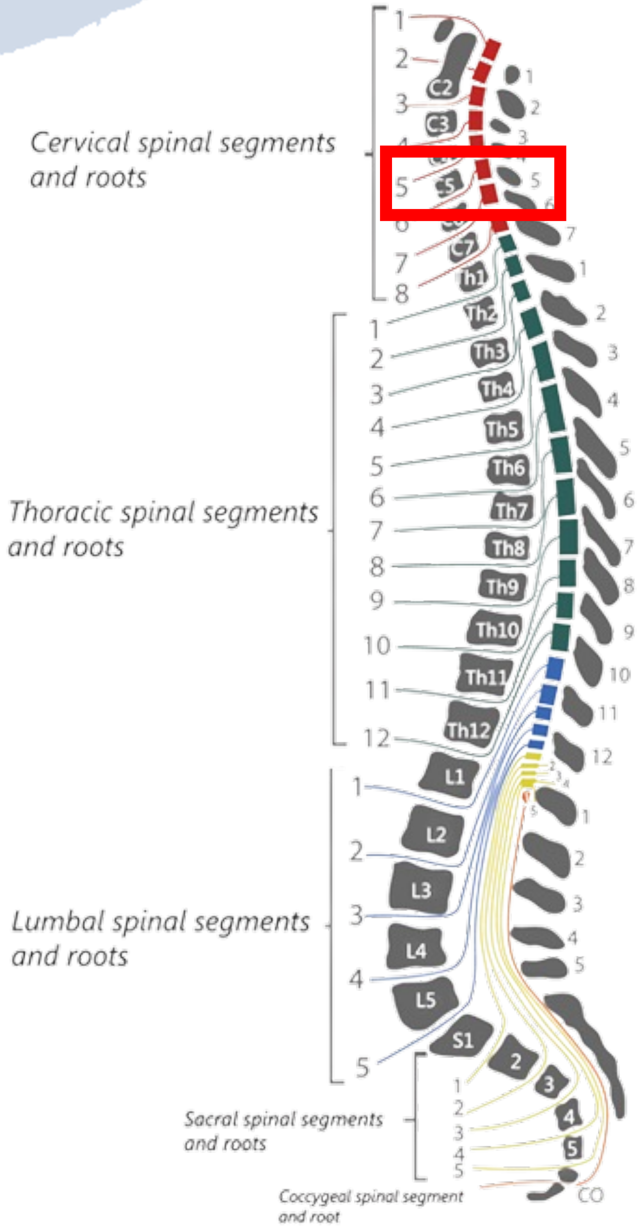
Hand Orthosis for Living Activities

Angela Souza, Zarifa Nazarali, Kathryn MacQuarrie, Faraz Ali

Group 5

Problem Statement

- **Spinal Cord Injury (SCI)** causes profound life changes, especially at the **C5 level** [1]
  - Patients at an American Spinal Injury Association (ASIA) C level retain some functionality below the injury [2]
- Impairments in **upper limb functionality** cause difficulty in completing Activities of Daily Living (ADLs) [1,3]
  - This compromises patient independence



Neomano [4]

The Market Gap

Current solutions offer effective movement, but require assistance and are time-consuming to don/doff

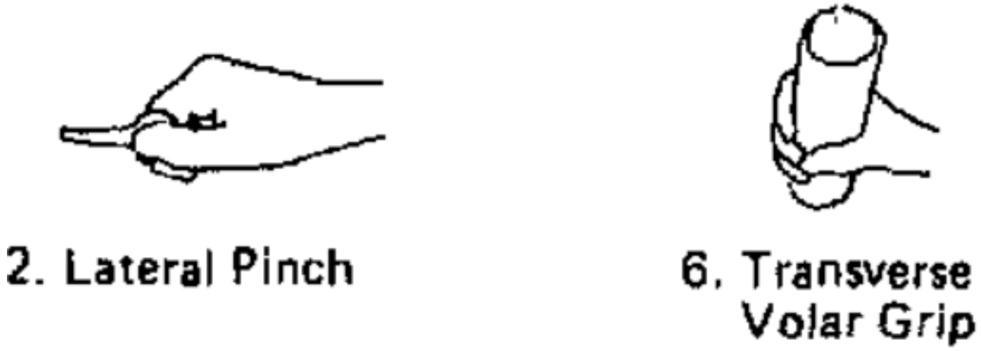
"If there's a device I need a care attendant to put on, I don't ever foresee using it."

- Andrew McPherson, C5/C6 Spinal Cord Injury Patient [6]

NESS H200 [5]

Situation Impact Statement

Design a device, to be used at home by C5 SCI patients classified at a C level on the ASIA scale, that allows for **independent donning, doffing,** and the performance of ADLs associated with **transverse volar grips (TVGs)** and **lateral pinches (LPs)**.

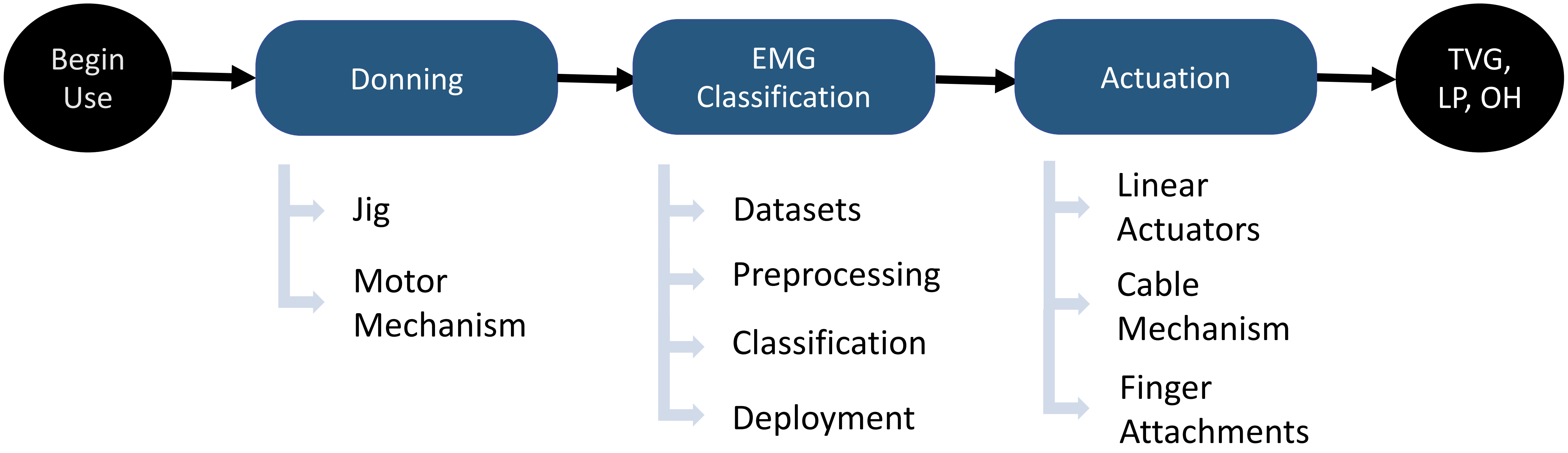


Targeted Grips [7]

Project Scope and Objectives

- Create a **high-fidelity prototype** that supports user independence and safely allows for the user to complete the desired hand grasps
- Develop a **highly specific classification algorithm** that leverages electromyography (EMG) signals to determine grasp intention
- **Conduct user testing** with an SCI patient to assess the ease of donning/doffing and overall functionality

