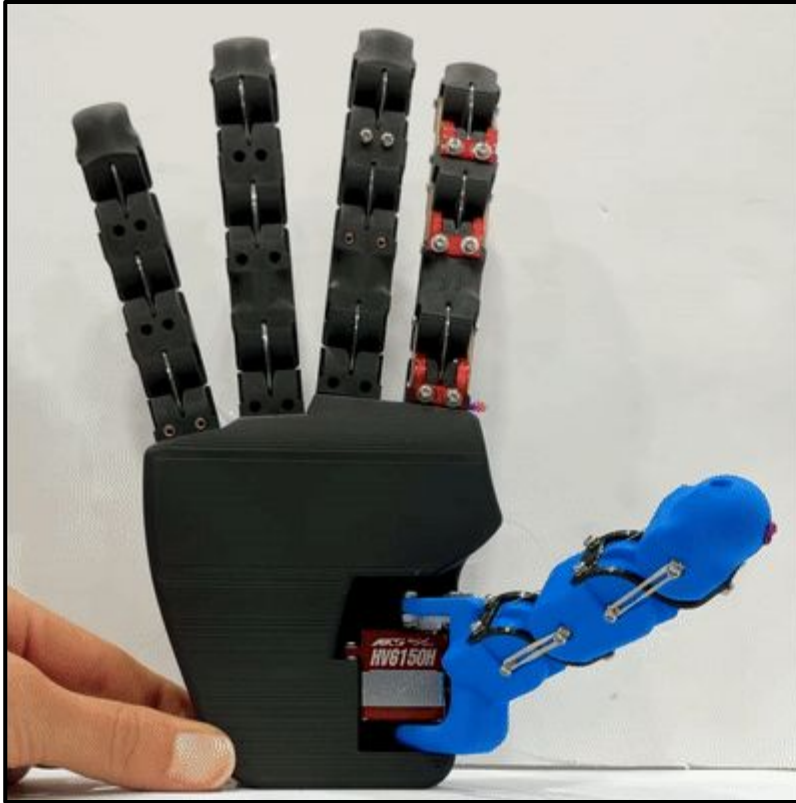


Hand Design: Thumb

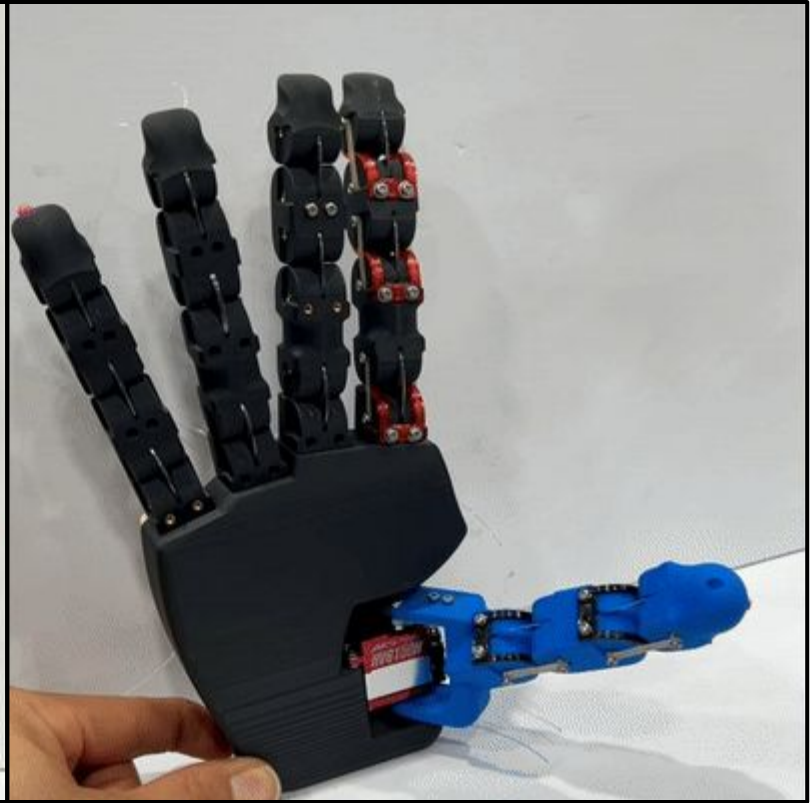


- Full assemblability was ensured

Hand Design: Thumb

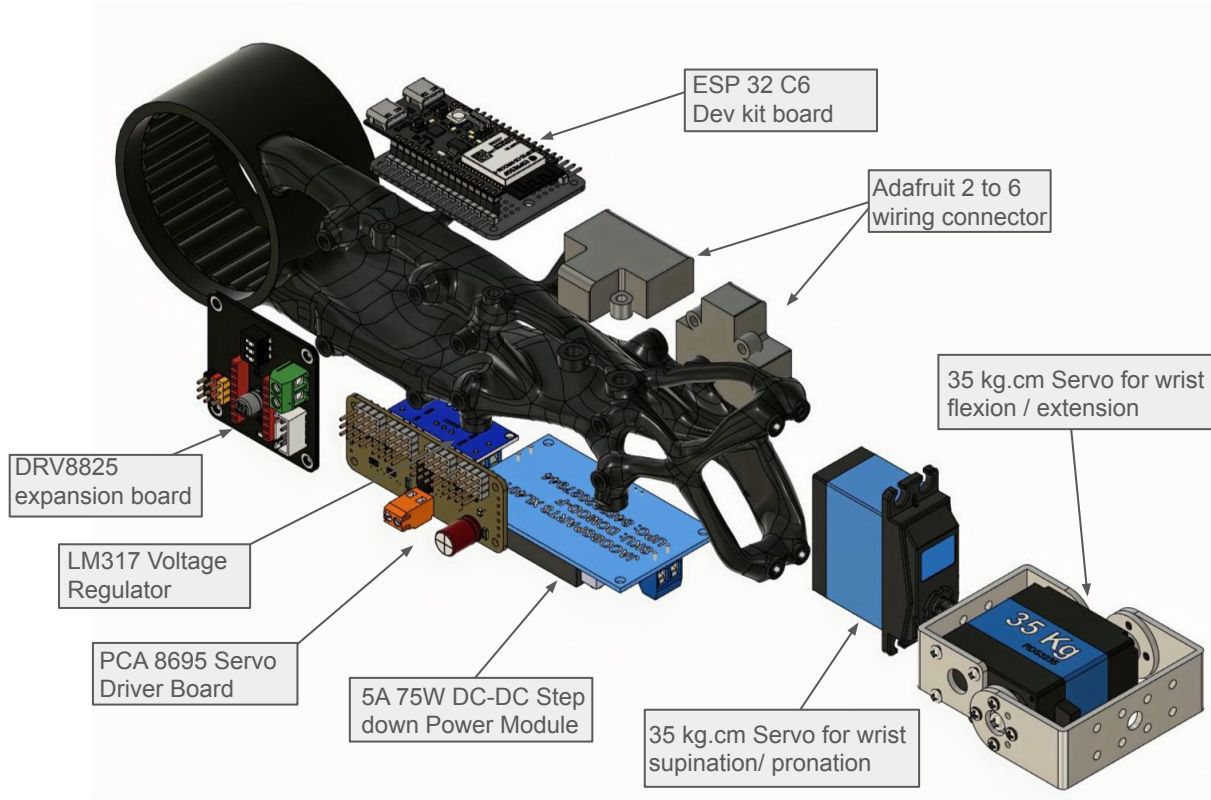


Front View



Angled View

Forearm Design



Material: PA6 CF20

Manufacturing : FDM 3D Printing
with 3 walls and 20% infill

Target FOS : 1.5

Design Load : 5 kg (50 N)

Weight : 87 grams

Forearm Design

Tensile Testing Results For PA6 CF20

10% Infill Samples



15% Infill Samples



20% Infill Samples



Forearm Design

Material	E_MPa	G_MPa	Yield Strength_MPa	UTS_MPa
Solid PA6-CF20 Dry (XY)	8637	3199	~80	109.3
Solid PA6-CF20 Wet (XY)	2508	929	~40	54.7
Printed PA6-CF 20 10% Infill	1066	395	18.62	41.42
Printed PA6-CF 20 15% Infill	1057	391	18.41	40.79
Printed PA6-CF 20 20% Infill	1084	401	19.57	42.64

Based on the tensile test data it was found that nylon behaves as wet material after absorbing moisture.

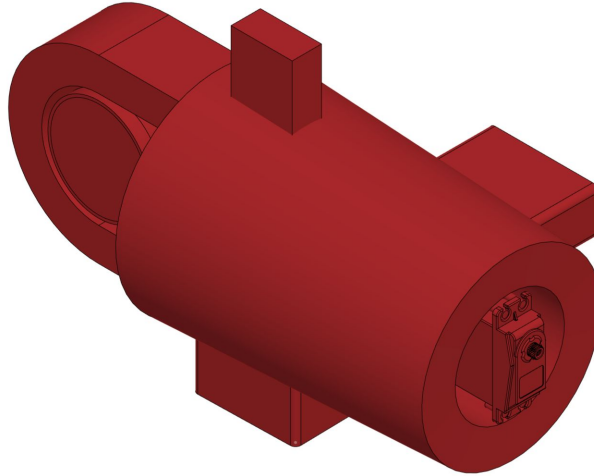
Forearm Design

Generative Design Study Setup

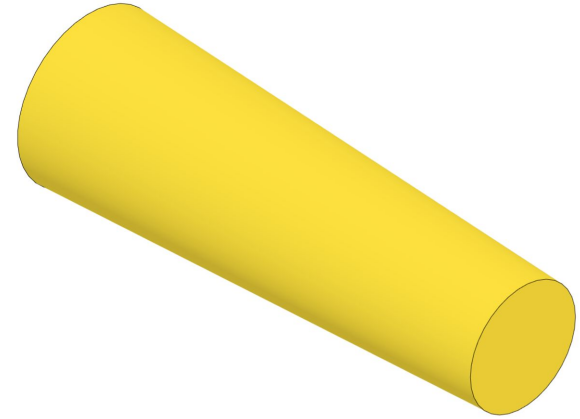
Preserve Geometry



Obstacle Geometry

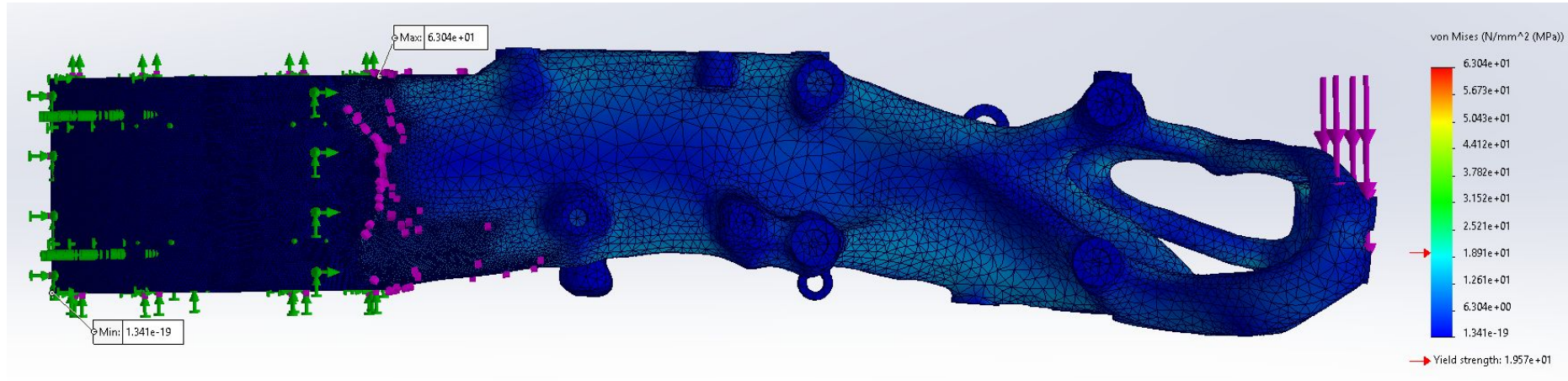


Starting Geometry



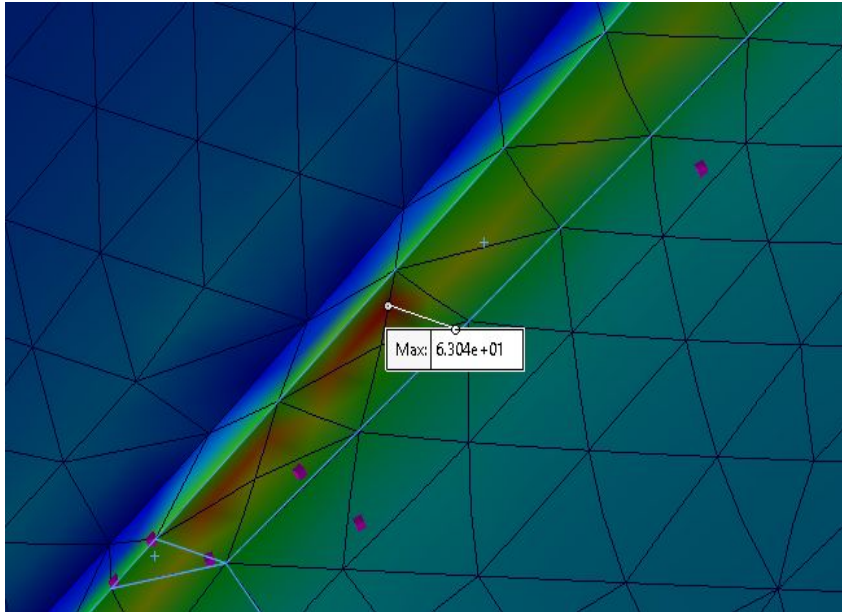
Forearm Design

Solidworks FEA



Forearm Design

Solidworks FEA



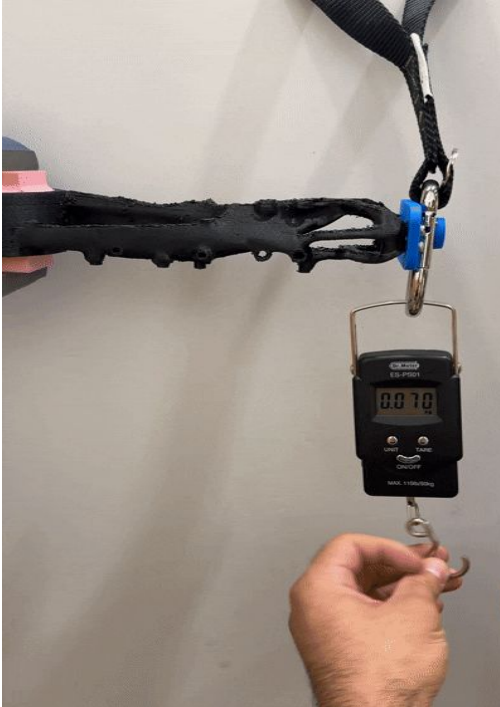
	Value	Unit
Sum	2.170e+04	N/mm^2 (MPa)
Avg	1.215e+01	N/mm^2 (MPa)
Max	6.304e+01	N/mm^2 (MPa)
Min	6.142e+00	N/mm^2 (MPa)
RMS	1.393e+01	N/mm^2 (MPa)

Regional Average = 12.15 MPa

$$\text{Regional FOS} = \frac{19.57 \text{ MPa}}{12.15 \text{ MPa}} = 1.61$$

Forearm Design

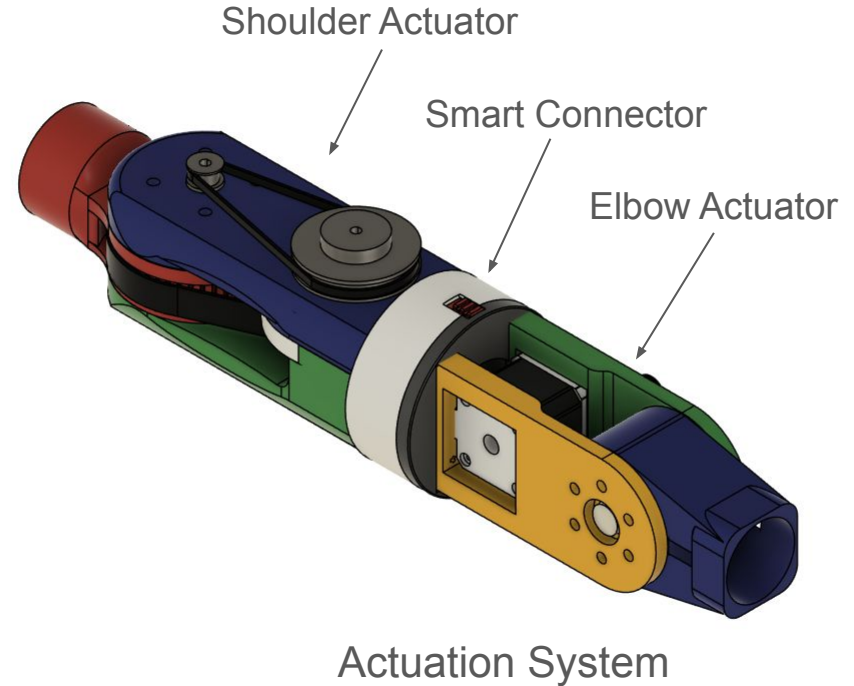
Experimental Results



$$\begin{aligned}\text{Experimental FOS} &= \frac{8.1kg}{5kg} \\ &= 1.62\end{aligned}$$

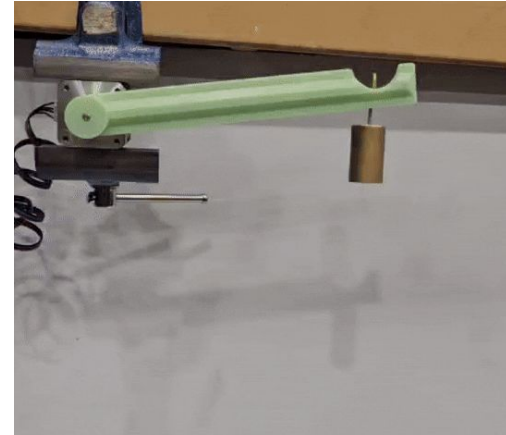
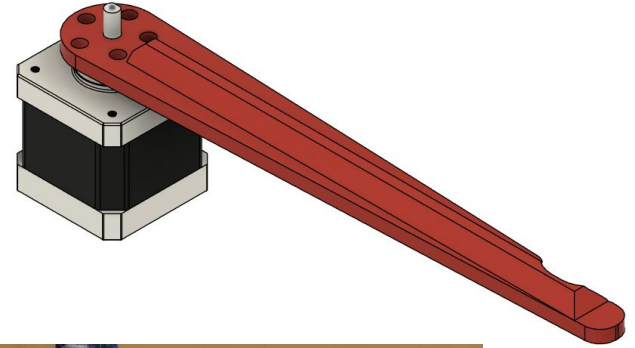
Robotic Arm Actuation

- Goal to solve ongoing challenge of reliable and functional weight lifting capacity.
- Industrial robotics actuation systems integrate gear reduction systems.
- Designed custom mechanical reduction solution with high torque density and low backlash under 1.8kg (4lb).