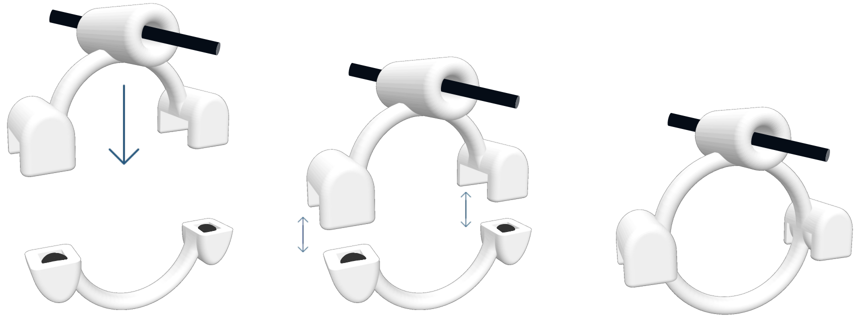
High Level Overview



Donning/Doffing – Jig

Goal: Open and position user's hand

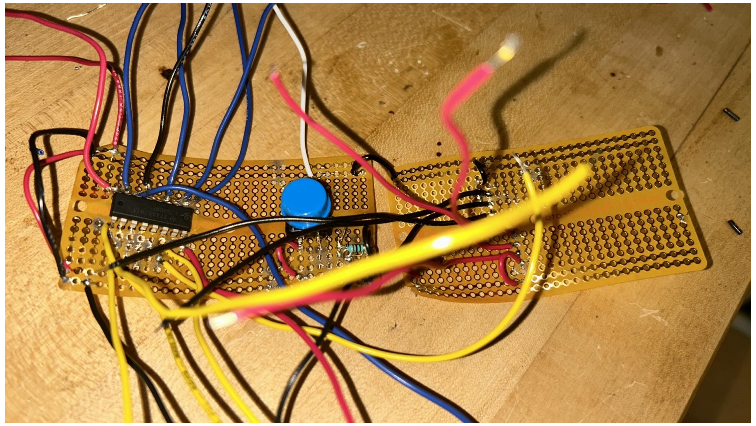
- Curved edge and grooves facilitate opening and alignment
- Indents hold and position the bottom half of the finger attachments

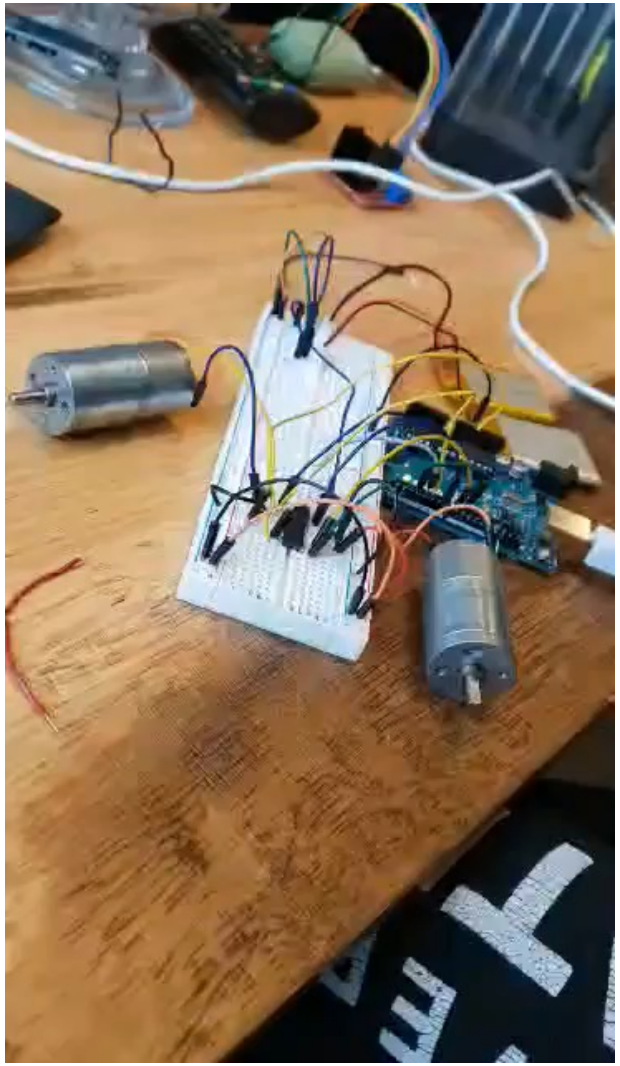


Donning/Doffing – Motor Mechanism

Goal: Facilitate independent donning/doffing

- Initiate via push button
- Motors appropriately timed to lower/raise top half of device
  - Doffing → higher current to lift against gravity
- Maintain weight balance of components through specific positioning
- Worm gear motors and rod holders to strengthen the rods and resist torque

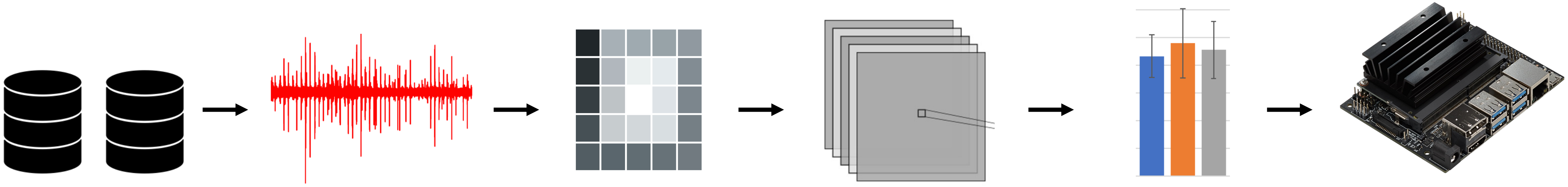




EMG Trigger – Overview

Goal: Detect user intent

Electromyograph (EMG) shown to be effective for intent detection [8-10]



Datasets → Preprocessing → Feature Extraction → Model → Offline Results → Deployment

EMG Trigger - Datasets

- Data requirements:
  - Max. 5 EMG channels
  - Specific placement of electrodes
  - Inclusion of Open Hand (OH) motion

NinaPro DB 10 [11]

29 healthy, 7 amputees
Transverse Volar Grip & Lateral Pinch Labels

+

GrabMyo [12]

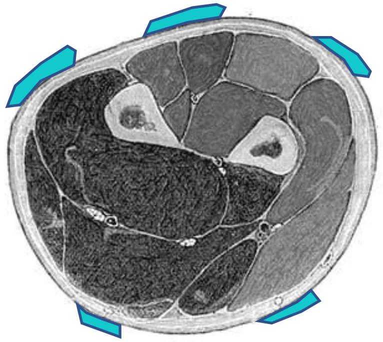
43 healthy
Open Hand Labels

EMG Trigger – Data Preprocessing

Datasets → Formatting → Filtering → Resampling → Preprocessed Signal

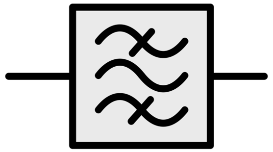
Electrode positions

Top

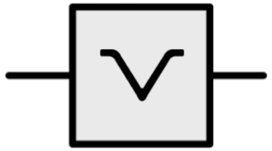


Bottom

Removal of unusable subjects/data

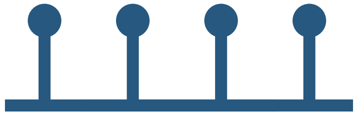


2nd Order Butterworth Band-Pass Filter 10-125 Hz

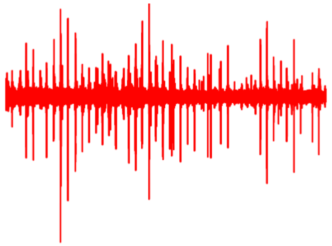


Notch Filter (QF = 30) 60 Hz

NinaPro DB 10 @ 1926 Hz
GrabMyo @ 2048 Hz

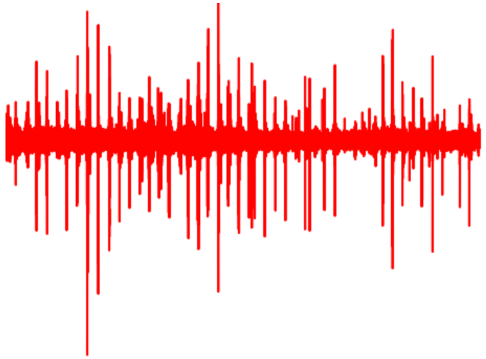


Resampled @ 250 Hz

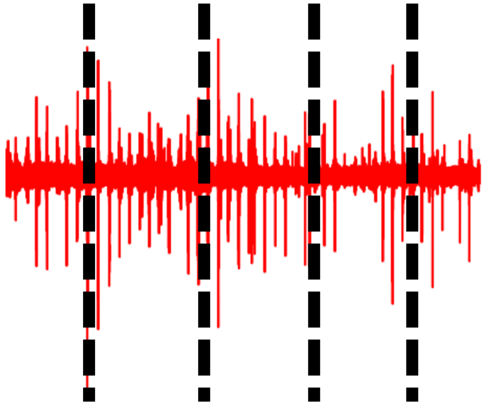


EMG Trigger – Feature Extraction

Preprocessed Signal

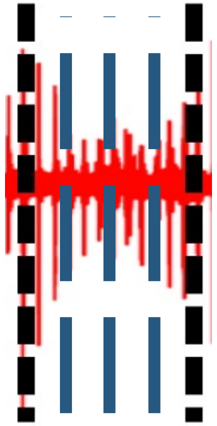


Windowing



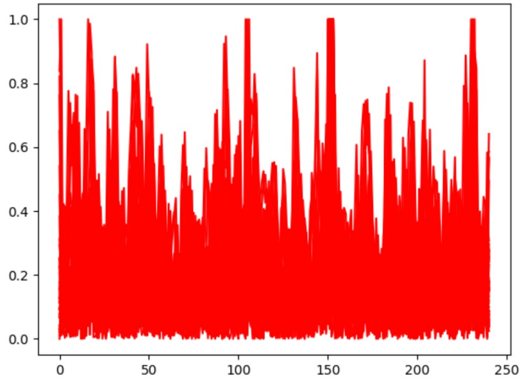
152 ms w/ 116ms overlap

Short Time Fourier Transform

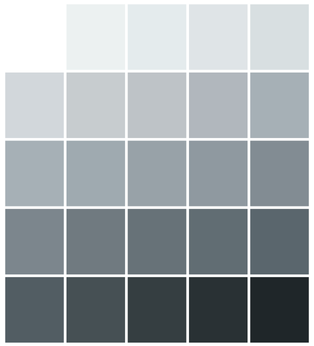


8 ms w/ 4.8 ms overlap

Min-Max Norm



Principal Component Analysis



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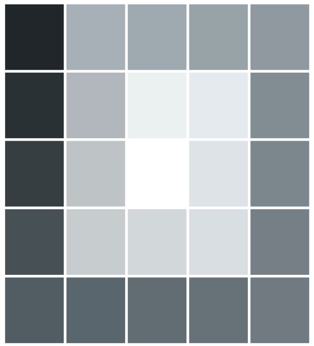
Spiral Reshape



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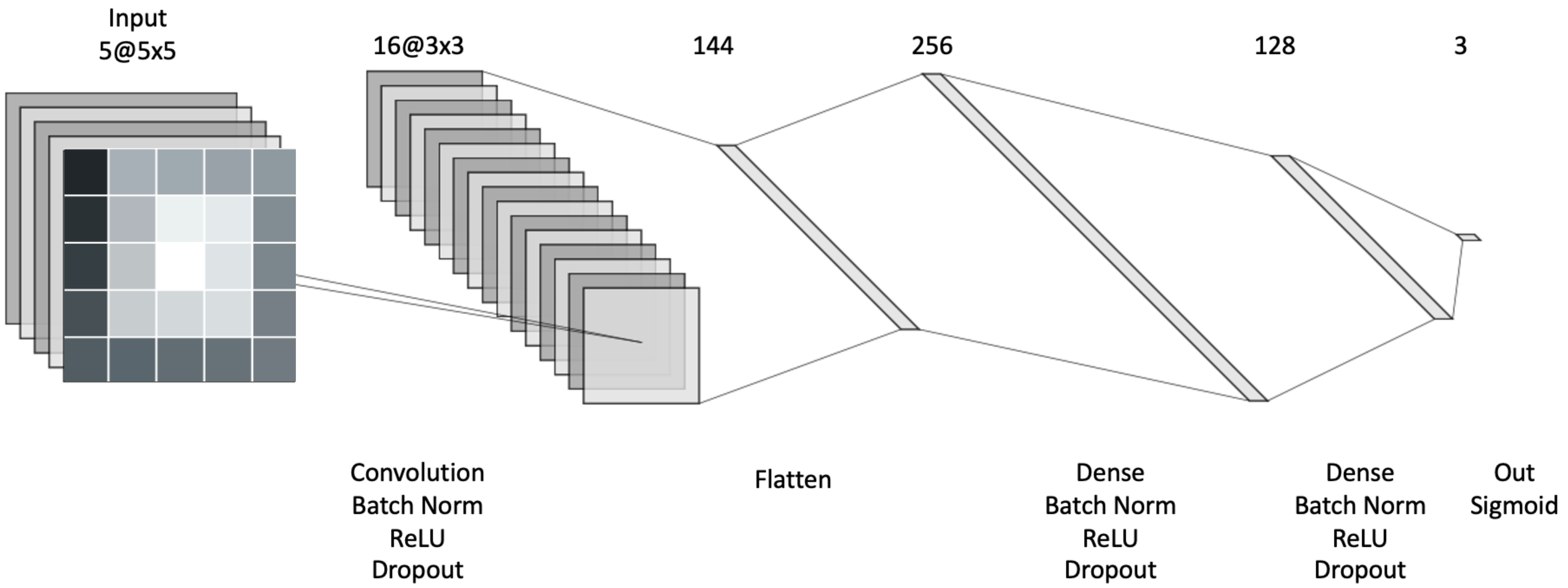
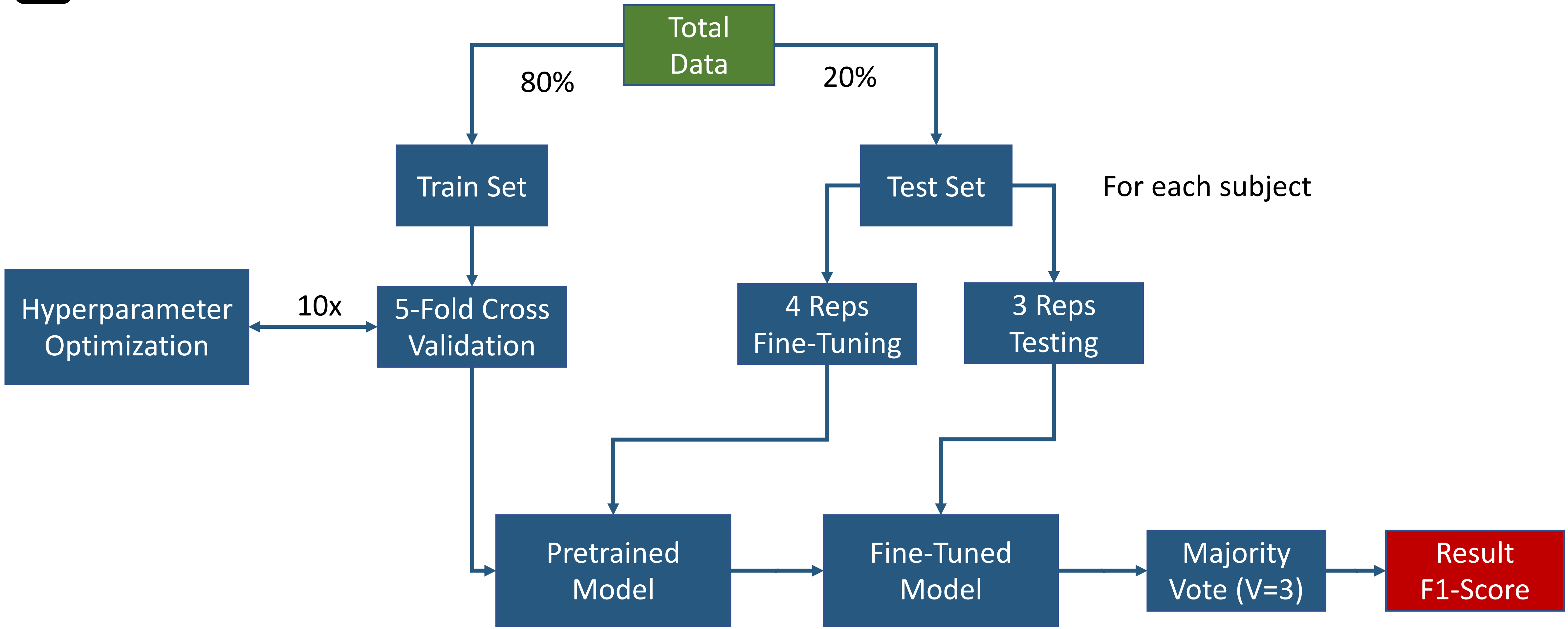
EMG Trigger – CNN Model Architecture