Actuation Strategy

- Nema 17 Stepper motor (0.42 Nm) for its size and relative weight of 258 grams when compared to higher torque motors.
- Using a combination of pulleys and cycloidal gear reductions the torque can be amplified.
- The mechanical reduction system provides low backlash for precise actuation.



Stock Stepper Motor Test (100g)

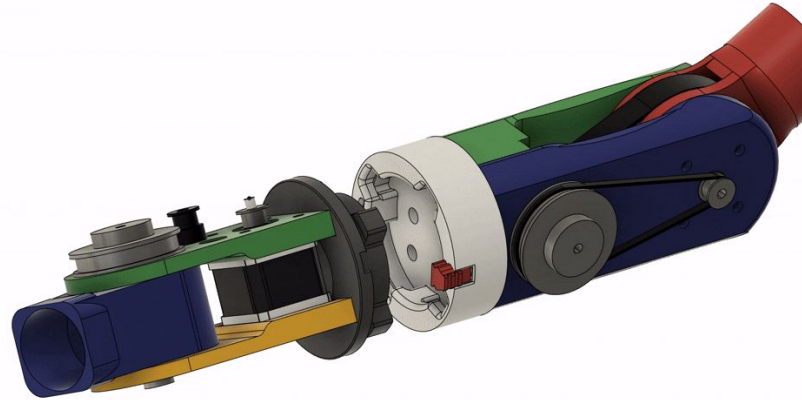
System Implementation

Elbow Actuator:

Goal of 8 Nm continuous torque for reliable strong extension of 4.5kg.

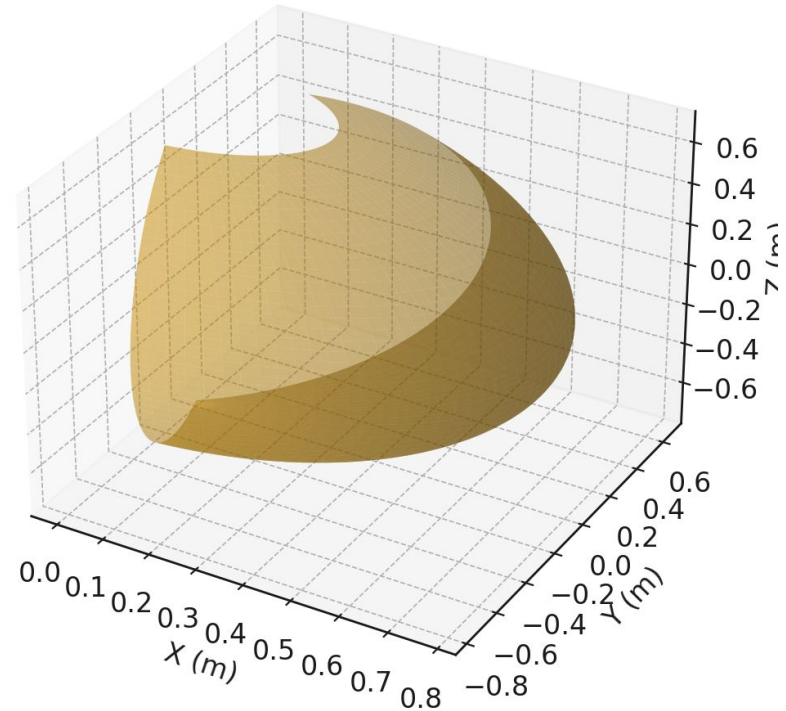
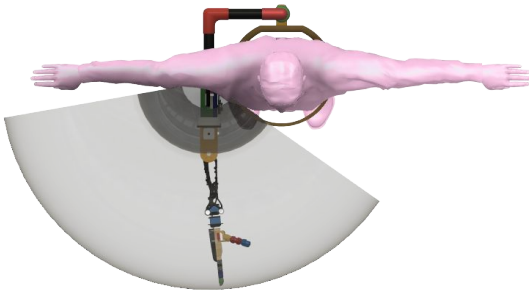
Shoulder Actuator:

Goal of 50 Nm continuous torque to lift 5kg.



Cerberus's Work Envelope

- Arm length: 0.78 m
- Horizontal sweep: 135°
- Vertical sweep: 157°
- Maximum vertical reach:
 - +0.718 m above joint
 - -0.78 m below joint



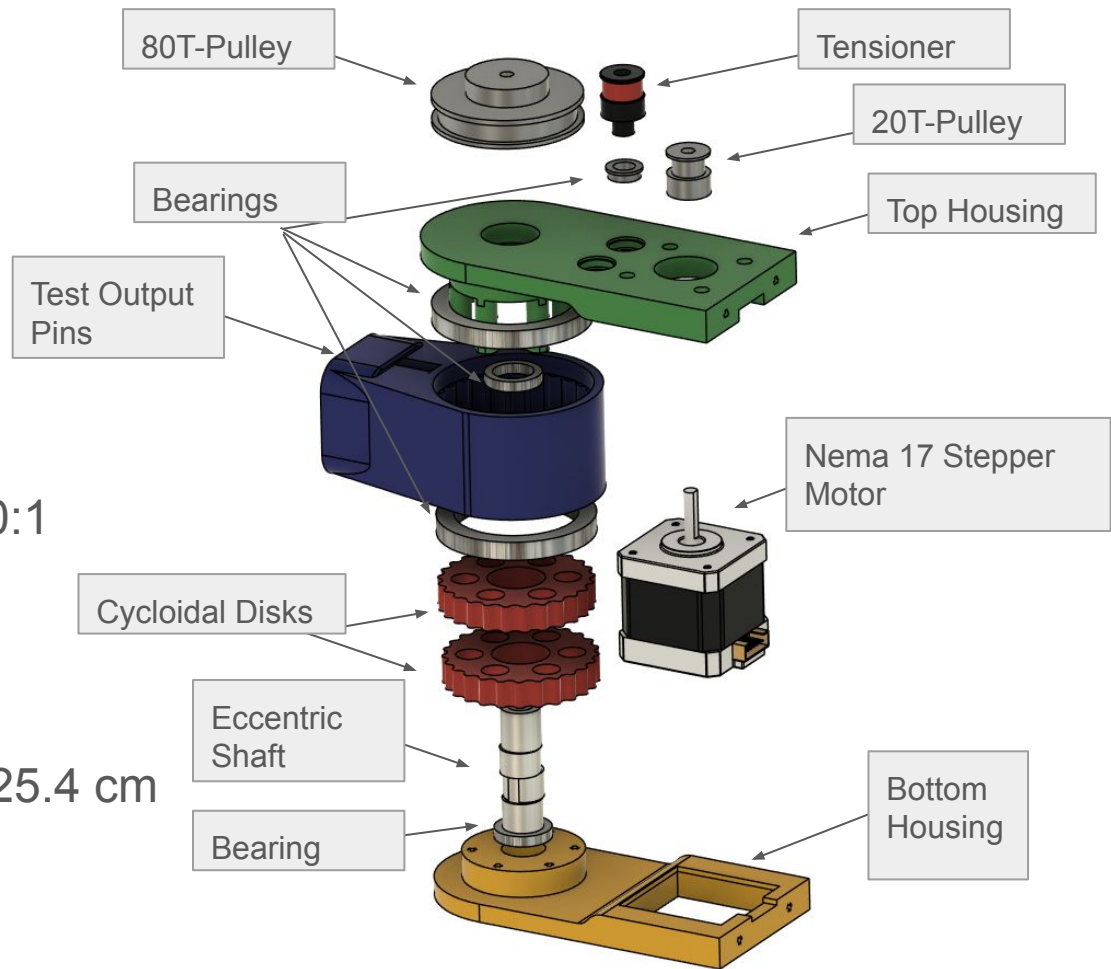
Elbow Actuation

Reduction:

- 4:1 Pulley
- 25:1 Cycloidal Drive
- Total System Reduction 100:1

Experimental Results:

- 2,023% Torque Gain
- Weight capacity 2.27 kg at 25.4 cm



Elbow Actuation

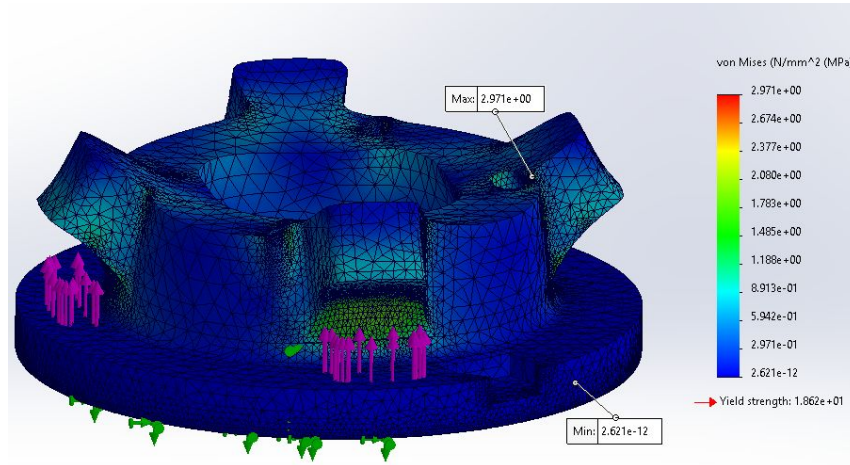
Torque (Nm)	Theoretical Amplification	Theoretical Output (Nm)	Experimental Torque (Nm)	Efficiency
0.42	100x	42	8.5	20.2%



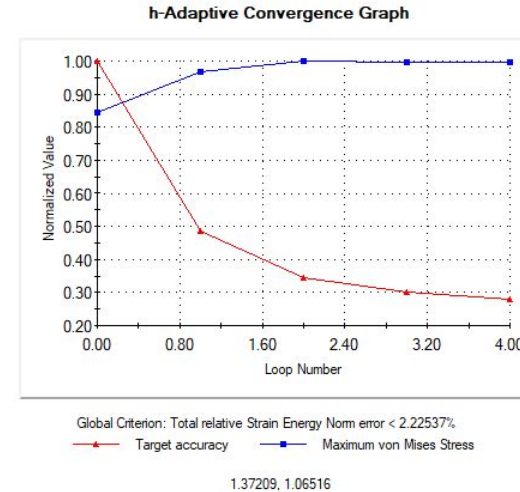
Actuation Test

Actuation FEA

Smart connector Top



- Nylon-CF 10% Infill
- Factor of Safety: 6.3



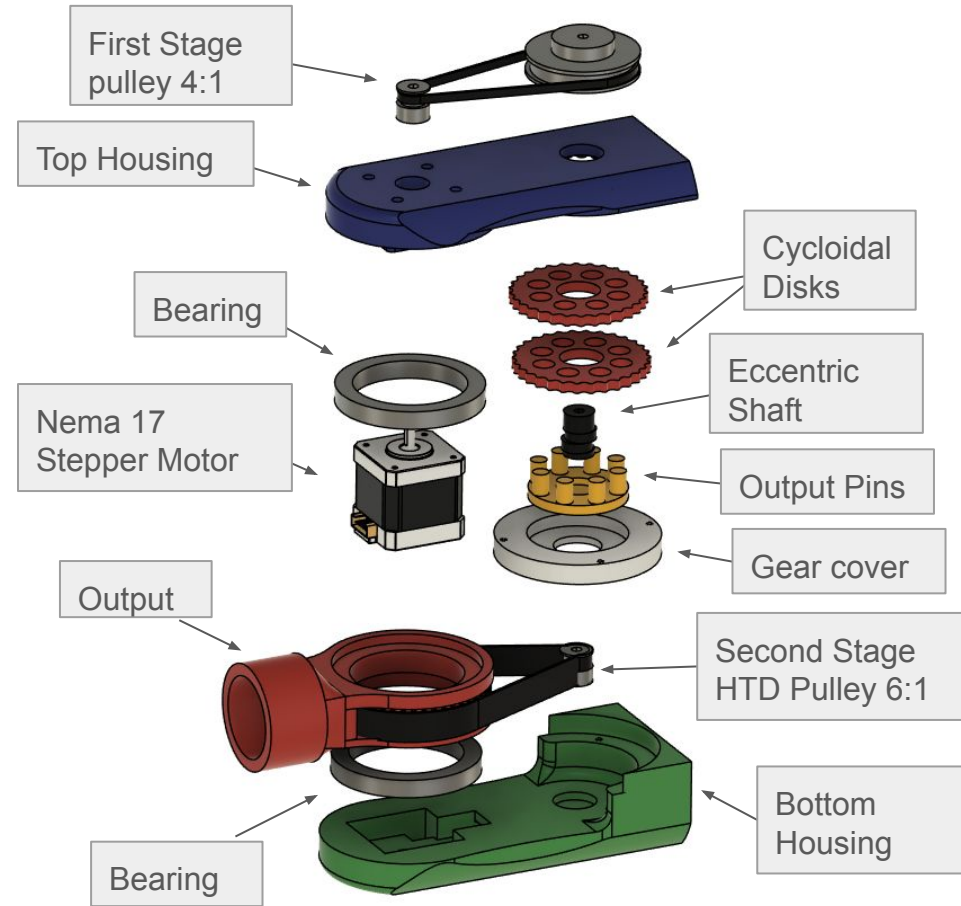
Shoulder Actuation

Reduction:

- 4:1 Input Pulley
- 30:1 Cycloidal Drive
- 5:1 Output Pulley
- Total System Reduction 600:1

Theoretical:

- Estimated efficiency 20% output 50.4 Nm
- Weight capacity pending



Shoulder Actuation

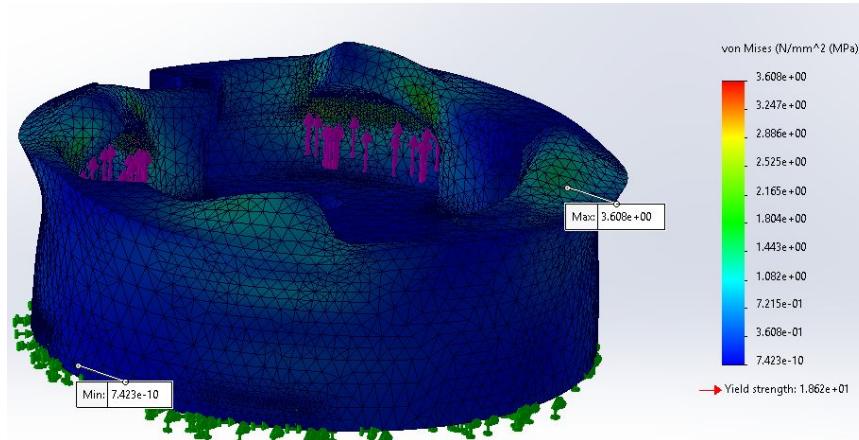
Torque (Nm)	Theoretical Amplification	Theoretical Output (Nm)	Experimental Torque (Nm)	Efficiency
0.42	600x	252	TBD	TBD



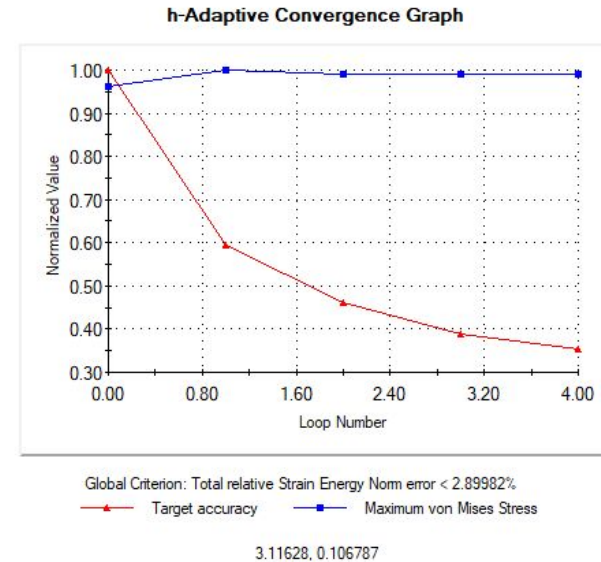
Partial Assembly

Actuation FEA

Smart connector Bottom



- Nylon-CF 10% Infill
- Factor of Safety: 5.2



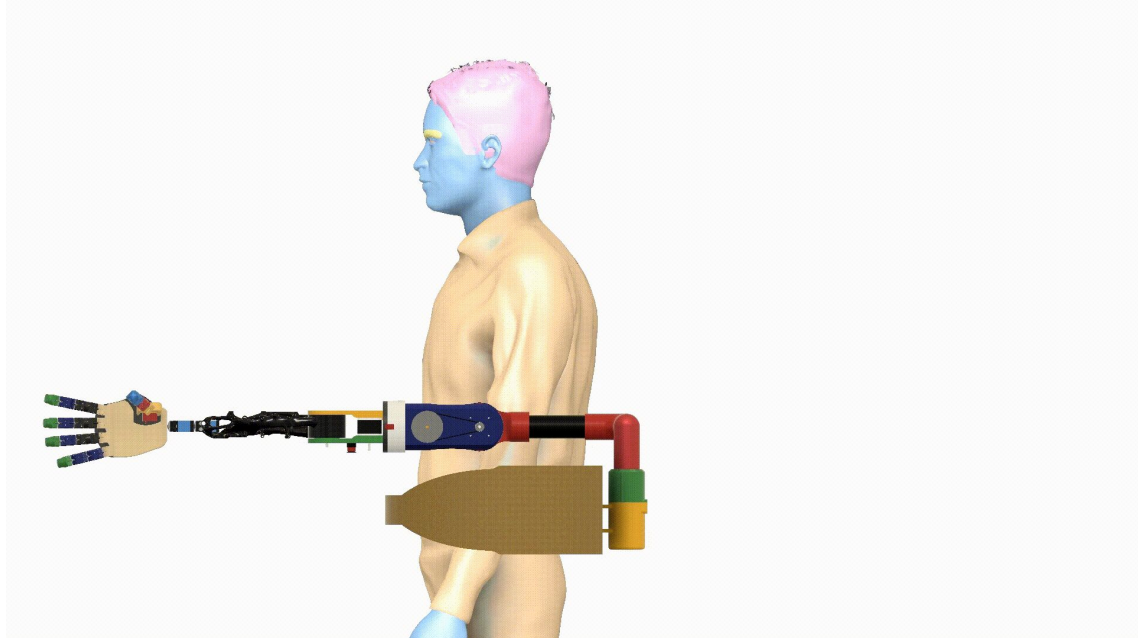
Actuator Weight

- Total Elbow weight 827g (1.8lb)
 - Stepper Motors 258g
 - Assembly without motor 569g
- Shoulder weight goal >1kg
- Off the shelf 8.5Nm Nema 34 stepper motor weight = 3.6kg