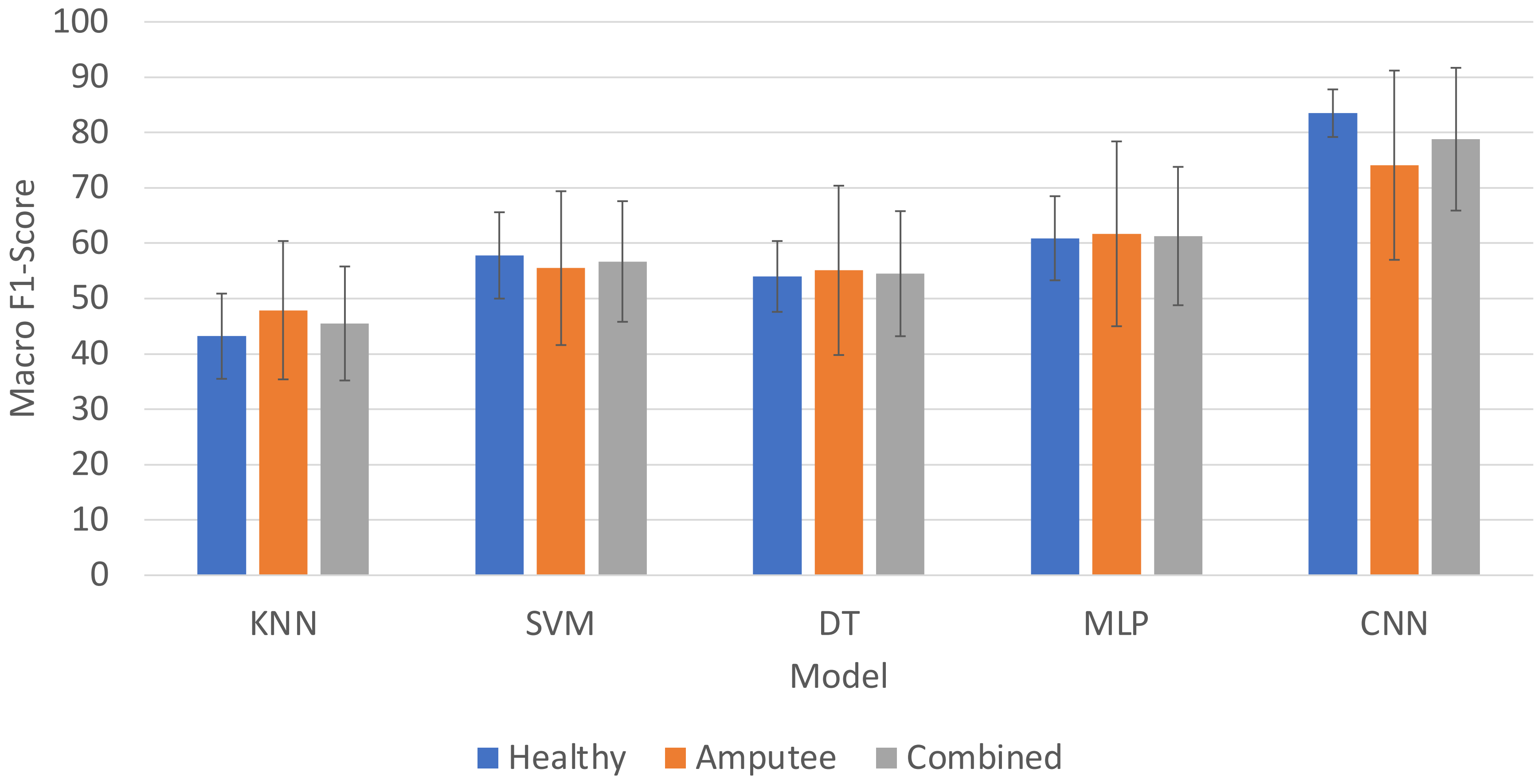
Minimizes cross-entropy loss function with class-specific weights