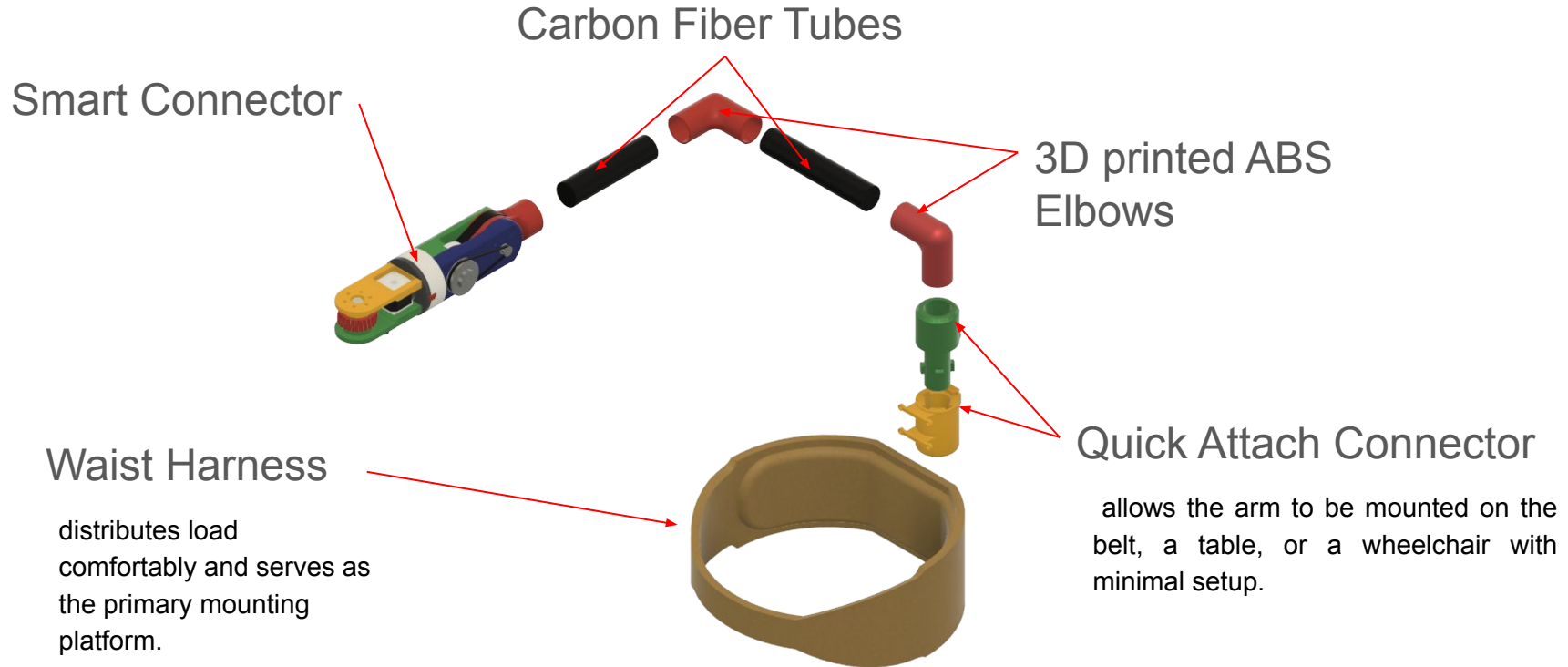


Adaptive Attachment System

- Enables the robotic arm to operate as a prosthetic.
- Quick and easy attachment and detachment system
- Allows user to connect arm to any system that has the quick connector.



Adaptive Attachment System (AAS)

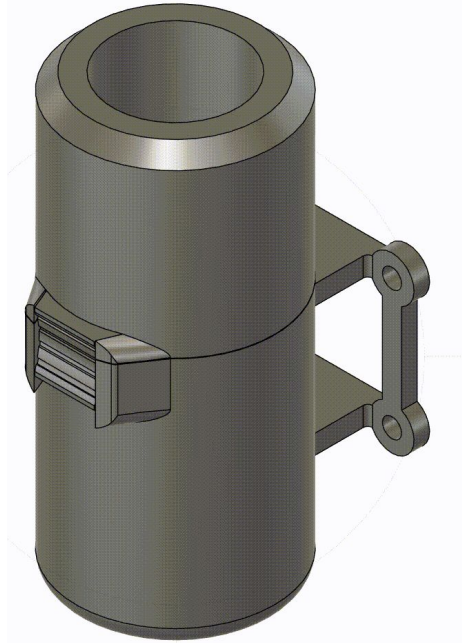
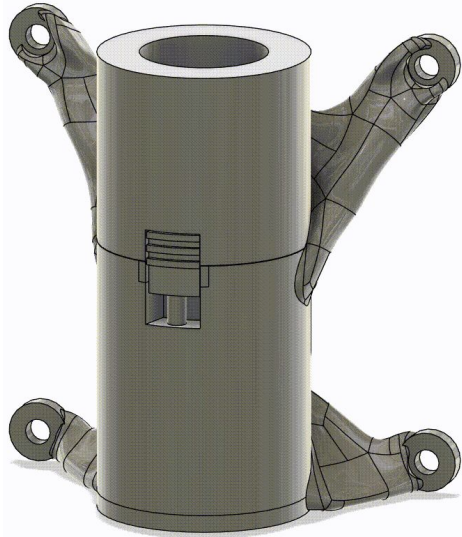


Adaptive System Material

- Carbon Fiber Tubes
- 3D printed PLA Elbows
- 3D printed PLA connector
- Stock belt with backplate



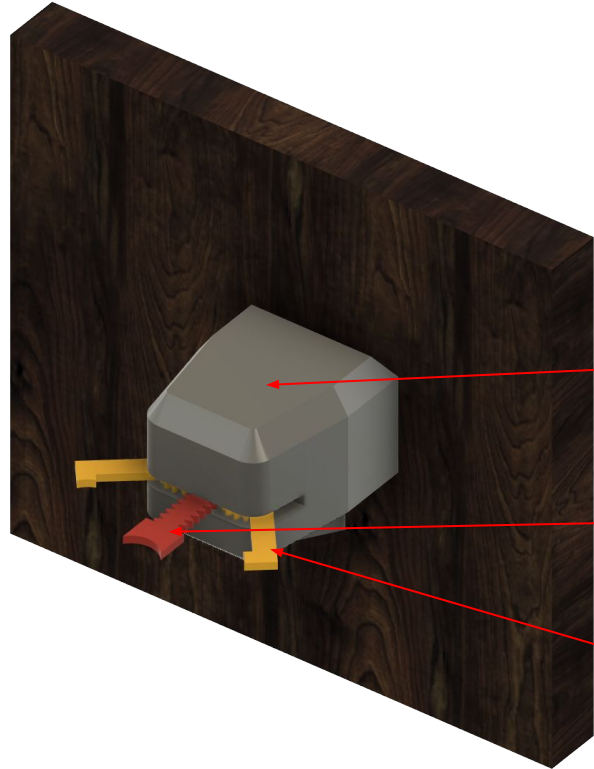
Connector



Generative
Design

The Claw

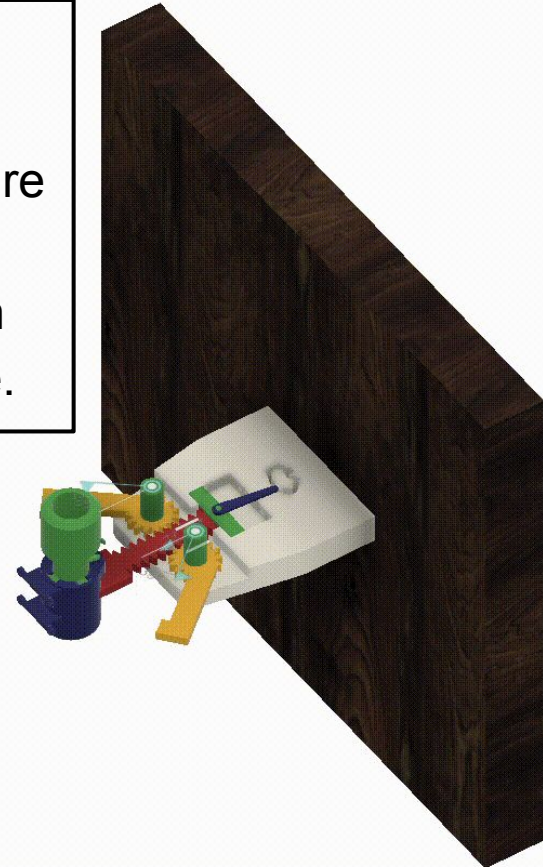
Wall-mounted docking station provides a secure parking, and storage location when not in use.



Housing

Push Activator

The claws



Arm Design Future Work

- The “Claw” Mechanism
- Additional Hand Strength Testing
 - Grip Strength
 - Pulling Test
- Place Electronics in Forearm
- Additional Actuator Tests
- Telescoping tube system to adjust length
- Assemble completed design
- Iterate from lessons we learn along the way

Foot Controller System

Team Members:

Hao Phan

Matthew Portillo

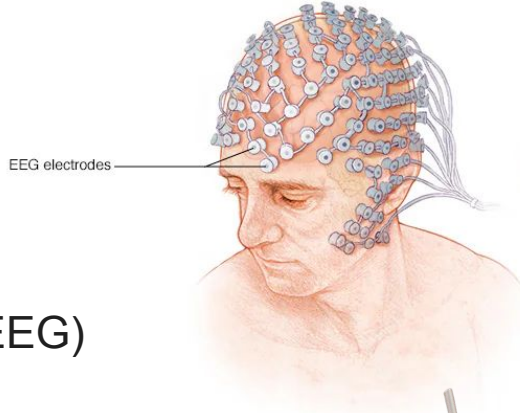
Kainen Shaw

Kurt Trocino

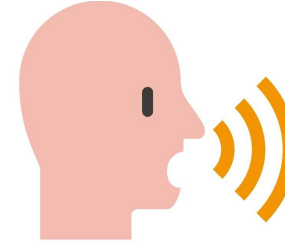
Background

Current control methods:

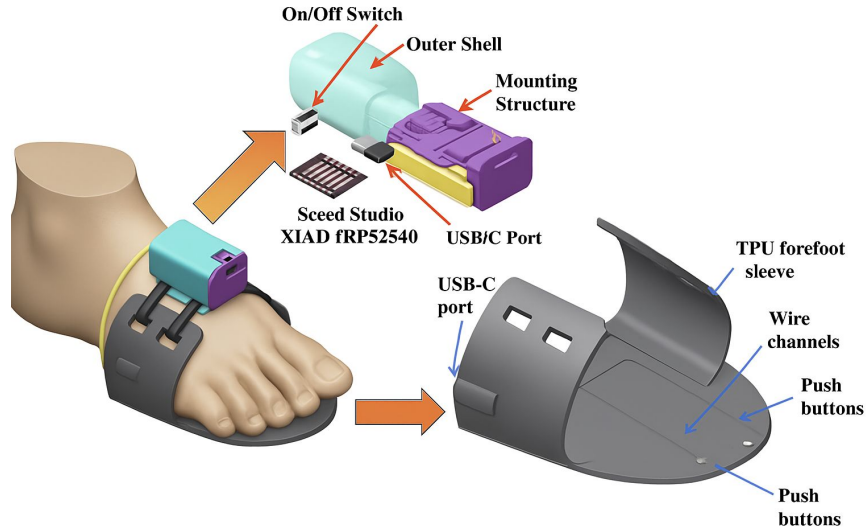
- Electroencephalography (EEG)
- Myoelectric (EMG)
- Vision control
- Voice control
- Exoskeleton



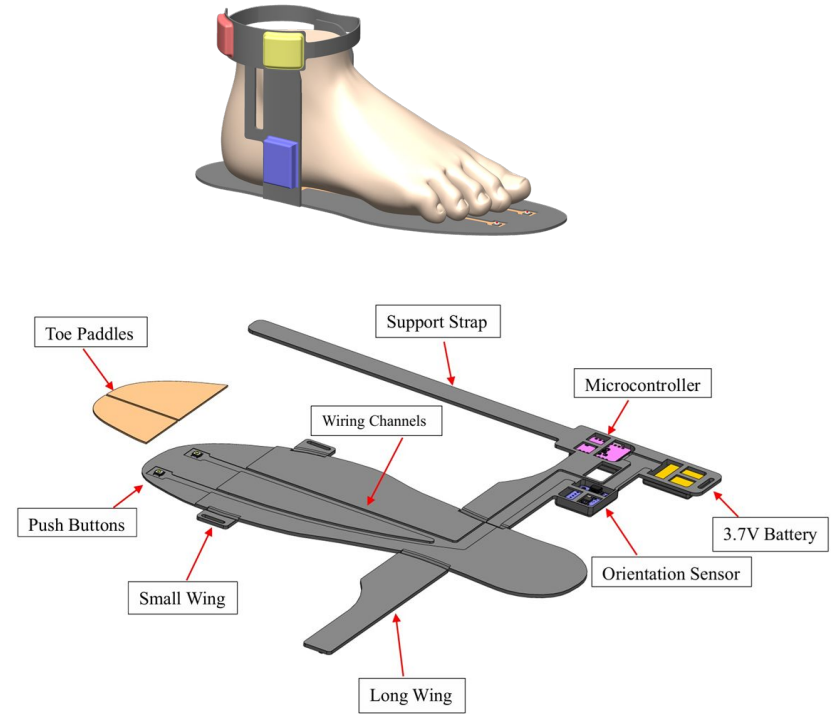
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7th and 8th Cohorts



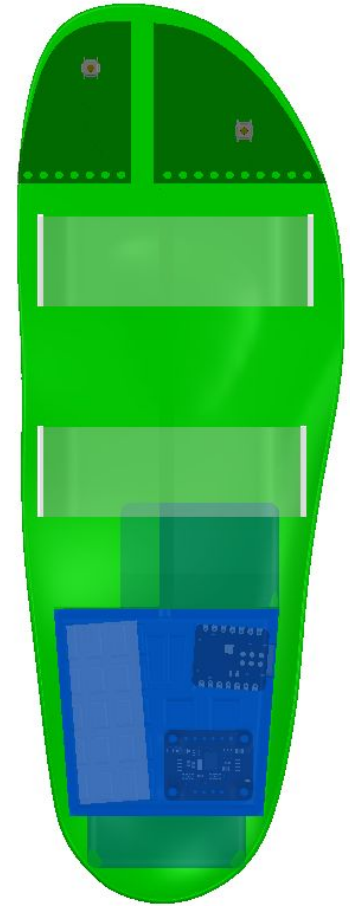
7th Cohort



8th Cohort

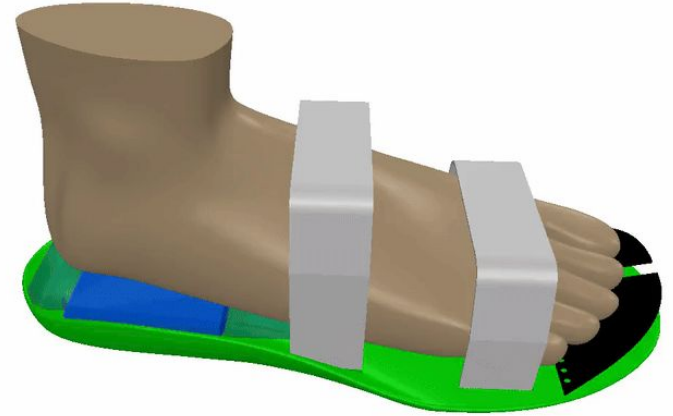
9th Cohort's Design Goals

- IMU Housed in Heel
 - Housing deflect less than 2 mm under 600 lb (2670 N) force
 - Max housing thickness of 12 mm for comfort
 - Factor of safety of at least 3
- Neural network accuracy above 95%
- Have full control of every joint
- Complete working prototype by December 19th

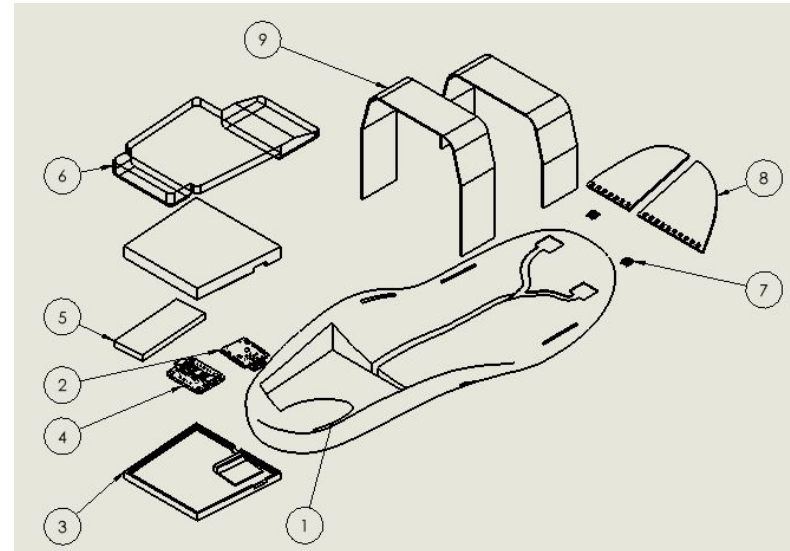
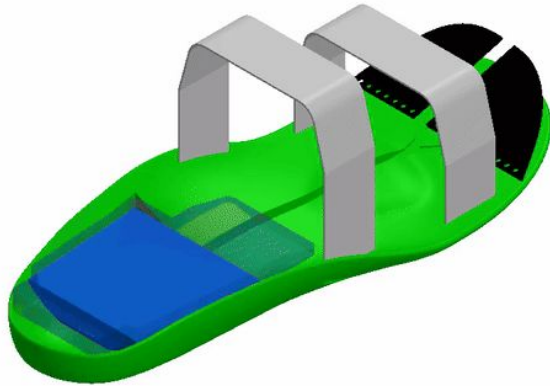


Foot Controller Redesign

- Heel Housing
 - Improved IMU data
 - Intentional protection of components
 - Testing comfort thickness of 12 mm
 - Polyurethane gel
- Robust insole for improved ergonomics
- 2.5x longer battery life
- Improved toe button flappers and relocated buttons
- Elastic straps for barefoot wearability



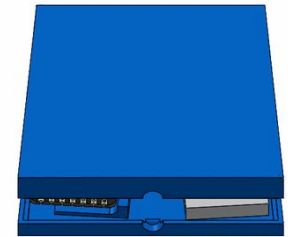
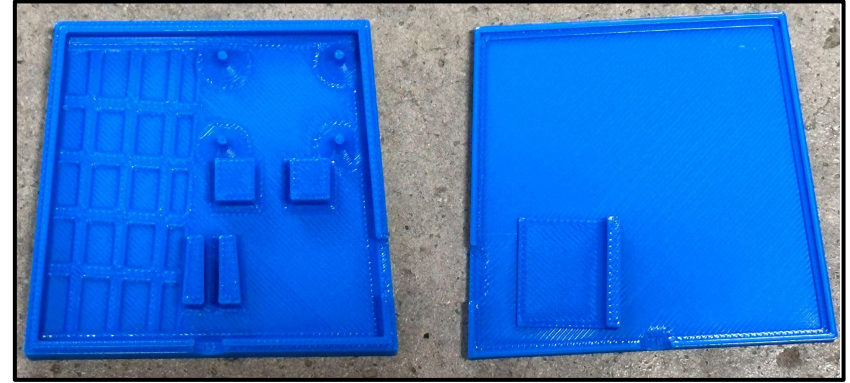
Foot Controller Components



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Foot Insole	XSTANCE Insole	1
2	ESP32	Seed Studio XIAO ESP32-C3	1
2	Heel Housing	3D Print of Polycarbonate	1
4	IMU	Adafruit BNO055	1
5	LiPo Battery	500mAh - 1S - 402050	1
6	Gel Pad	Polyurethane Elastic Fiber	1
7	Toe Button	5mm x 5mm x 1.5mm	2
8	Toe Flappers	3D Print of PLA	1
9	Elastic Band	Elastic Band	1

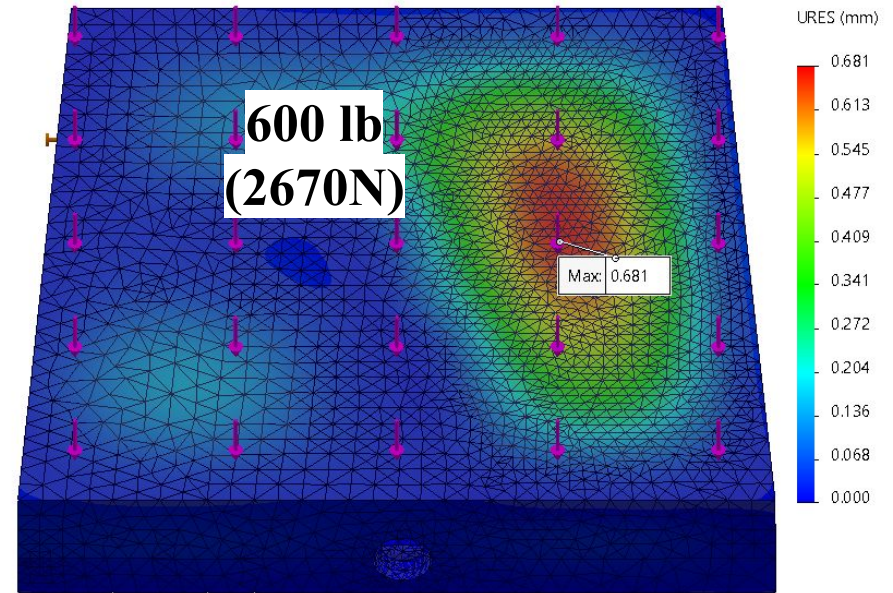
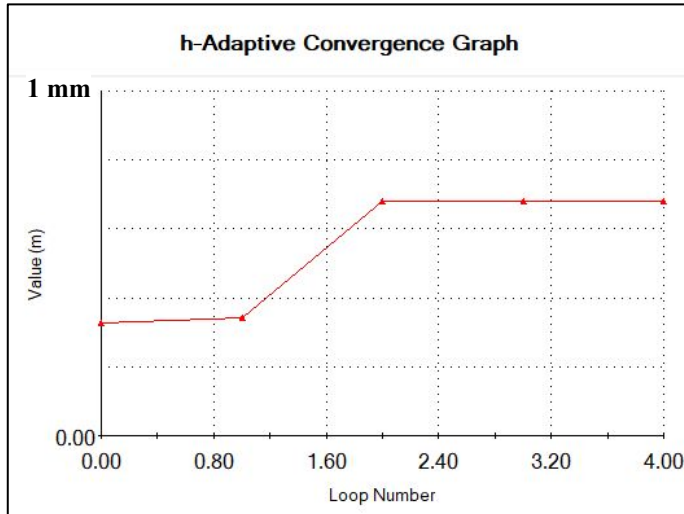
Our Design—Heel Housing

- 3D Printed Polycarbonate
 - High impact strength, compression strength, durability, and thermal resistance
- 2.5 mm shelled thickness
 - 2.1 mm can hold at least 205 lbs (912N)
- Support towers
- Ribs to distribute force
- 2.0 mm gap above battery
- Holders for IMU and ESP32

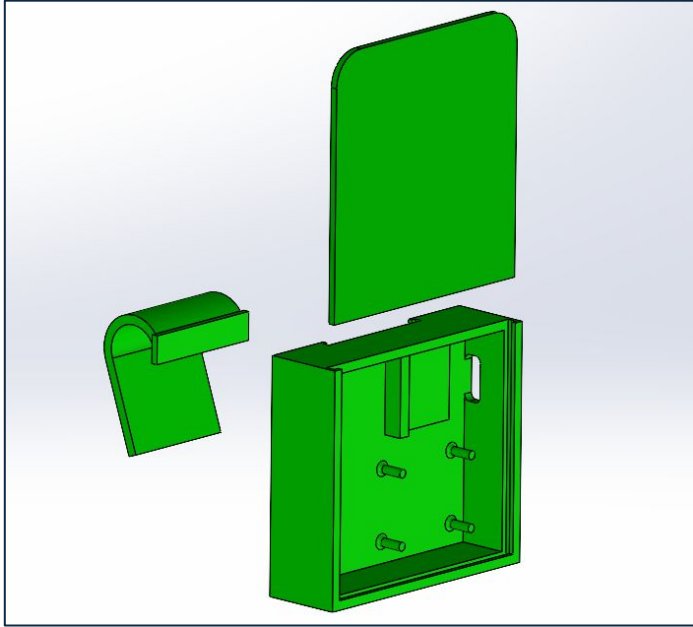


FEA

- 3D Printed Polycarbonate (Ductile)
- FoS = 3
 - Average male weight of 200 lbs (890N)



Walking Detection—Hip IMU



CAD Model of the Hip
Housing



3D Printed Hip Housing

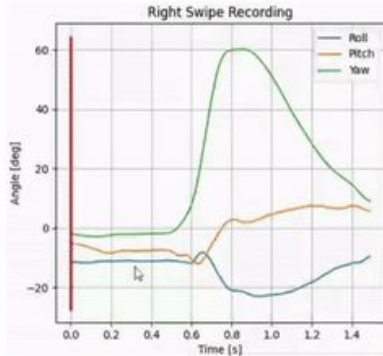
Walking Detection

- Uses a hip IMU along with the foot controller. It uses the linear acceleration and orientation as a global coordinate system
- Zero Velocity Update will be use to counter drift propagation,
- Uses Kalman filtering to filter the raw data before analysis
- The first goal is to have recognition of walking vs standing



Gesture Recognition

- **Goal:** Train a neural network to distinguish between six gestures using IMU data in real time



Neural Network

List of Gestures

Toe Tap



Right Swipe



Heel Tap



Left Swipe



Flat Tap



Heel Click



Convolutional Neural Network (CNN)

- Learns local patterns inside of gesture recordings
- Less likely to **overfit** than a plain feedforward network
- Efficient for real-time computation

1 _{x1}	1 _{x0}	1 _{x1}	0	0
0 _{x0}	1 _{x1}	1 _{x0}	1	0
0 _{x1}	0 _{x0}	1 _{x1}	1	1
0	0	1	1	0
0	1	1	0	0

Image

4		

Convolved
Feature

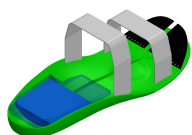
Convolution Operation Visualization

Data Collection

```

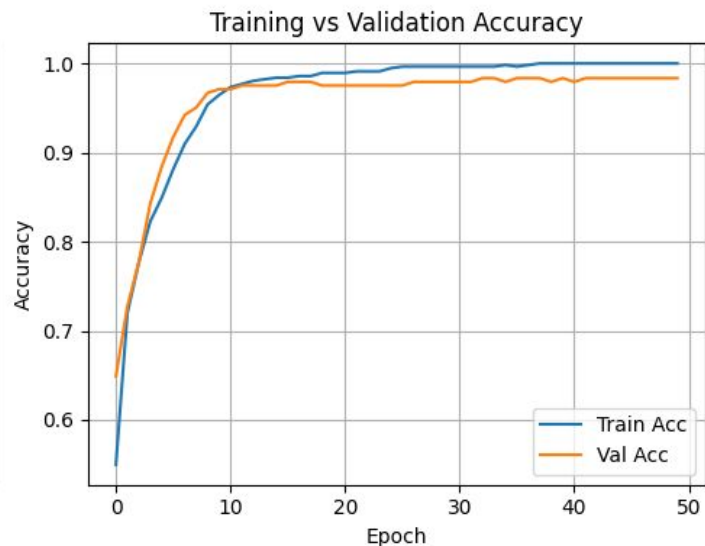
10:45:07.056 -> 0.05,-0.06,-0.98,13.38,-51.00,2.25,0.00,84.00
10:45:07.056 -> 0.08,-0.20,-0.95,13.13,-49.94,2.25,14.63,85.00
10:45:07.056 -> 0.08,-0.19,-0.90,12.75,-48.69,2.19,5.10,86.00
10:45:07.096 -> 0.19,-0.13,-0.83,12.38,-47.38,2.13,14.35,87.00
10:45:07.096 -> 0.19,-0.13,-0.83,12.00,-45.94,2.06,0.00,88.00
10:45:07.096 -> 0.08,0.04,-0.87,11.56,-44.38,2.00,20.64,89.00
10:45:07.096 -> -0.06,-0.06,-0.82,11.19,-42.75,1.94,17.92,90.00
10:45:07.132 -> -0.23,-0.13,-1.00,10.81,-41.00,1.94,25.73,91.00
10:45:07.132 -> -0.31,-0.23,-1.08,10.44,-39.19,1.94,15.10,92.00
10:45:07.132 -> -0.16,-0.63,-1.04,10.00,-37.31,2.00,42.91,93.00
    
```

ax	ay	az	roll	pitch	yaw	jerk	sample	trial	name	gesture
	0.05	-0.04	-0.43	-2.5	4.06	0	1	0	0 Hao	heel click
	0.03	-0.05	-0.43	-2.5	4.06	0	2.24	1	0 Hao	heel click
	0.03	-0.04	-0.46	-2.5	4.06	0	3.16	2	0 Hao	heel click
	0.07	-0.02	-0.44	-2.5	4.06	0	4.9	3	0 Hao	heel click
	0.03	-0.01	-0.45	-2.56	4.06	0	4.24	4	0 Hao	heel click
	0.06	-0.01	-0.4	-2.56	4.12	0	5.83	5	0 Hao	heel click
	0.05	0	-0.43	-2.56	4.12	0	3.32	6	0 Hao	heel click
	0.06	-0.01	-0.44	-2.56	4.12	0	1.73	7	0 Hao	heel click
	0.06	-0.02	-0.41	-2.56	4.19	0	3.16	8	0 Hao	heel click
	0.06	-0.02	-0.43	-2.56	4.19	0	2	9	0 Hao	heel click
	0.06	-0.01	-0.45	-2.56	4.19	0	2.24	10	0 Hao	heel click
	0.04	-0.03	-0.44	-2.56	4.19	0	3	11	0 Hao	heel click
	0.05	-0.02	-0.45	-2.56	4.19	0	1.73	12	0 Hao	heel click
	0.02	-0.02	-0.45	-2.56	4.19	0	3	13	0 Hao	heel click
	0.05	-0.05	-0.44	-2.56	4.19	0	4.36	14	0 Hao	heel click
	0.04	-0.03	-0.44	-2.56	4.19	0	2.24	15	0 Hao	heel click
	0.05	-0.03	-0.43	-2.56	4.25	0	1.41	16	0 Hao	heel click
	0.06	-0.04	-0.45	-2.56	4.25	0	2.45	17	0 Hao	heel click
	0.04	-0.03	-0.43	-2.56	4.25	0	3	18	0 Hao	heel click
	0.04	-0.04	-0.45	-2.62	4.25	0	2.24	19	0 Hao	heel click
	0.04	-0.03	-0.42	-2.62	4.25	0	3.16	20	0 Hao	heel click
	0.04	0	-0.46	-2.62	4.31	0	5	21	0 Hao	heel click
	0.03	-0.01	-0.46	-2.62	4.31	0	1.41	22	0 Hao	heel click
	0.04	-0.01	-0.43	-2.62	4.31	0	3.16	23	0 Hao	heel click
	0.03	-0.03	-0.41	-2.62	4.31	0	3	24	0 Hao	heel click



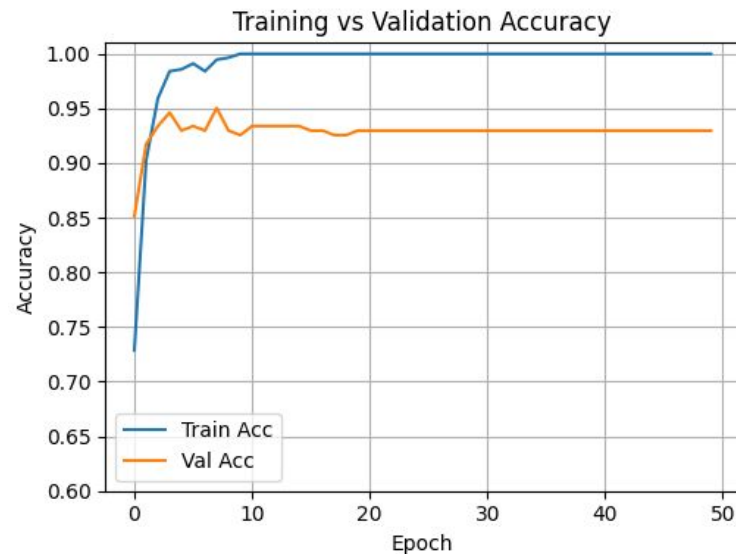
Neural Network Comparison

Convolutional NN



98.35% Validation Accuracy

Feedforward NN



93.39% Validation Accuracy

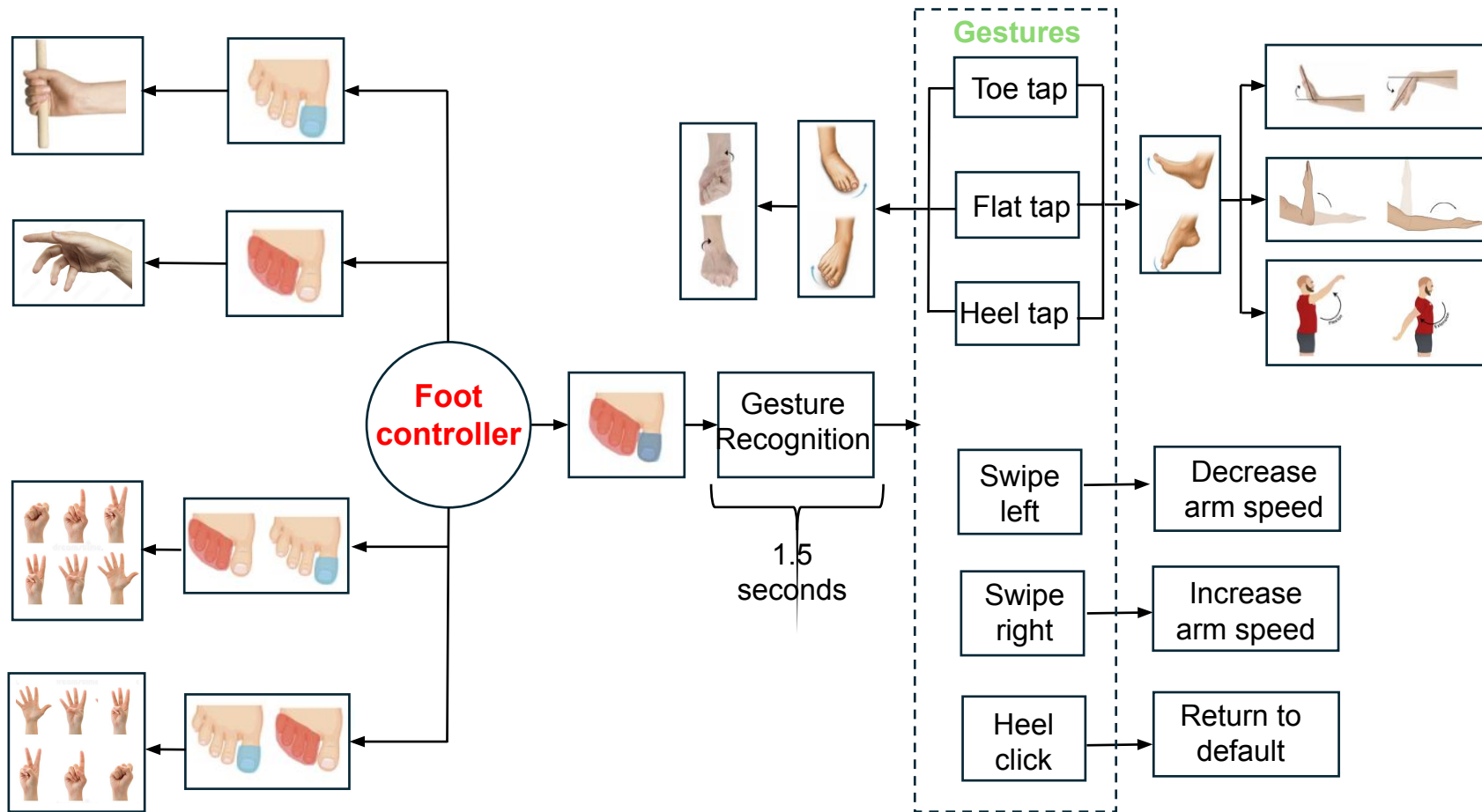
Live Testing



Live Testing

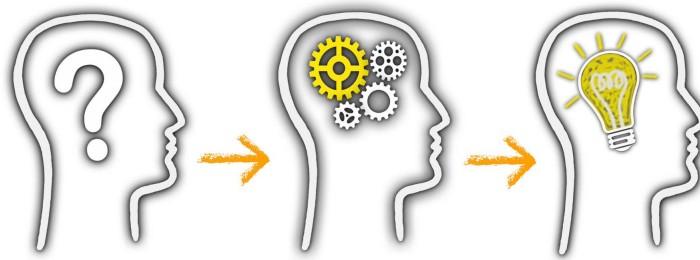
		Correct	Incorrect
Toe Tap		20	0
Heel Tap		20	0
Flat Tap		20	0
Right Swipe		20	0
Left Swipe		19	1
Heel Click		20	0

99%
Accuracy!



Lessons Learned

- 3D printing engineering materials is complicated
- Neural network can process data quickly on an ESP32
- Using a Linux distro (Ubuntu) for faster sketch compiling in Arduino IDE



Future Work

- 3D print our own insole
- Add a vibration motor for haptic alerts
- Collect more training data once final foot controller is built
- Test controls with arm and get user feedback
- Test and improve the hip detection



Haptic Feedback

Team Members:

Jorge Alvarez

Nathan Handal

Christopher Lopez

Vanessa Montejano

What is a Haptic Feedback System?