EMG Trigger – Experimentation Scheme



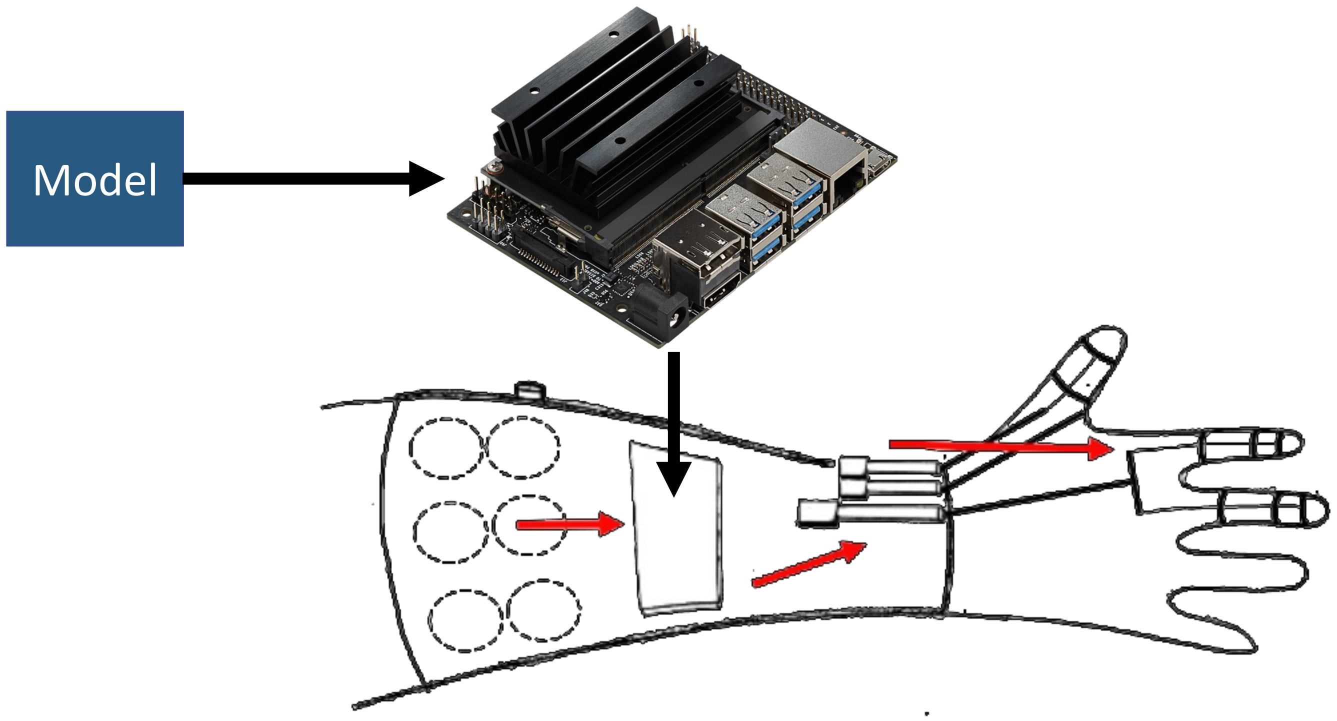
EMG Trigger – Offline Results

- Macro F1-Scores: 84% for Healthy, 74% for Amputees, 79% Combined



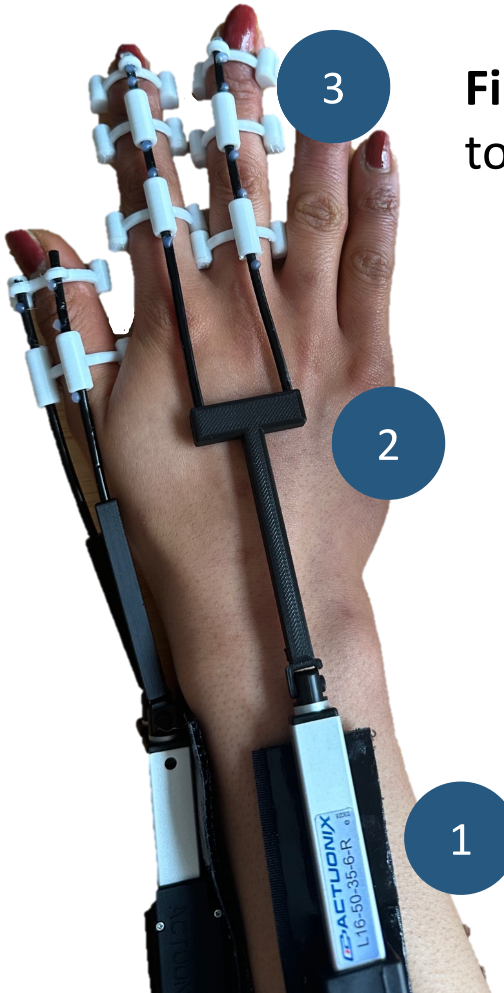
EMG Trigger – Deployment

- Deployed CNN model onto Jetson Nano microcontroller for real-time intent detection



Actuation – Overview

Goal: Facilitate desired grasps



3 **Finger attachments** to perform grasps

2 **Cable mechanism** to transmit force

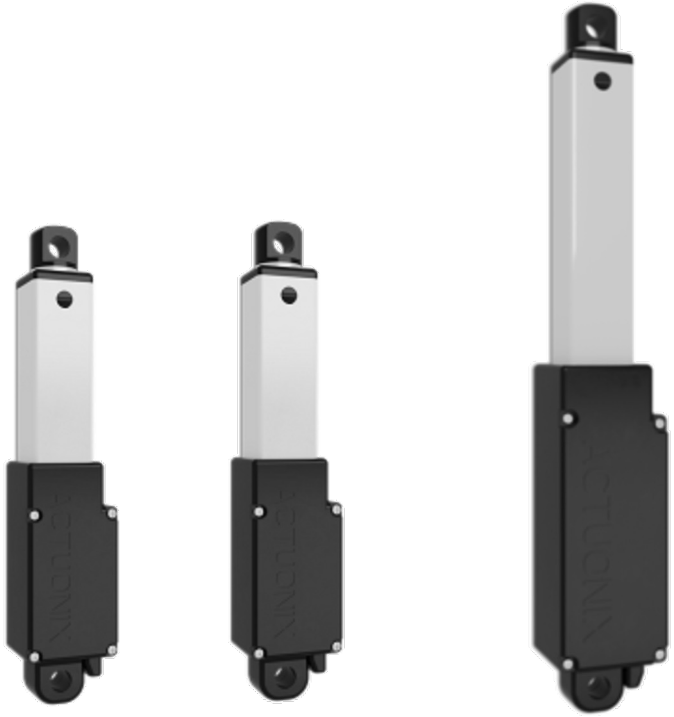
1 **Linear actuators** to generate force

Actuation – Linear Actuators

Goal: Generate force using Actuonix Rapid Control (RC) linear servos

Thumb: L12-30-50-6-R

- 30mm stroke length
- 34g mass
- 22N max force
- 25mm/s max speed
- 12N backdrive force



Flexion Extension | Abduction Adduction | Flexion Extension

Middle/Index: L16-50-35-6-R

- 50mm stroke length
- 56g mass
- 50N max force
- 32mm/s max speed
- 31N backdrive force

[13,14]

Actuation – Linear Actuators

Goal: Control force using Servo library

Transverse Volar Grip

```
void TVG() {
  // Abduct thumb
  for (pos = 0; pos <= 120; pos += 1) {
    thumb_abd.write(pos);
    delay(15);
  }

  delay(1000);

  // Flex index/middle
  for (pos = 0; pos <= 100; pos += 1) {
    index.write(pos);
    delay(15);
   }
}
```

Lateral Pinch

```
void LP(){
  // Flex index/middle
  for (pos = 0; pos <= 100; pos += 1) {
    index.write(pos);
    delay(15);
   }

  delay(2000);

  // Abduct and flex thumb
  for (pos = 0; pos <= 100; pos += 1) {
    thumb_flex.write(pos);
    thumb_abd.write(pos);
    delay(15);
  }
}
```

Actuation – Cable Mechanism

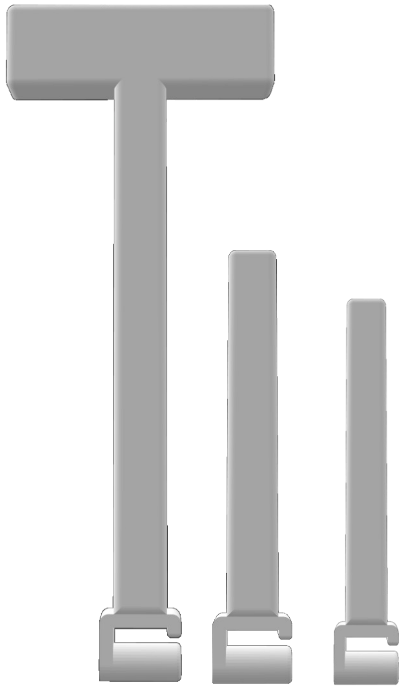
Goal: Transmit force from linear actuators

Benefits:

- Low-profile & compact
- Lightweight
- Comfortable
- Compliant

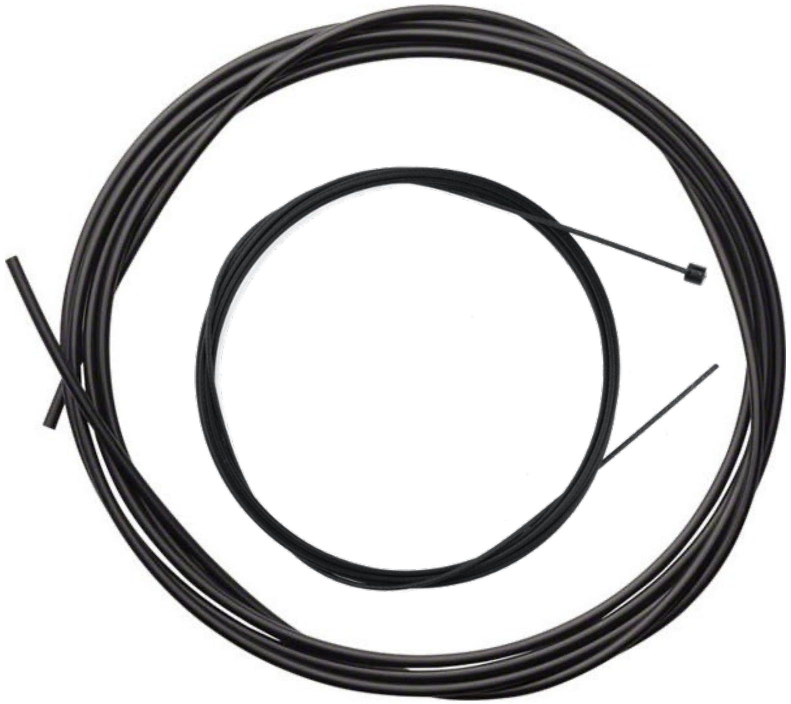
Challenges:

- Diminished strength
  - Friction
  - Buckling



3D printed connector

+



Inner: Teflon-coated cable
Outer: Seal liner

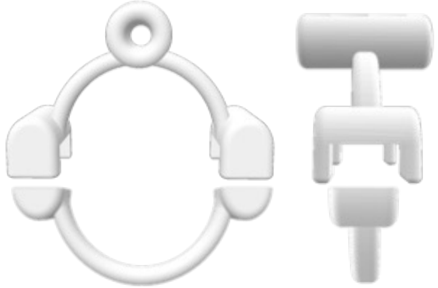
[15-17]

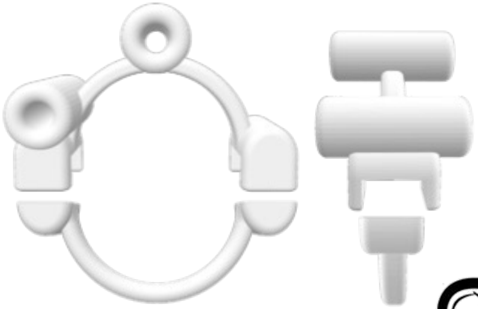
Actuation – Finger Attachments

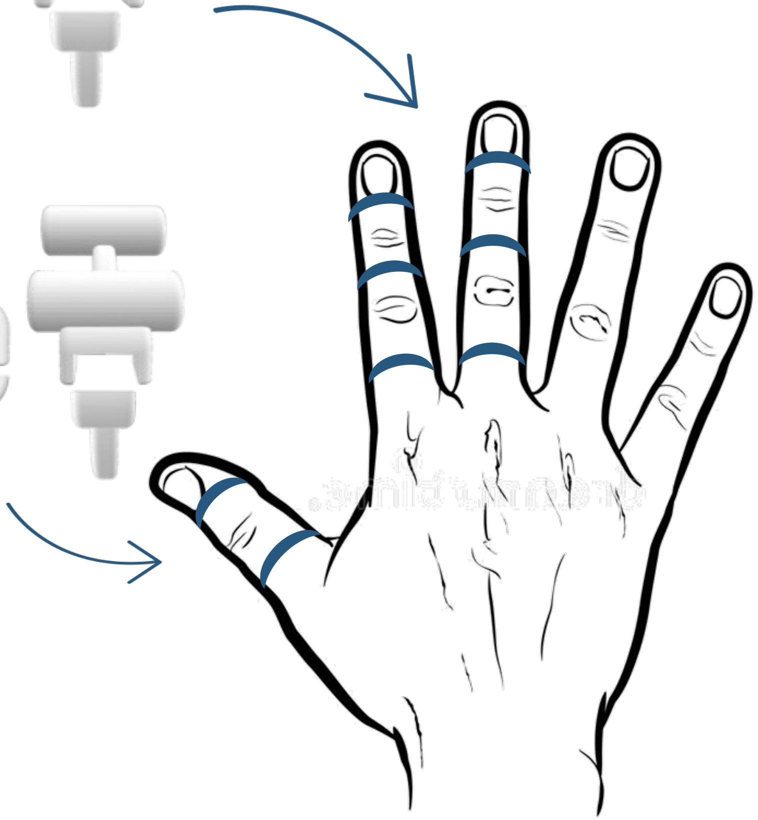
Goal: Deliver force to fingers

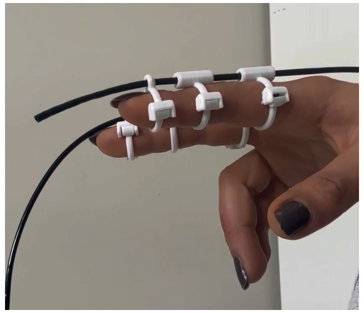
Requirements:

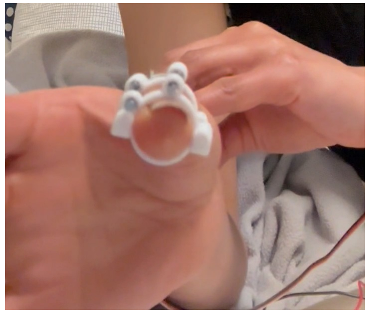
- Bend at joints vs. allow force transmission
- Prevent buckling vs. maintain comfort
- Independent donning/doffing vs. secure attachment