A way to bridge the gap between the digital and physical worlds



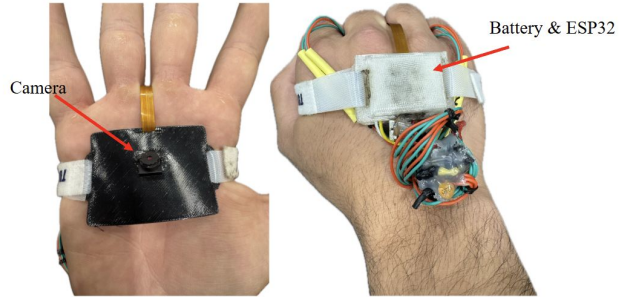
Vincent, James. "Haptic feedback is making VR surgery feel like the real thing." The Verge, 14 Aug. 2018, [theverge.com/2018/8/14/17670304/virtual-reality-surgery-training-haptic-feedback-fundamentalvr](https://www.theverge.com/2018/8/14/17670304/virtual-reality-surgery-training-haptic-feedback-fundamentalvr).



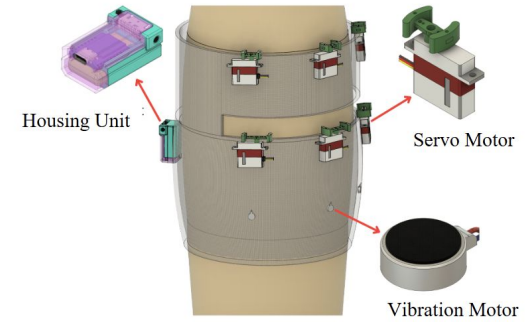
European Space Agency *"METERON Project."* ESA — Automation & Robotics, [https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Automation_and_Robotics/METERON_Project](https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Automation_and_Robotics/METERON_Project).

From smartwatch vibrations, to VR-assisted surgery, to astronauts remotely controlling robotic systems

8th Cohort's Design



Texture Identification

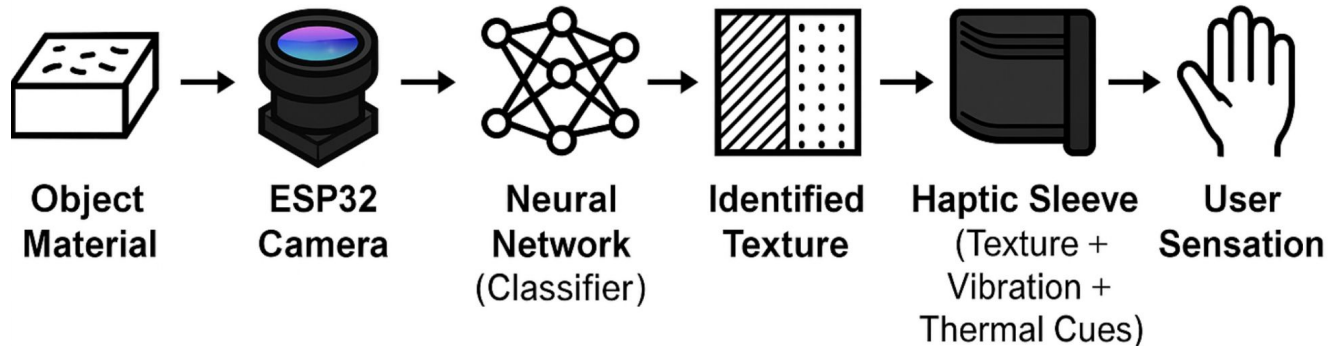


Texture Application

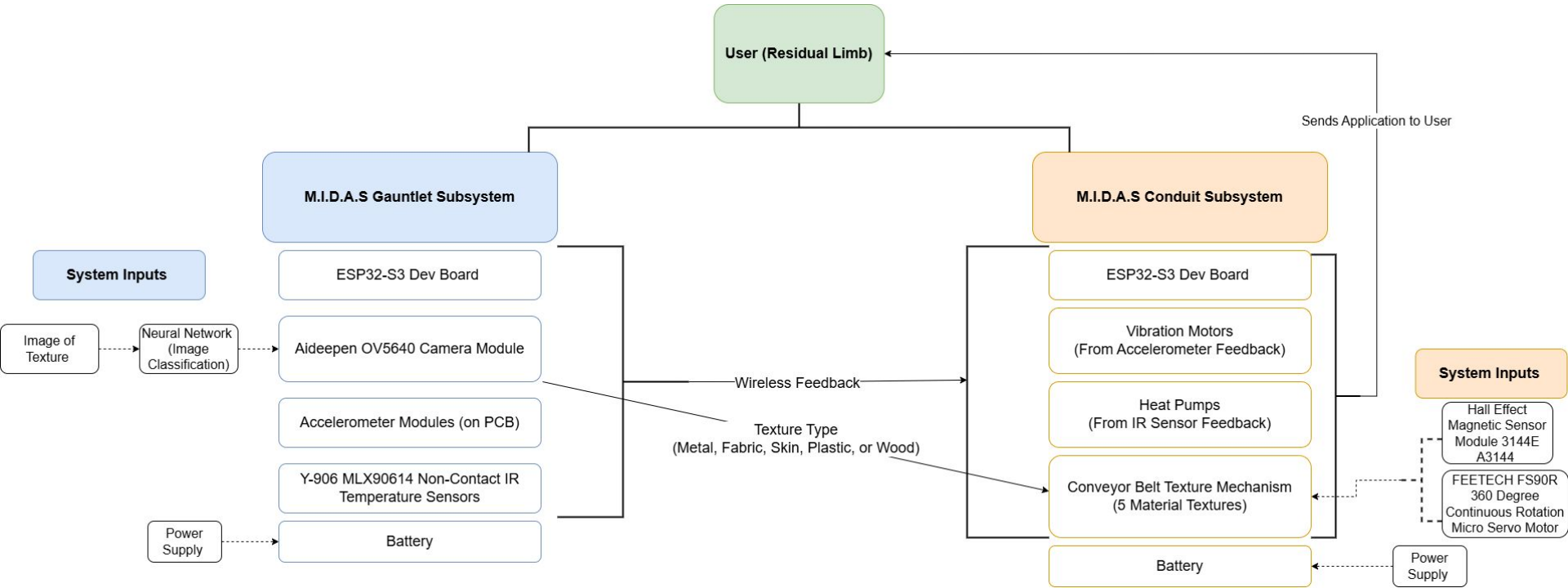


Purpose and Goals

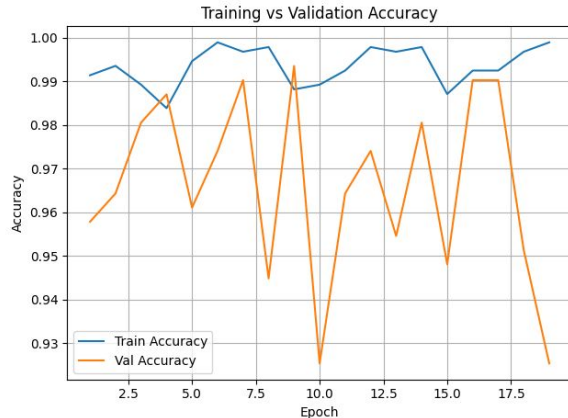
- Provide sensory feedback to users missing limbs or nerve endings
- Detect different objects seen on a day to day basis and apply closest material on lower tricep
- Easily attachable and detachable for integration with any upper limb prostheses
- Integrate vibrational and thermal sensors to enhance the sensory feedback



Full System Block Diagram

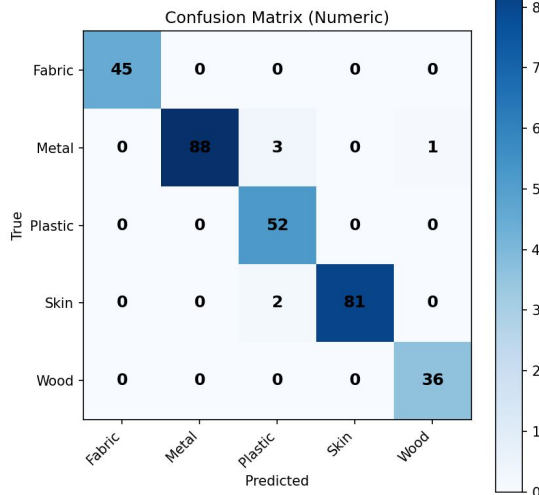


Neural Network Training



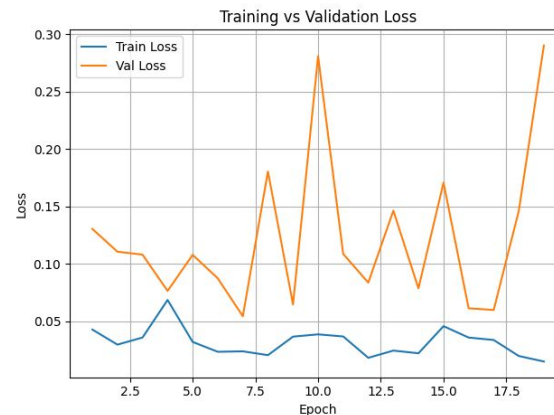
Training vs Validation Accuracy

- High, stable training accuracy (~0.98-1.0).
- Validation accuracy fluctuates more across epochs.



Confusion Matrix

- High correct predictions across all classes.
- Minor confusion in Plastic vs Metal/Skin classifications.



Training vs Validation Loss

- Training loss remains low and stable.
- Validation loss is more variable, indicating generalization fluctuation.

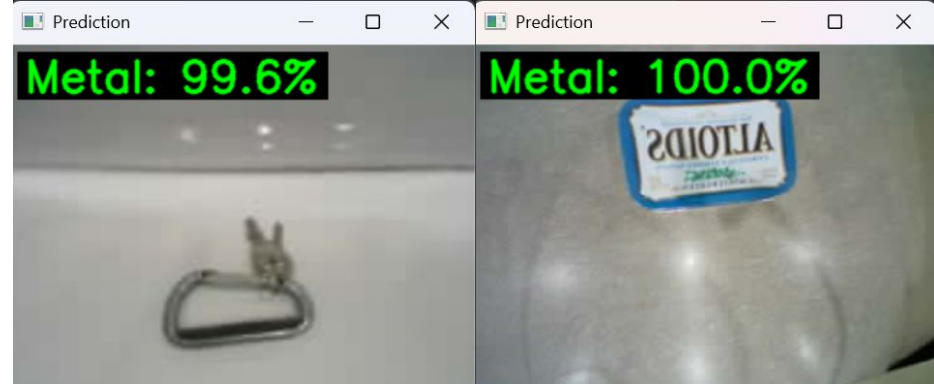
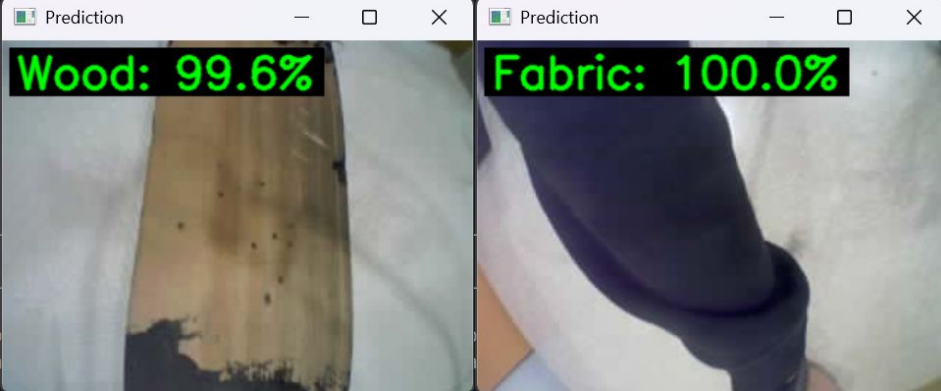
Prediction Testing

```
2025-12-05 15:47:48.036639: I tensorflow/core/platform/cpu_feature_guard.cc:210] This TensorFlow binary is optimized to use available CPU instructions in performance-critical operations.
To enable the following instructions: AVX2 AVX_VNNI AVX_VNNI_INT8 AVX_NE_CONVERT FMA, in other operations, rebuild TensorFlow with the appropriate compiler flags.
Top-1: Skin confidence: 100.0%

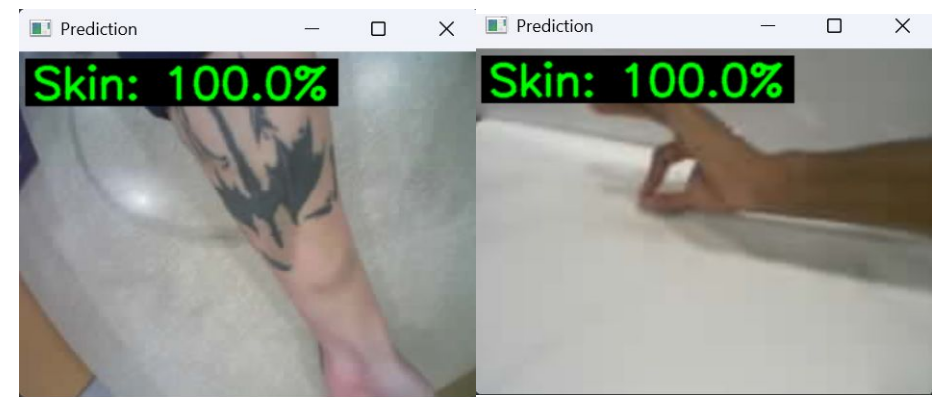
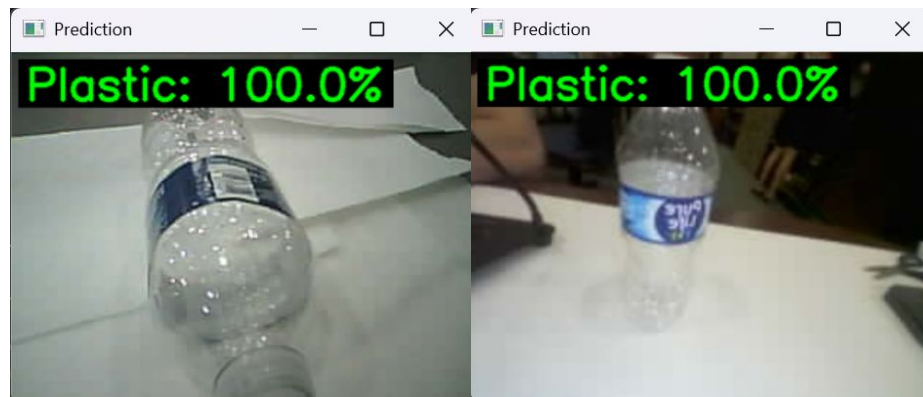
Per-class probabilities:
Skin      100.00%
Fabric     0.00%
Plastic    0.00%
Metal      0.00%

Traceback (most recent call last):
  File "C:\Users\natha\OneDrive\Documents\material_nn\predict_image.py", line 105, in <module>
    print(f" {classes[i]:<8} {probs[i]*100:6.2f}%")
          ~~~~~^
IndexError: list index out of range

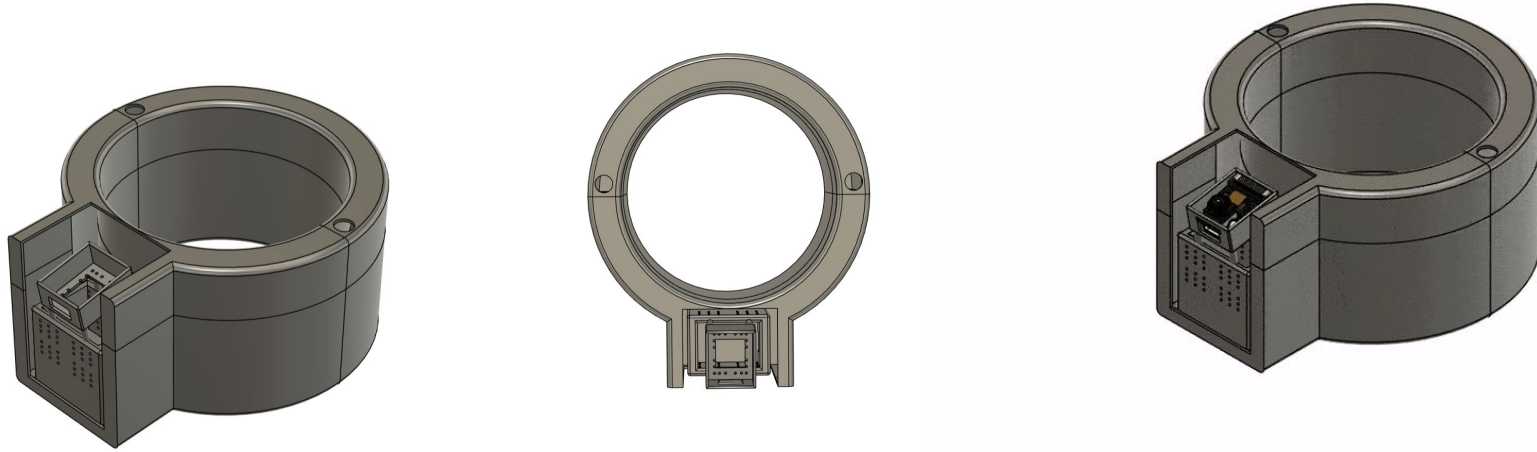
(.venv) PS C:\Users\natha\OneDrive\Documents\material_nn> python predict_image.py "C:\Users\natha\OneDrive\Documents\material_nn\Test_I\espcamtest2.jpg"
```



Neural Network Prediction Testing

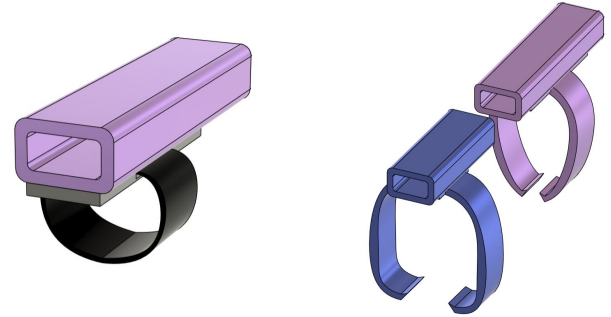
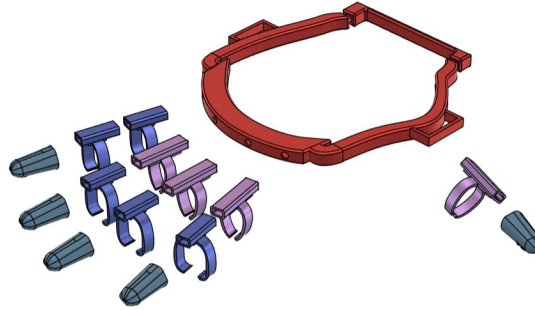
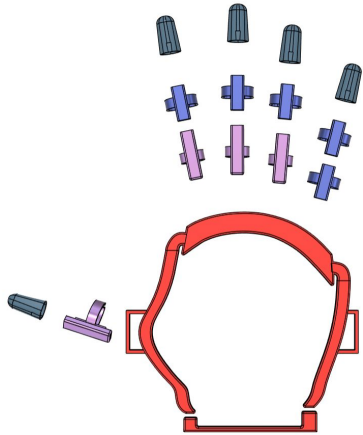


Wrist Attachment



- Compact wrist-mounted housing for sensors/electronics with modular fit.
- Secure attachment with access for wiring, Power compartment, and expansion.