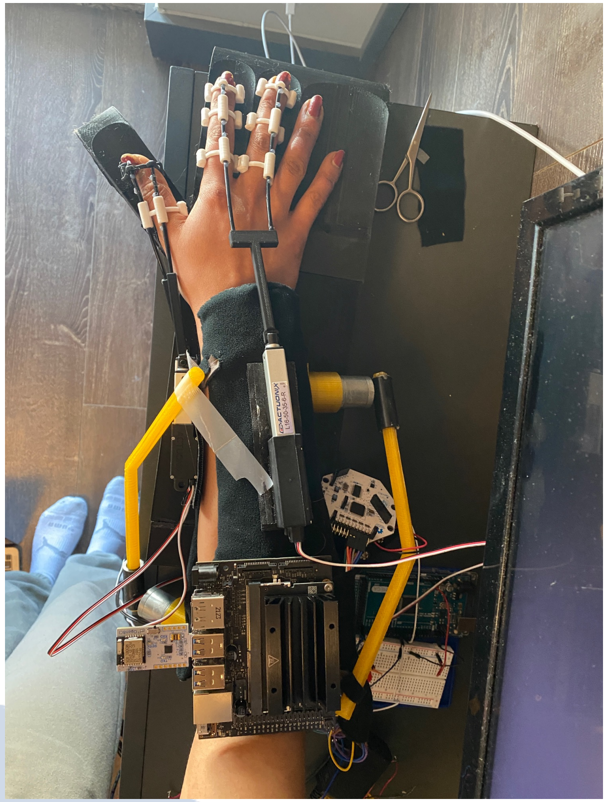


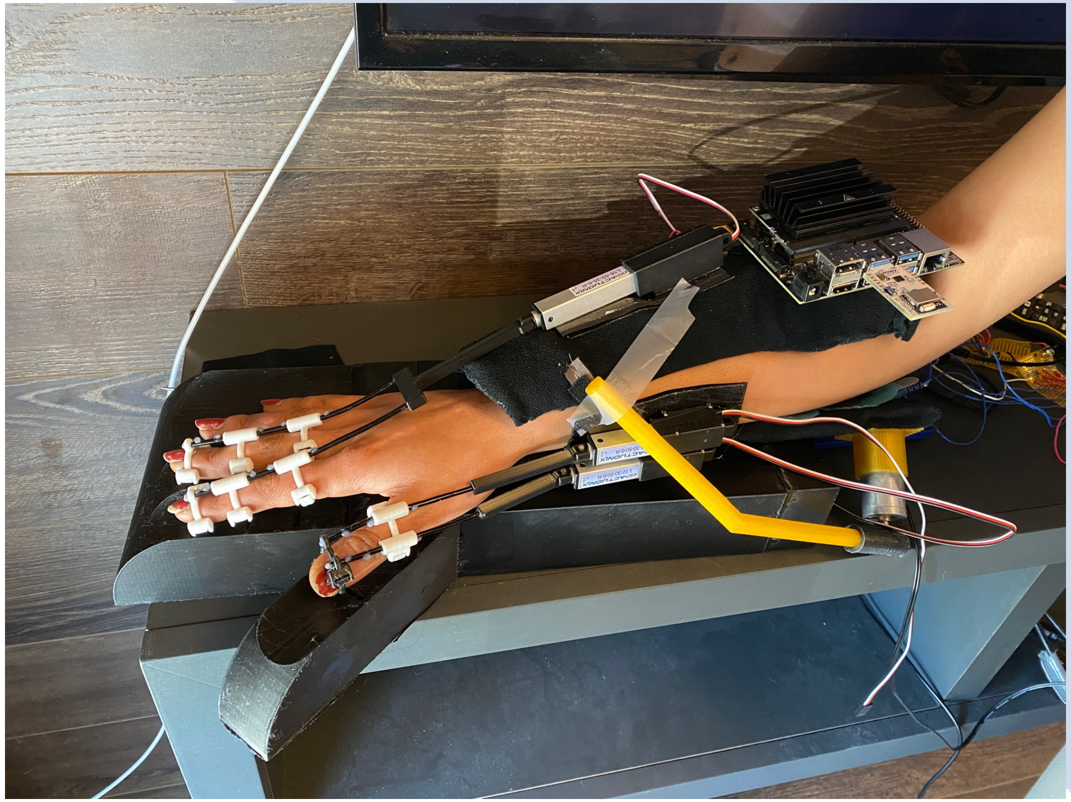






Designed Solution



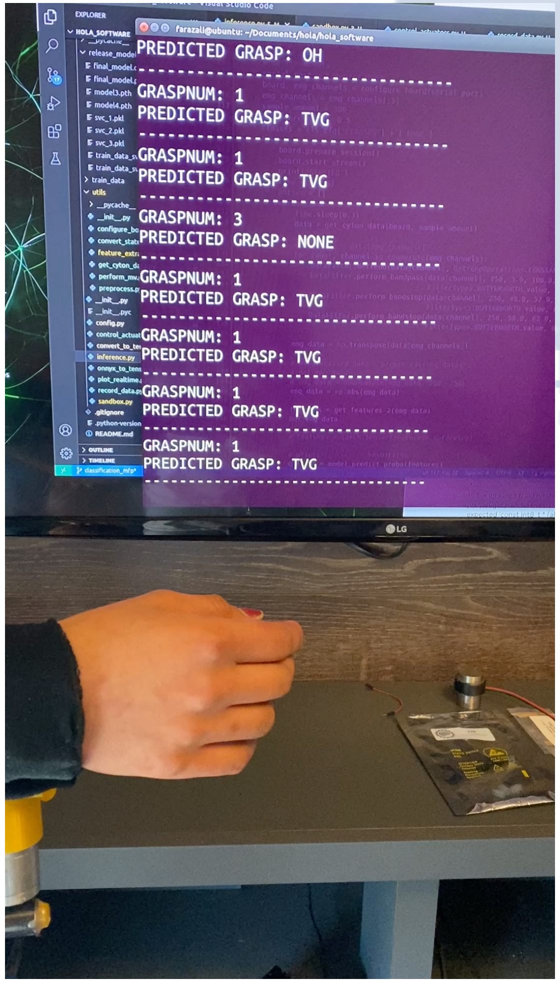


Designed Solution – Actuation

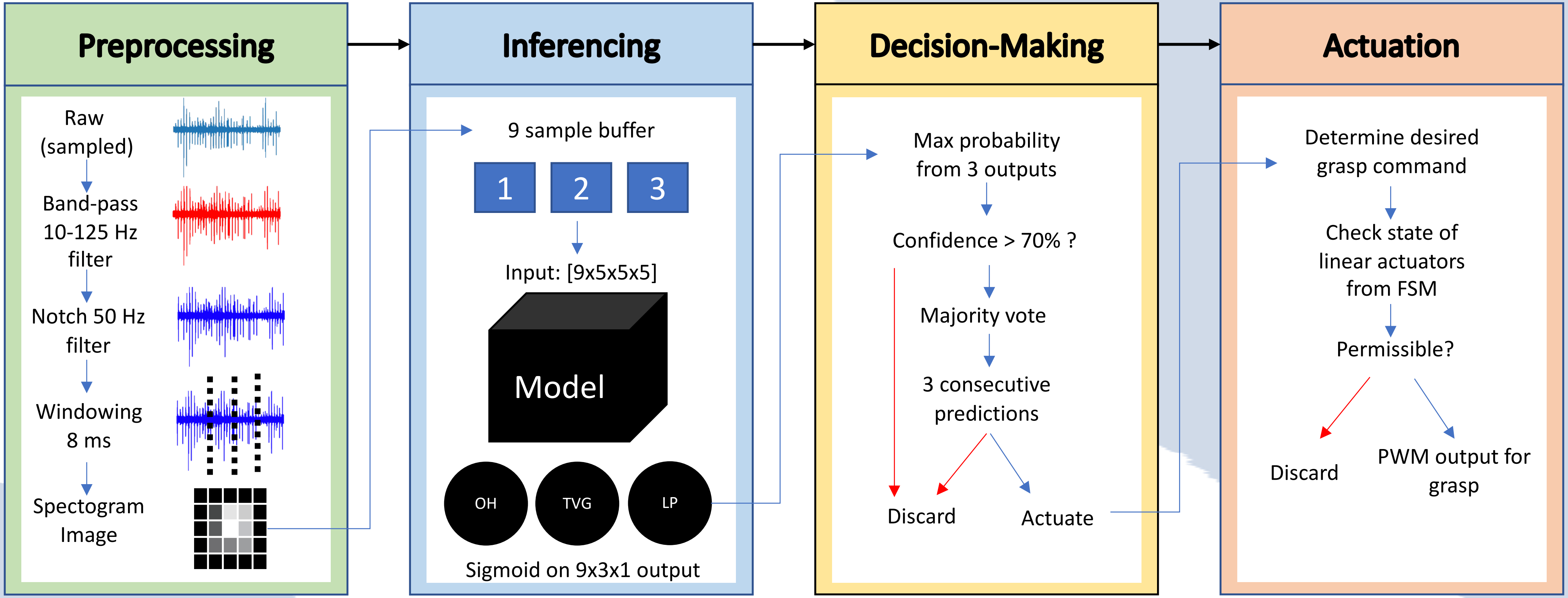
Transverse Volar Grip

Lateral Pinch

Designed Solution – Intent Detection



Designed Solution – Control Flow



Verification & Validation

Specification	Result
Device must provide a minimum output force of 45N and 25N during TVG and LP, respectively	Able to lift a 500g weight via TVG and LP; further testing required to get to specification weight
Device’s trigger classification model must have at least 90% F1-score for all grasping motions	75.9% for SCI participant (offline) 70.1% for proxy healthy user (real-time)
Device must retain at least 80% of the user’s natural ROM	42%
Device must not weight more than 550g	823g
Device must enable the user to perform TVGs and LPs	Grasp performance complete in isolation; unable to test in assembly

Other specifications required an SCI patient (e.g., Jebsen-Taylor Hand Function Test) or were not feasible given the single prototype (e.g., tensile testing)

Limitations

- Designed solution is bulky (273g over target weight)
- Designed solution is highly specific to one user (component dimensions, jig alignment)
- Discrepancy in EMG electrode placement (limited to top and bottom of forearm)
- EMG classification data came from differing datasets, resulting in turbulent learning

Safety & Regulations

Regulation

- Device subject to FDA Class I regulation [18,19]

Prevent Device Heating

- Motors contained in 3D printed housings
- Linear actuators and Jetson Nano separated from Fabrifoam layer

Cable Management

- Limited wire exposure

User Comfort

- Fabrifoam reduces skin irritation and supports long-term wearability
- Finger attachments feature a split design to mitigate pinching concerns

Impacts

Social

- Device supports user independence and autonomy in completing ADLs, restoring self-confidence and providing a sense of empowerment

Economic

- Device is less expensive than competitors by >$500 before streamlining manufacturing

Environmental

- Dry electrodes are reusable for ~100 sessions
- Use of additive manufacturing reduces impact

Challenges & Successes

Challenges

- Individual components had their own unique technical challenges, resulting in delayed integration and testing
- Limited access to target user group impacted validation activities
- Scarcity/delay of required resources (e.g., microcontroller, batteries, motors)
- Inconsistencies with 3D printing technology

Successes

- Executed several design loops to create and test individual components
  - Actuation workflow effectively transmitted force to perform the desired grasps
  - 5-channel EMG classification achieved comparable results to dense sampling approaches
  - Jig and motors facilitated the independent donning/doffing process

Conclusion & Recommendations

Conclusion

- Classification algorithm achieved a high level of accuracy, with only a small amount of data required for calibration
- Actuation mechanism successfully allowed for execution of TVG and LP grasps
- Device supported independent donning/doffing capability

Recommendations

- Reduce device bulk to improve formfactor and comfort
- Further improve finger attachment design to facilitate gripping
- Implement closed-loop feedback to allow for automatic grip strength control
- Collect and aggregate EMG dataset with consistent electrode placement
- Conduct validation with SCI patient

Thank you!