Gauntlet



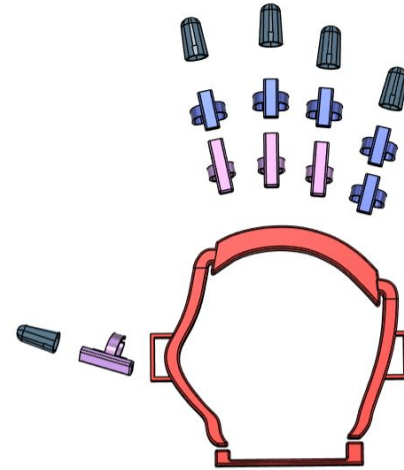
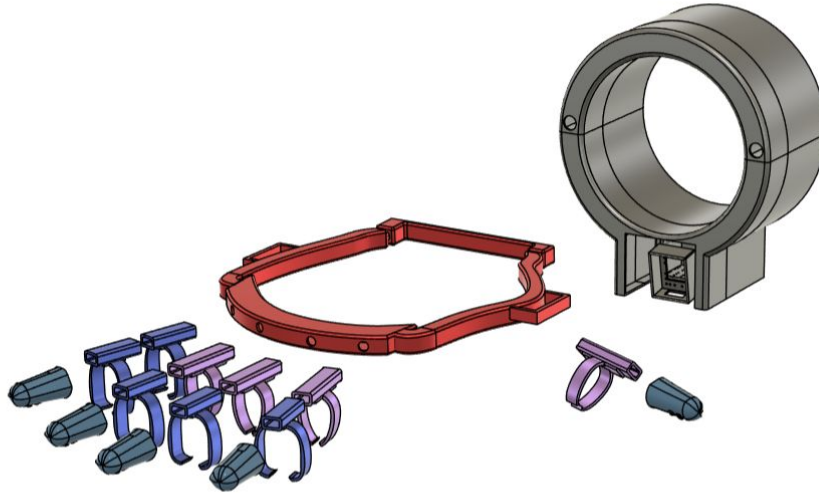
Adaptable Wire Casing



Silicone Finger Tip with sensors

- Modular glove system with interchangeable sensor mounts.
- Exploded layout shows how clips, fasteners, and shell assemble together.

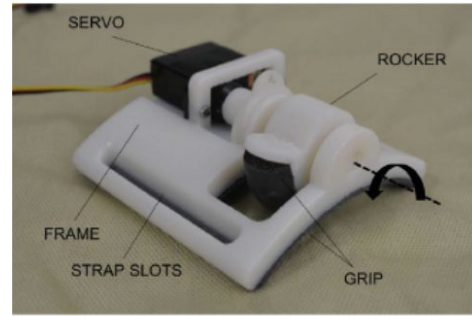
M.I.D.A.S Gauntlet



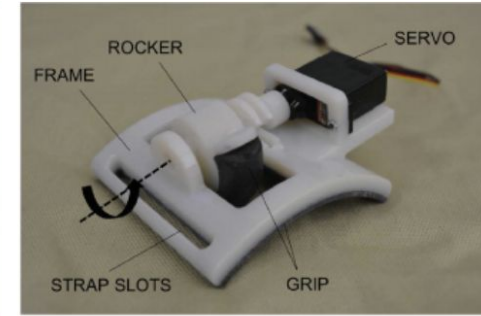
- Full assembly combining gauntlet + wrist attachment.
- Designed for easy component swapping for multiple haptic configurations.

Research

- Longitudinal stretch outperformed lateral with lower user error.
- Skin stretch proved effective for conveying proprioceptive cues.
- Longitudinal orientation gave clearer, more intuitive feedback.



(a) Lateral Rocker Orientation



(b) Longitudinal Rocker Orientation

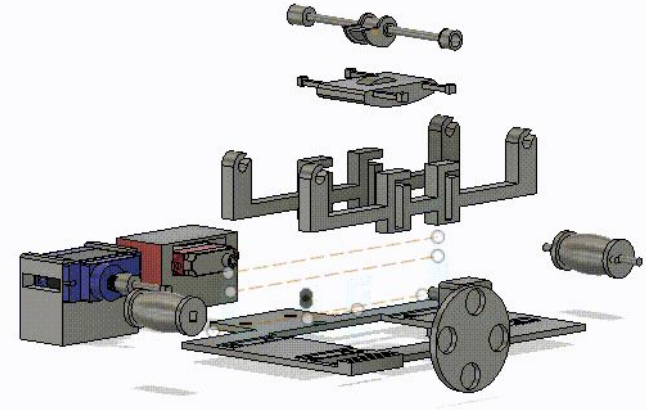
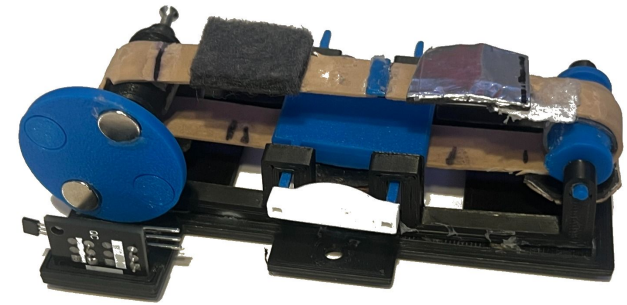
Rice Haptic Rocker



Skin Stretch Testing

Conveyor Belt Subsystem Purpose

- Provide the user with reliable tactile feedback
- **Functional Requirements**
 - Must rotate to five different texture positions
- **Design Constraints**
 - Textures must be flexible and keep the sensory characteristics of the real materials



Mechanical Iterations and Improvements

- Moved from using two bands to using one thicker band to eliminate different stretching
- **Rollers**
 - Changed geometry to maintain smooth movement and prevent belt wandering
- **Magnet Location**
 - Started with the magnets on the belt with the textures
 - Lastly we went with adding the magnets on a disk that moves with the roller

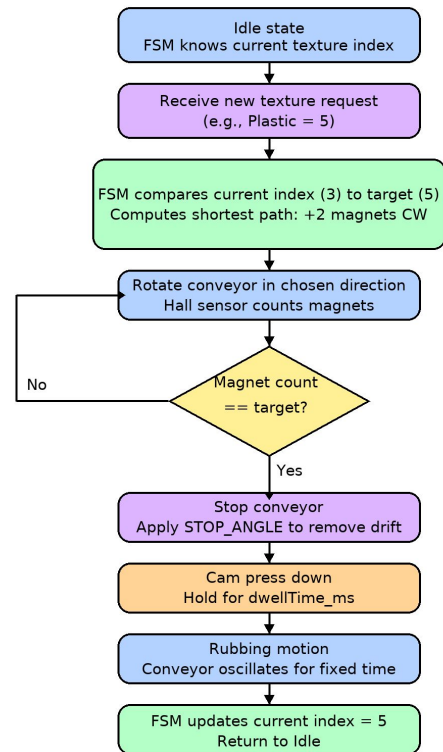


Code Architecture

- Position Detection
 - A single Hall sensor detects and counts magnets
 - 360° servo rotates index the magnets index matches the input
- Texture Selection Logic
 - Implemented a finite state machine (FSM)
 - Reduces total movement time
- Cam Mechanism and Rubbing
 - Cam pushes a platform to the users skin and the 360° servo rubs the texture for 4 seconds

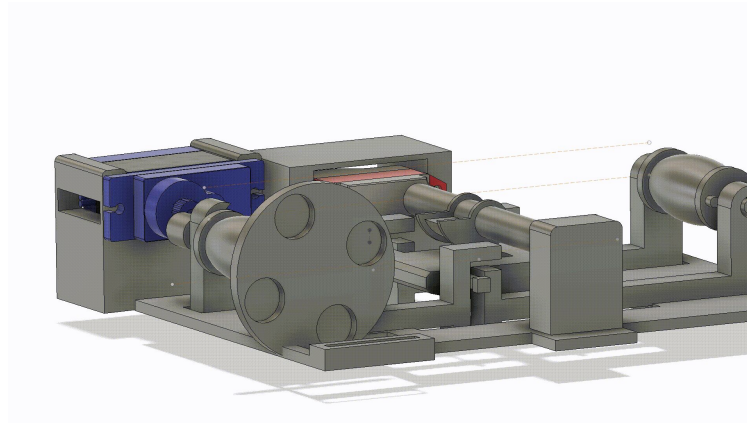
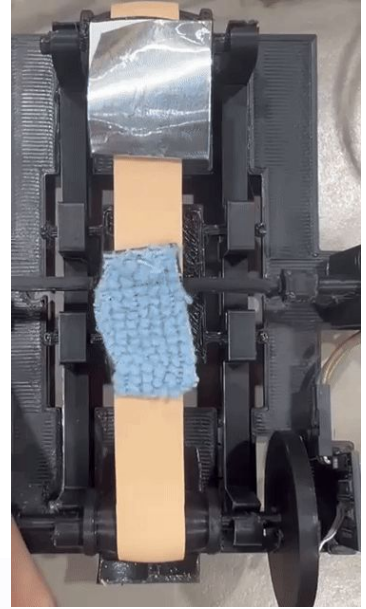
Conveyor Control Logic - FSM Example

Example: current = Wood (3) → Request = Plastic (5)



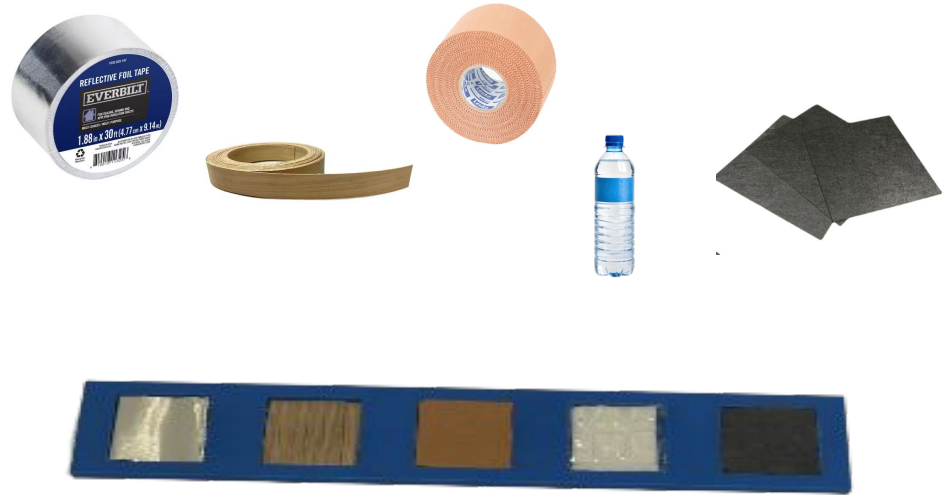
System at Work

- Accurate texture indexing with consistent magnet count and position
- Stable and smooth conveyor motion



Material Selection

- Metal => Reflective Foil Tape
- Wood => White Birch Veneer Wood
- Skin => Leukotape
- Plastic => Plastic Water Bottle
- Fabric => Felt



Material Testing

10 participants tested under 2 methods on lower tricep

6 trials for each of the 5 textures = 30 trials per test

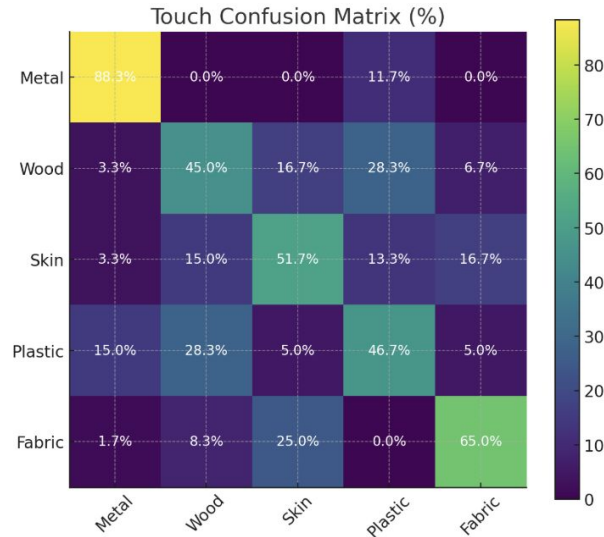
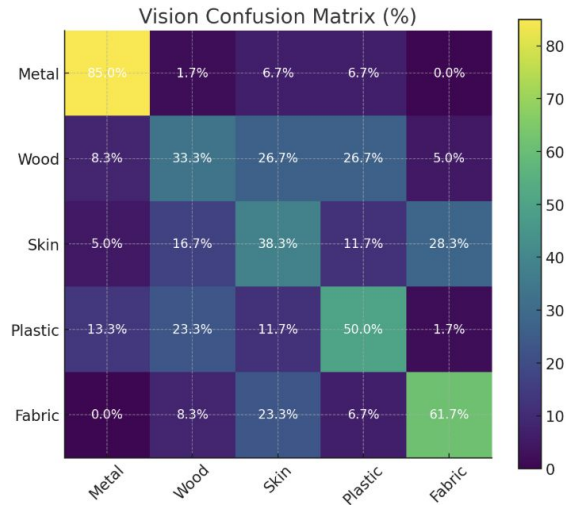
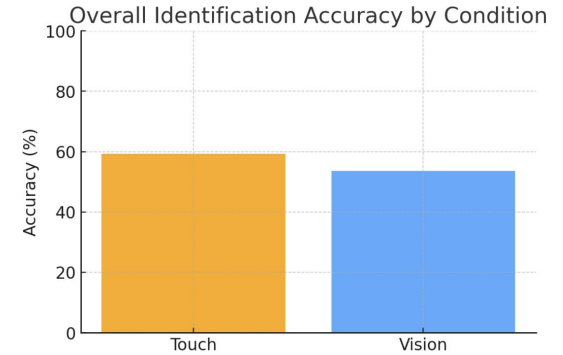
- Vision Only:
 - Only able to look at sample tray but not touch
- Touch Only:
 - Only able to touch sample tray but not look

These tests were done to reduce any cross-modal bias



Material Evaluation

Touch Only (59.3%) performance was slightly higher than Vision Only (53.7%),
indicating that visual perception is almost as strong as tactile

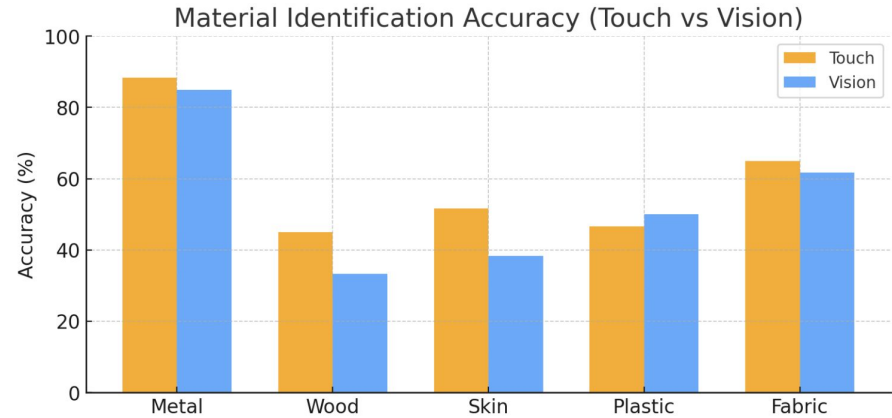


Material Changes

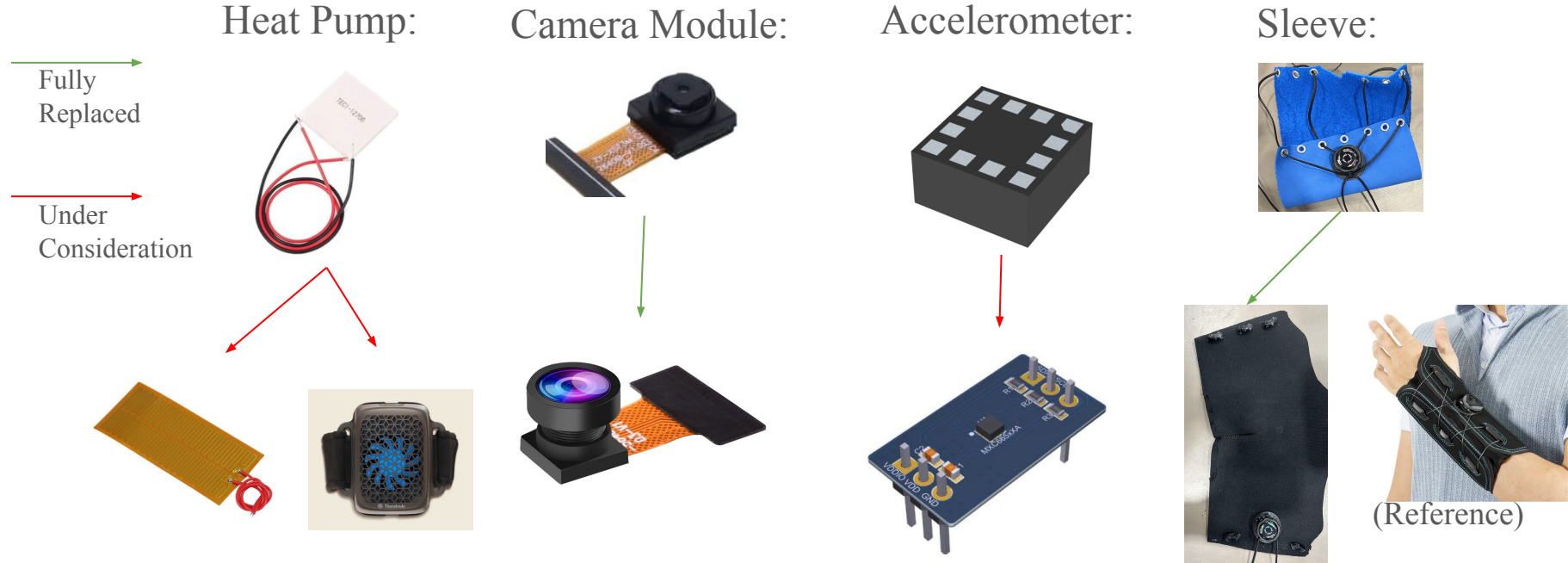
To reach over 80% accuracy on each material we will keep metal and upgrade the rest:

- Wood => Tree Bark Sheet
- Skin => Second Skin
- Plastic => PET (polyethylene terephthalate) sheet
- Fabric => Microfiber towel

These new materials have highly distinct textures, surface roughness, and thermal conductivities, making them much easier for users to distinguish through haptic feedback.



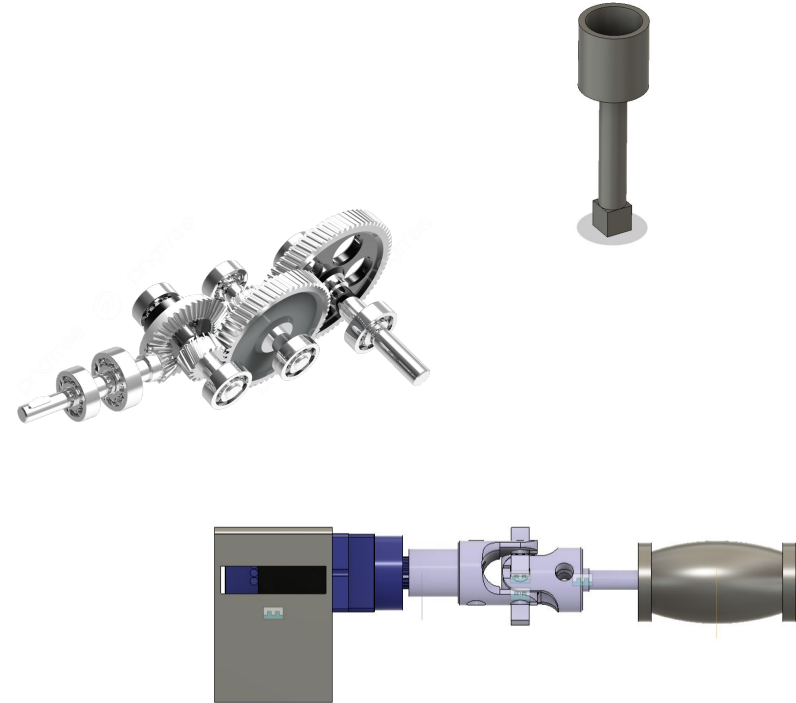
Future Component Improvements/Updates



- Temperature and Vibration Tests are pending due to sensor complications
- Prioritizing Texture Application Tests

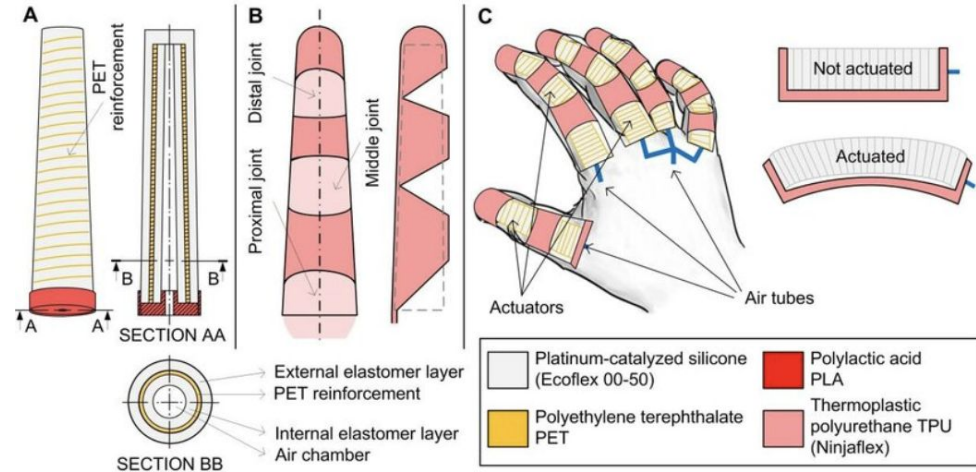
Future Work

- Use a metal roller shaft to prevent shearing and improve durability.
- Add a gear reduction to slow the magnet disk, allowing a shorter disk and a slimmer system.
- Include a universal joint so the servo conveyor assembly can pivot and better wrap around different arm sizes.



Possible Casing

- PET(Polyethylene Terephthalate) keeps the material from bulging outward and guides it to stretch in a clean, controlled way.
- It adds strength and stability, helping the structure handle pressure without deforming or tearing.
- Used between wire clips, it keeps the housing from swelling into gaps and protects cables from bends or wear.



Alves, Samuel & Babcinski, Mihail & Silva, Afonso & Neto, D.M. & Fonseca, Diogo & Neto, Pedro. (2023). Integrated Design Fabrication and Control of a Bioinspired Multimaterial Soft Robotic Hand. 10.48550/arXiv.2308.04516.

9th Cohort Calendar

- CDR: December 8th, 2025
- Cal State Biotech Fair: January 24th, 2026
- Report: March 22nd, 2026
- CSUN Posium: April 2026
- CSUN Showcase: May 2025

Thank you!
Any Questions?

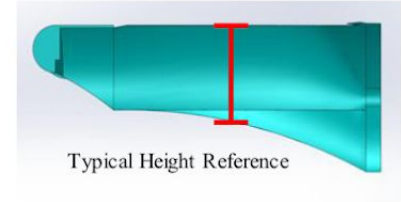


Appendix & Additional Info

Palm Dimensions Comparison

8th Cohort Palm Specifications

Cohort Year	5 th Cohort	6 th Cohort	7 th Cohort (Persistence)	8 th Cohort
Maximum Width [mm]	94	107	96	96
Maximum Length [mm]	124	176	133	115
Typical Height [mm]	27	32	27	31
Wrist Width [mm]	48	66	66	66



9th Cohort Palm

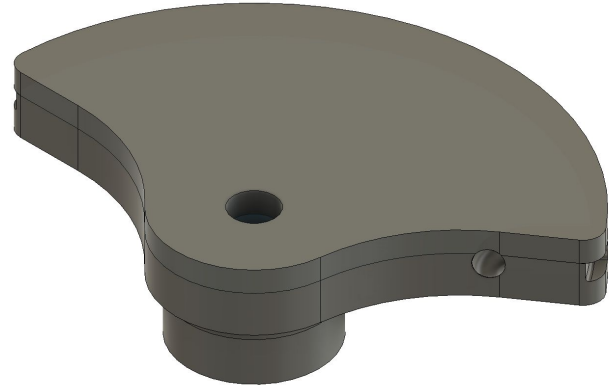
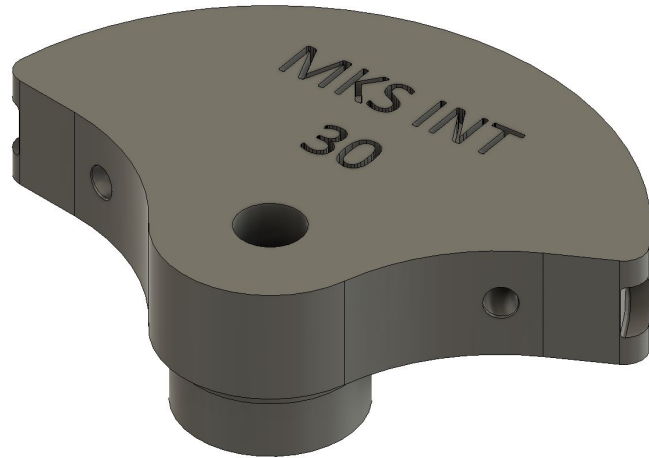
94.0

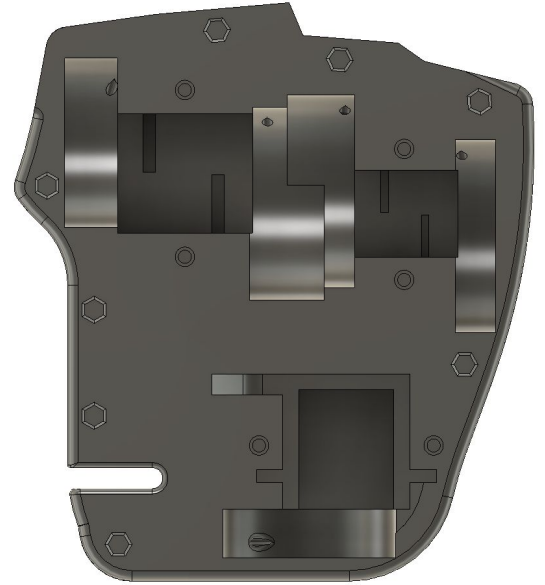
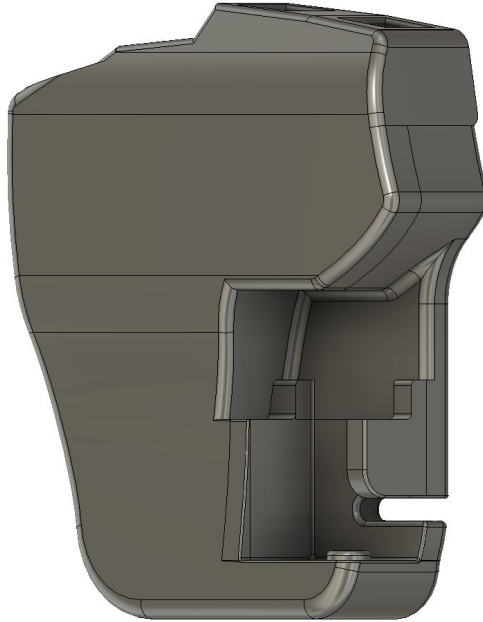
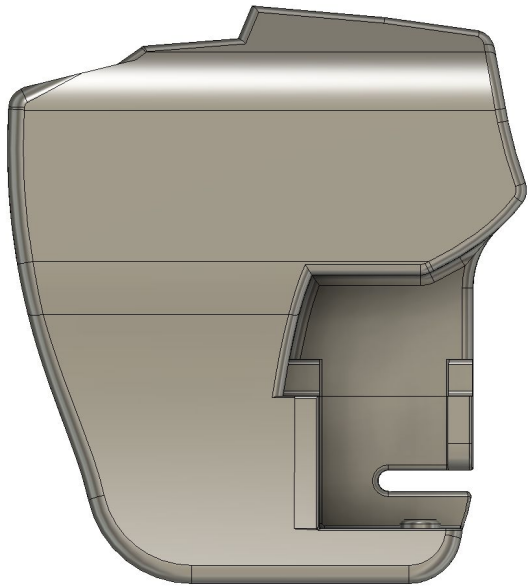
121.8

25.7 → 37.6
(with cover)

65

Spools for Servos

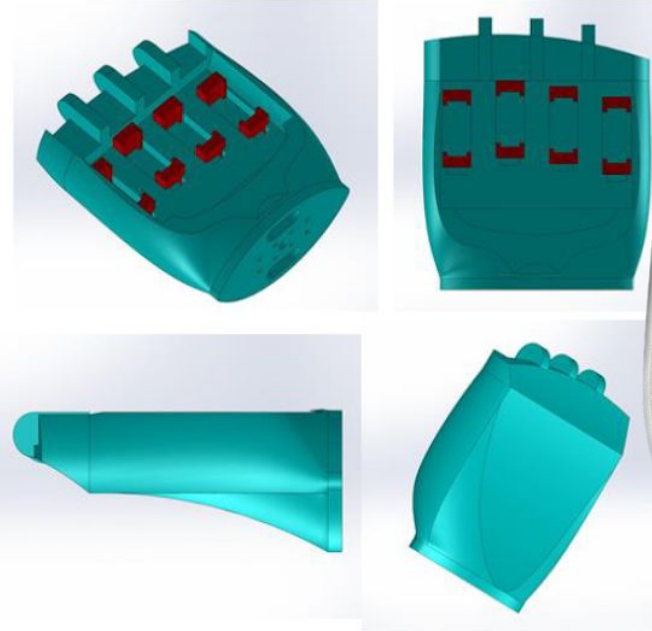




Palm Weight

Optimization Palm

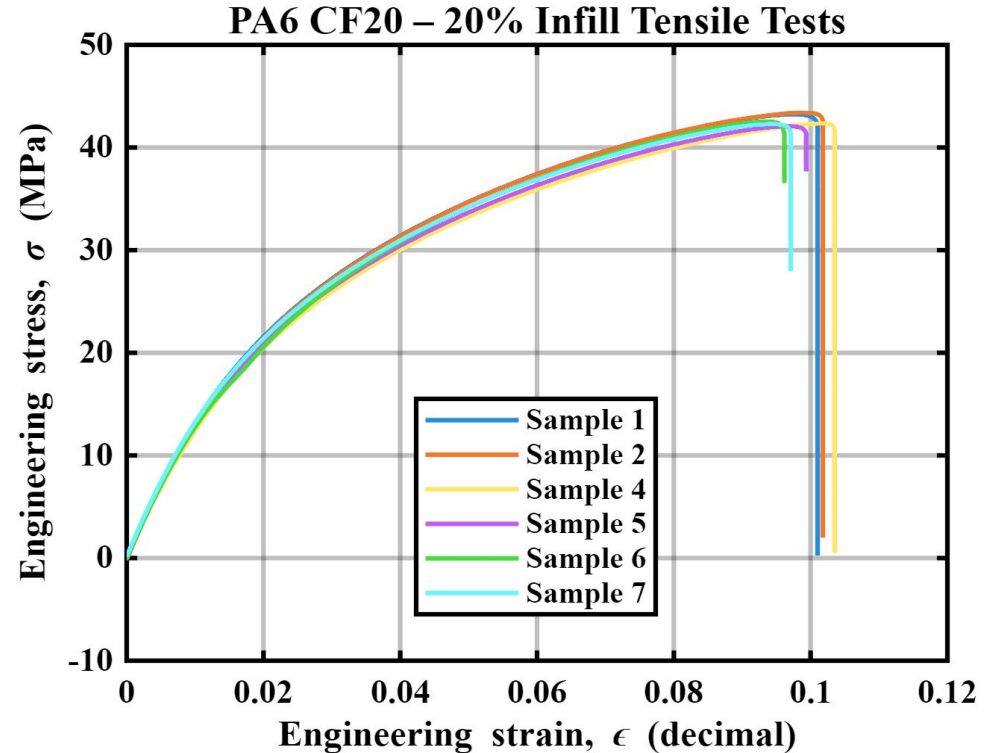
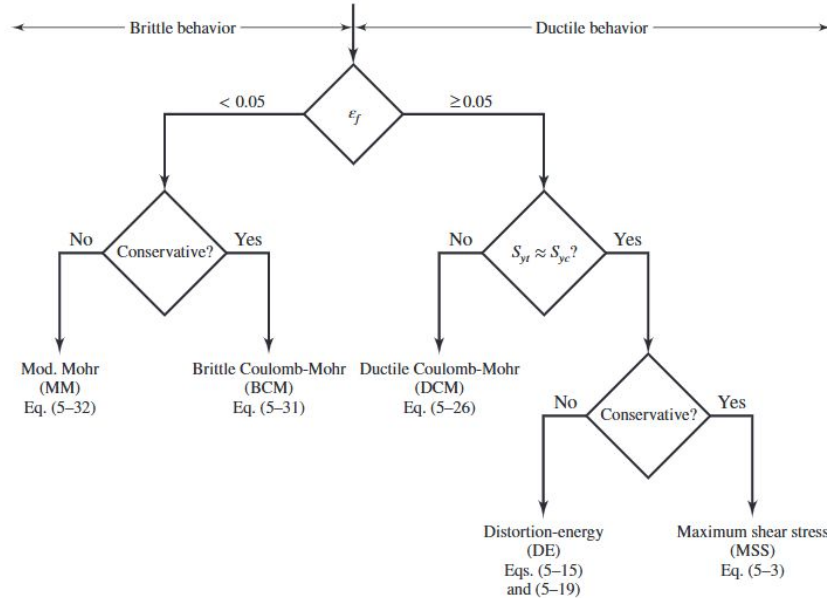
- Designed to fit AO8 servo motors, new drivetrain, and updated finger
- Mass has been reduced to from ~300g (0.66lb) to 127g (0.28 lb)
- Roof removed for now, has been replaced with slots to guide the fingers
 - Will most likely look to add some form of roof or cover in later iterations



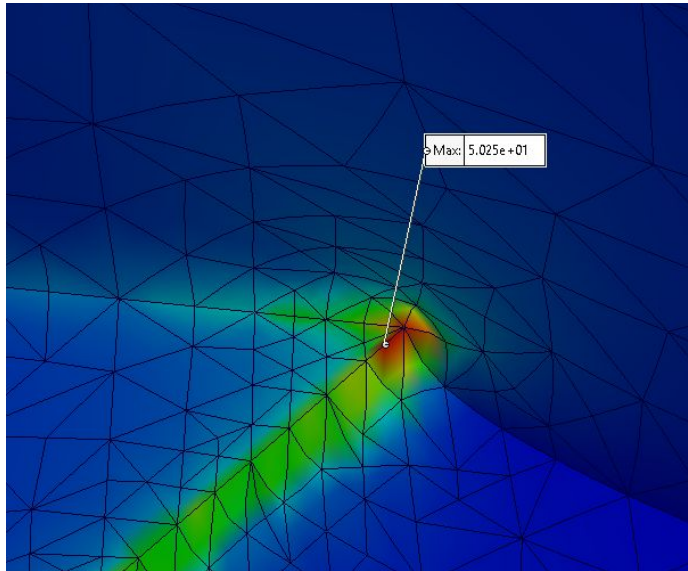
Finger strengths KST A08 Raw Values (Squeeze)



Tensile Testing Overlapped Graph for 20% infill Samples



Shoulder Actuation FEA



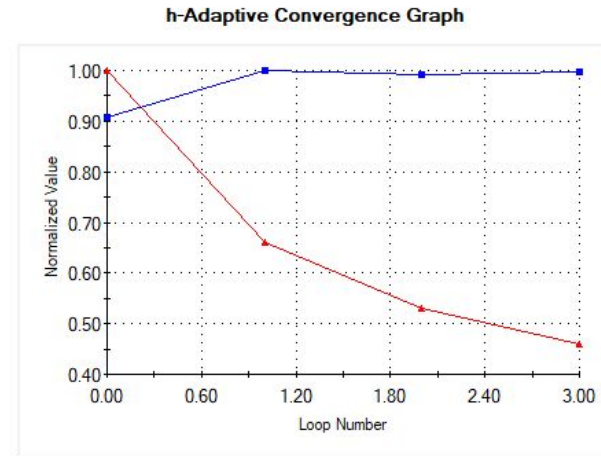
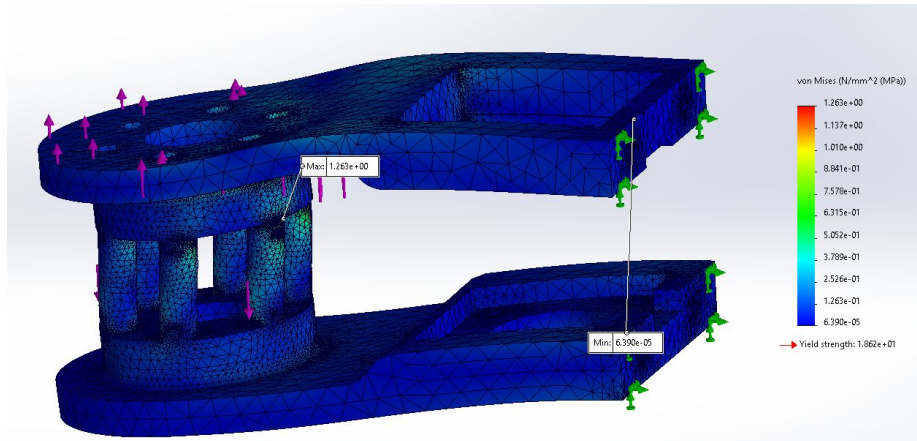
	Value	Unit
Sum	1.362e+02	N/mm^2 (MPa)
Avg	1.702e+01	N/mm^2 (MPa)
Max	3.649e+01	N/mm^2 (MPa)
Min	1.866e+00	N/mm^2 (MPa)
RMS	2.046e+01	N/mm^2 (MPa)

Regional Avg: 17.02 Mpa

$$\text{Factor of Safety: } \frac{18.62 \text{ MPa}}{17.02 \text{ MPa}} = 1.09$$

Elbow Actuation FEA

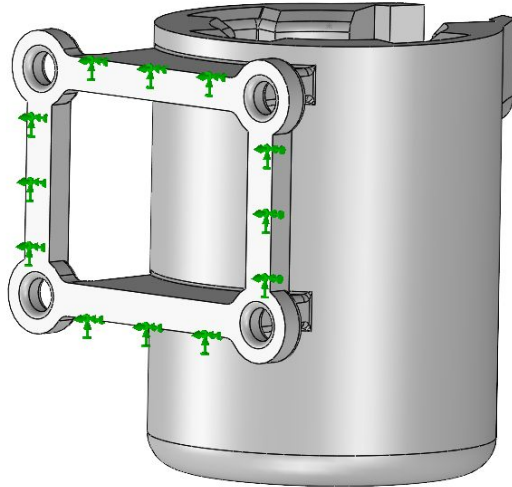
Factor of Safety: 15



Global Criterion: Total relative Strain Energy Norm error < 3.21162%
— Target accuracy — Maximum von Mises Stress

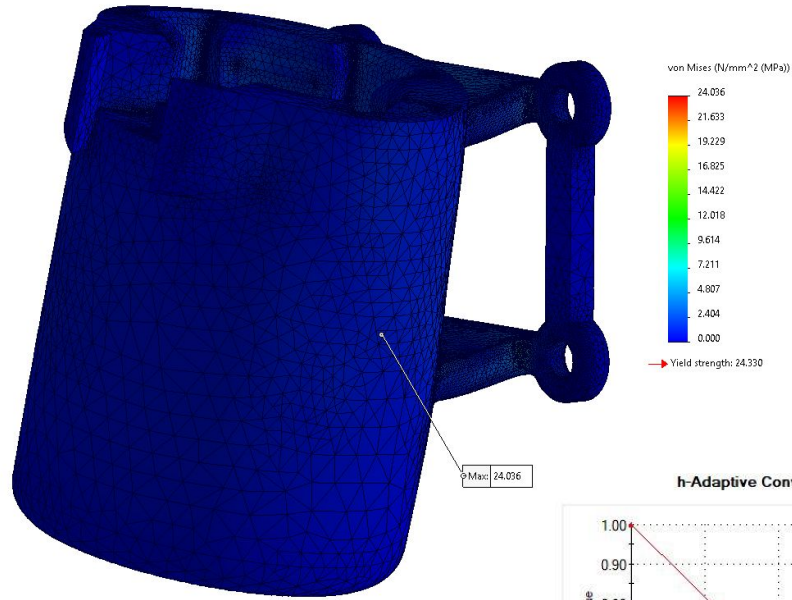
3.2093, 0.834389

FEA of connector

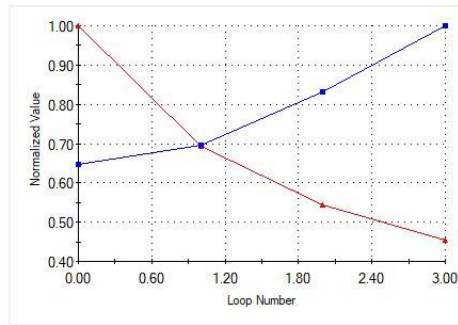


- PLA Gyroid 10% Infil

Property	Value	Units
Elastic Modulus	1602	N/mm ²
Poisson's Ratio	0.394	N/A
Shear Modulus	1092	N/mm ²
Mass Density	1020	kg/m ³
Tensile Strength	24.33	N/mm ²
Compressive Strength	12	N/mm ²
Yield Strength	24.33	N/mm ²
Thermal Expansion Coefficient		/K
Thermal Conductivity	0.2256	W/(m·K)
Specific Heat	1386	J/(kg·K)
Material Damping Ratio		N/A



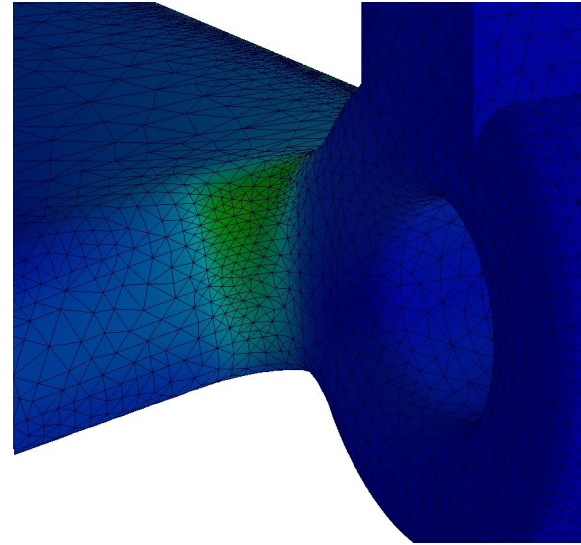
h-Adaptive Convergence Graph

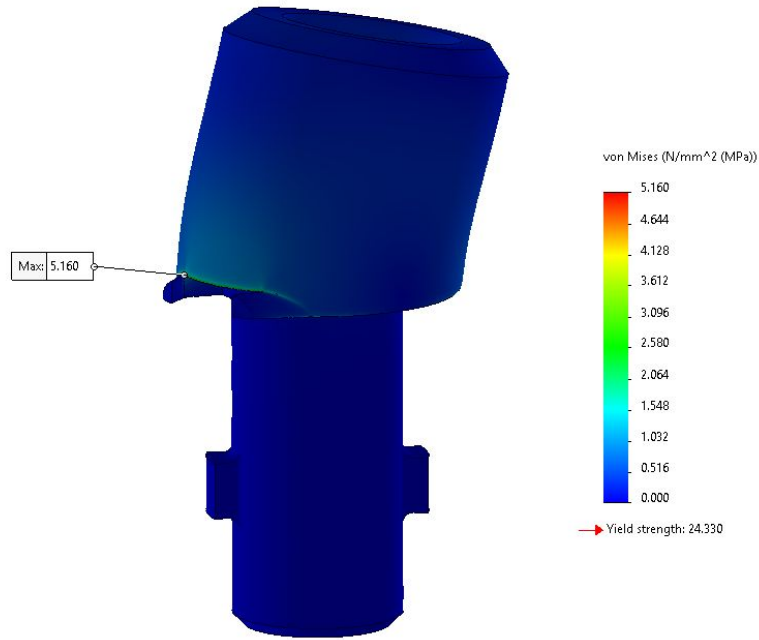


Global Criterion: Total relative Strain Energy Norm error < 1.81773%

—▲— Target accuracy —■— Maximum von Mises Stress

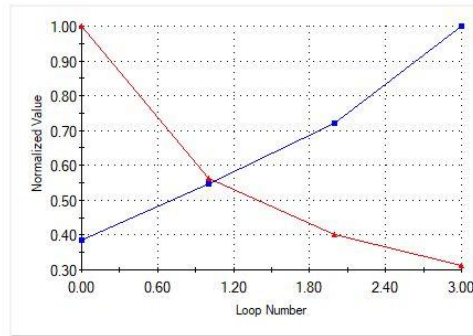
-0.0697674, 1.05158





Max: 5.160

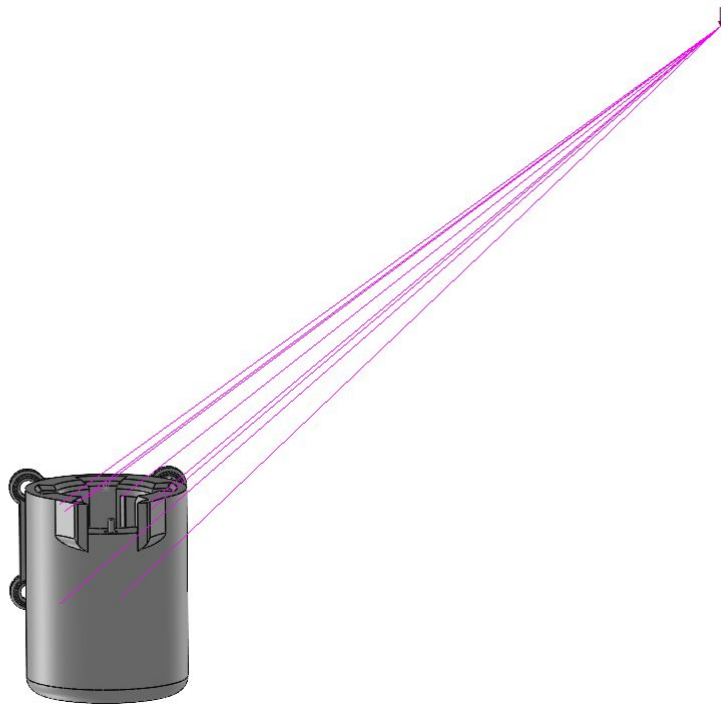
h-Adaptive Convergence Graph



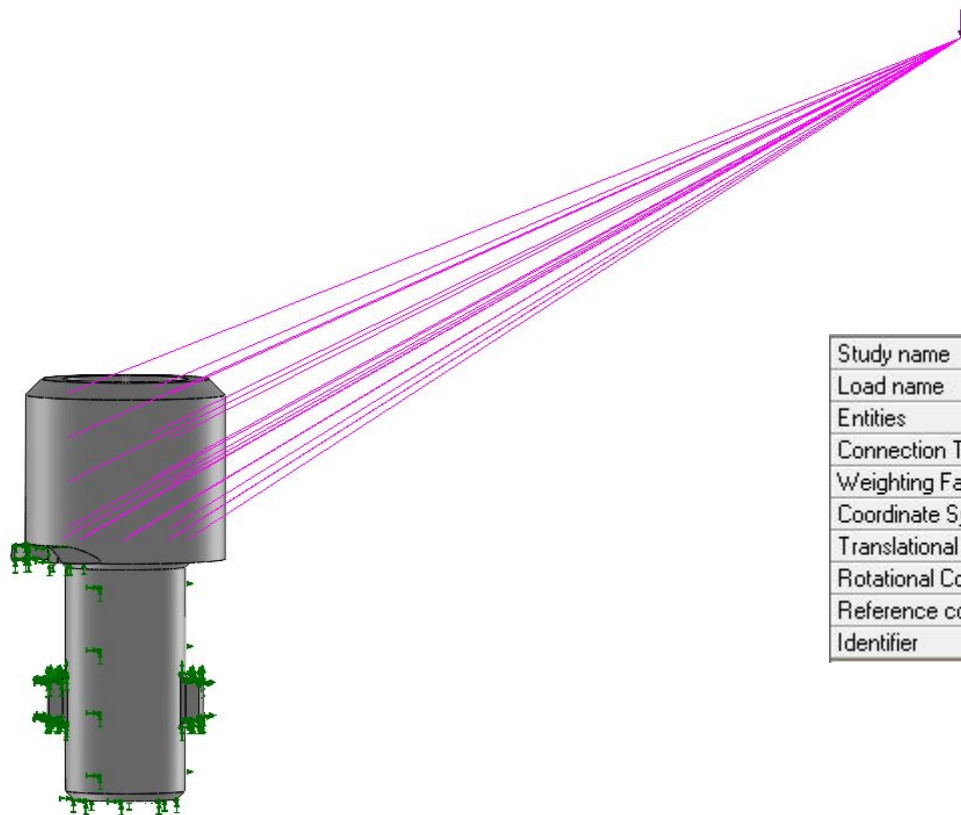
Global Criterion: Total relative Strain Energy Norm error < 1.82335%

Target accuracy Maximum von Mises Stress

0.968023, 1.06018



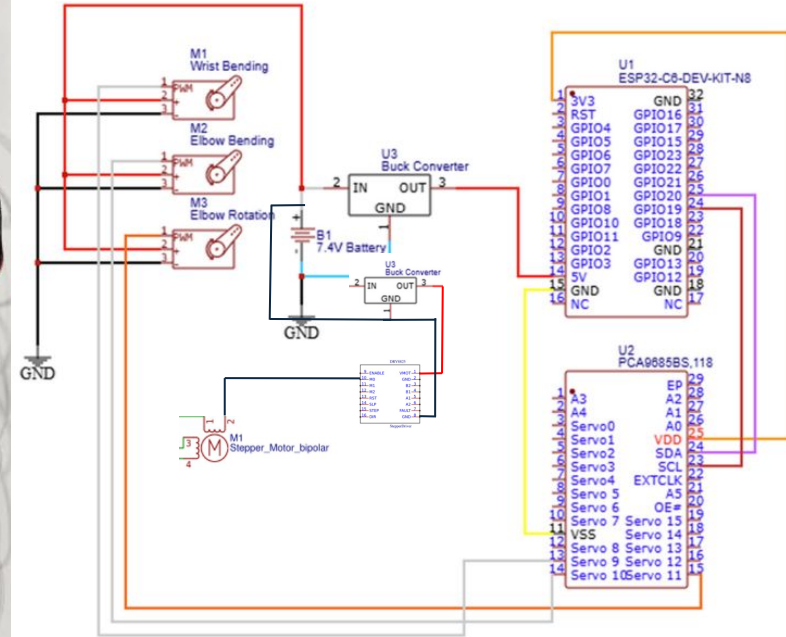
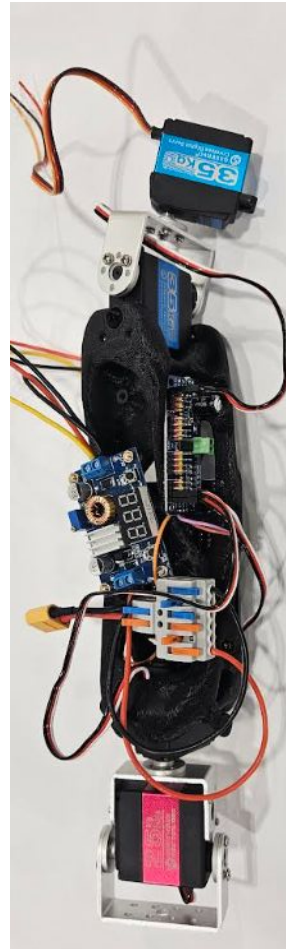
Study name	Static 1* (-Default-)
Load name	Remote Load (Distributed con
Entities	3 face(s)
Connection Type	Distributed
Weighting Factor	Default (Constant)
Coordinate System	Coordinate System1
Translational Components	---,---,15 lbf
Rotational Components	---,---,---
Reference coordinates	10 6 6 in
Identifier	2



Study name	Static 1* (-Default-)
Load name	Remote Load (Distributed con
Entities	2 face(s)
Connection Type	Distributed
Weighting Factor	Default (Constant)
Coordinate System	Coordinate System1
Translational Components	---,---,15 lbf
Rotational Components	---,---,---
Reference coordinates	10 6 4 in
Identifier	2

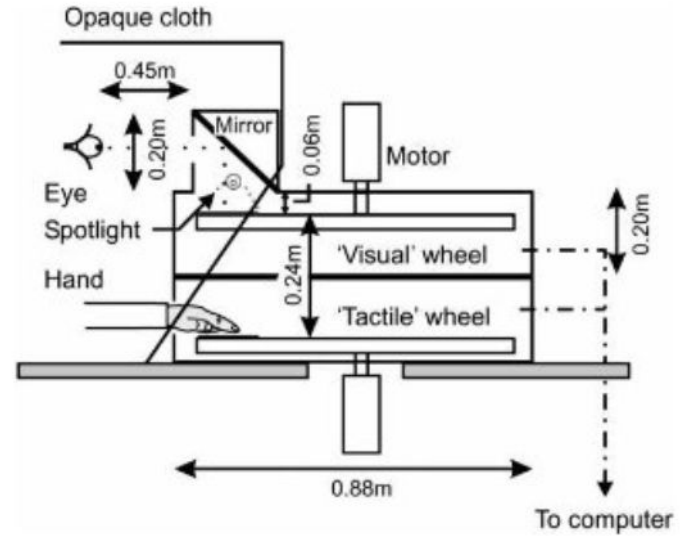
Prototype Arm

- Based off the last cohort's design with an added shoulder to resemble the DOF of the new arm.
- Will Run ESP32 at 8v along with servos for performance
- Can add more safety features if deemed necessary



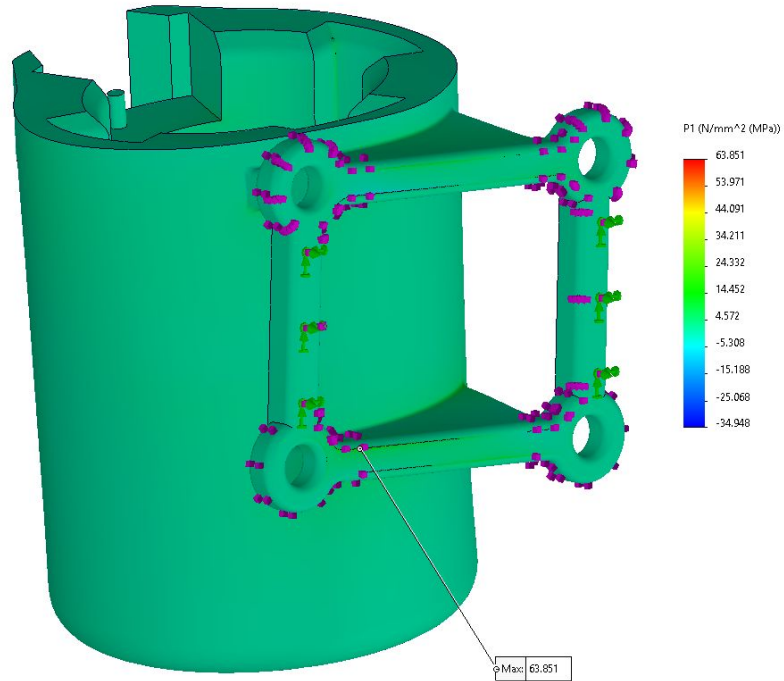
Testing Validation

- Tests compare vision vs touch vs combined sensing to evaluate discrimination performance.
- Measures sensitivity and bias to see if multisensory input improves perception or divides attention.
- Validates whether combining cues is beneficial or redundant for prosthetic texture feedback.



Spence, C. (2003). What role does multisensory integration play in the visuotactile perception of texture? *International Journal of Psychophysiology*.
[https://doi.org/10.1016/S0167-8760\(03\)00125-9](https://doi.org/10.1016/S0167-8760(03)00125-9)

Brittle Mohr FEA



Control System