Questions?

References

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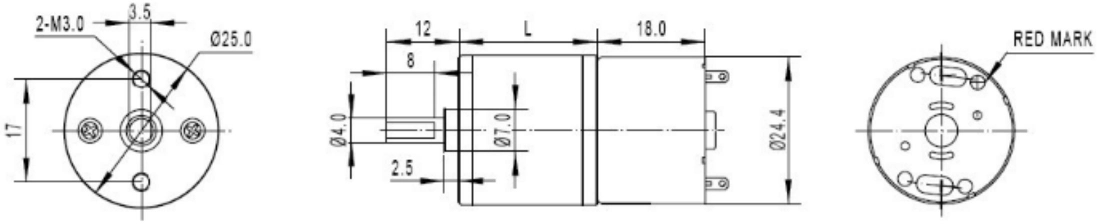
Supporting Content

Motor Specs

Metal DC Geared Motor - 6V 15RPM 10Kg.cm

SKU:FIT0495-A



INTRODUCTION

This is a metal DC geared motor, 478:1 metal reducer. It has a small size and large torque. The maximum torque could arrive 10 kg.cm. It is stable and durable!

SPECIFICATION

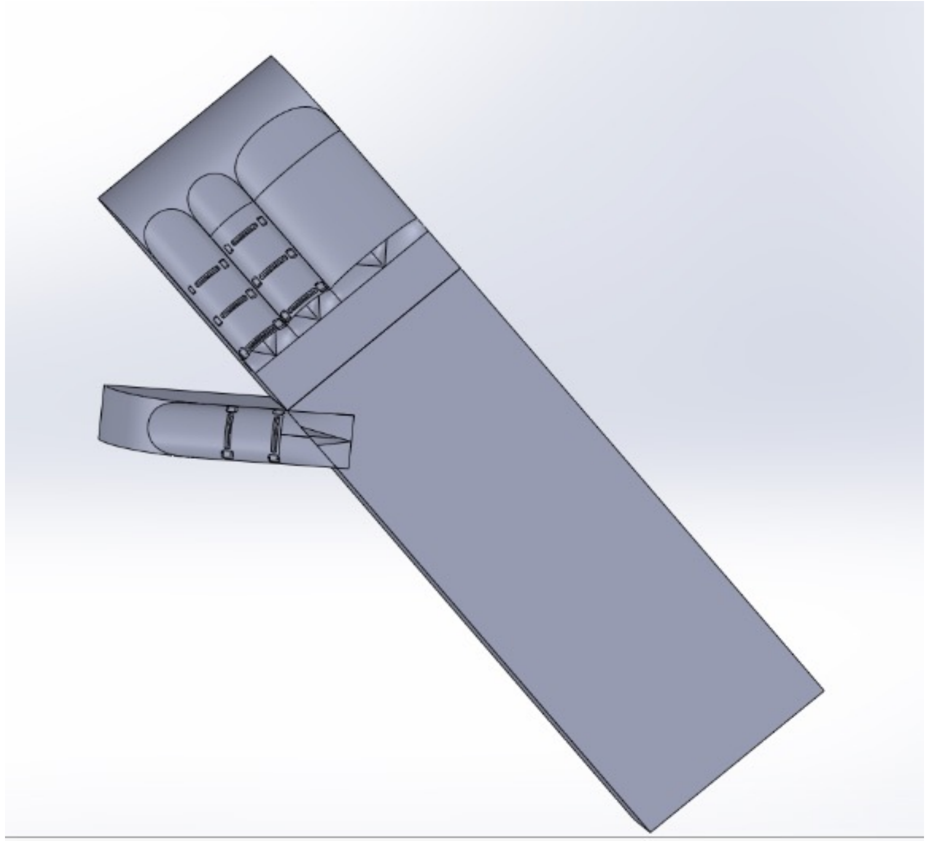
- Rated Voltage: 6 V
- Operating Voltage Range 2~7.5V
- Gear reduction ratio: 478.1:1
- Gearbox length: 27 mm
- "D" shape shaft diameter: 4 mm
- No-load speed: 15 RPM @ 6V
- No-load current: 50 mA
- Locked-rotor torque: 10 Kg.cm
- Locked-rotor current: 0.6 A
- Operating Temperature: -20～60℃
- Weight:74g

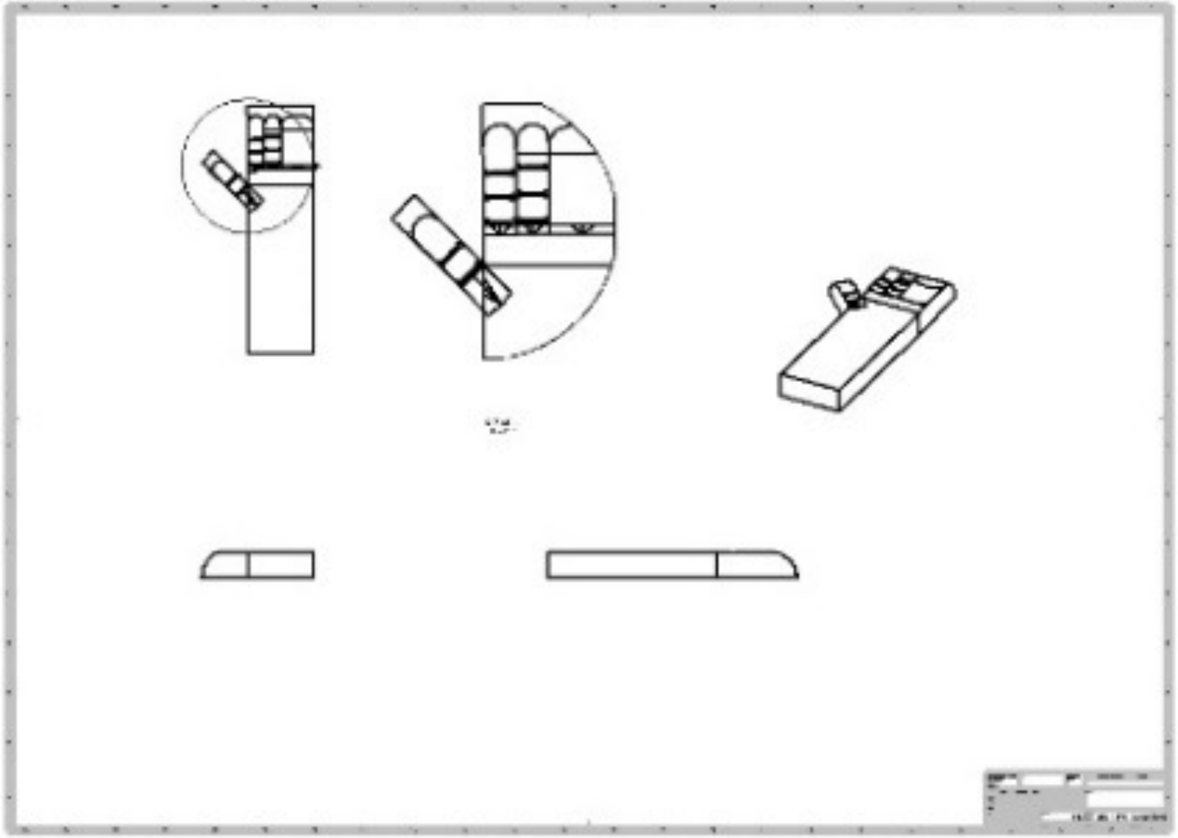
SHIPPING LIST

- Metal DC Geared Motor - 6V 15RPM 10Kg.cm x1

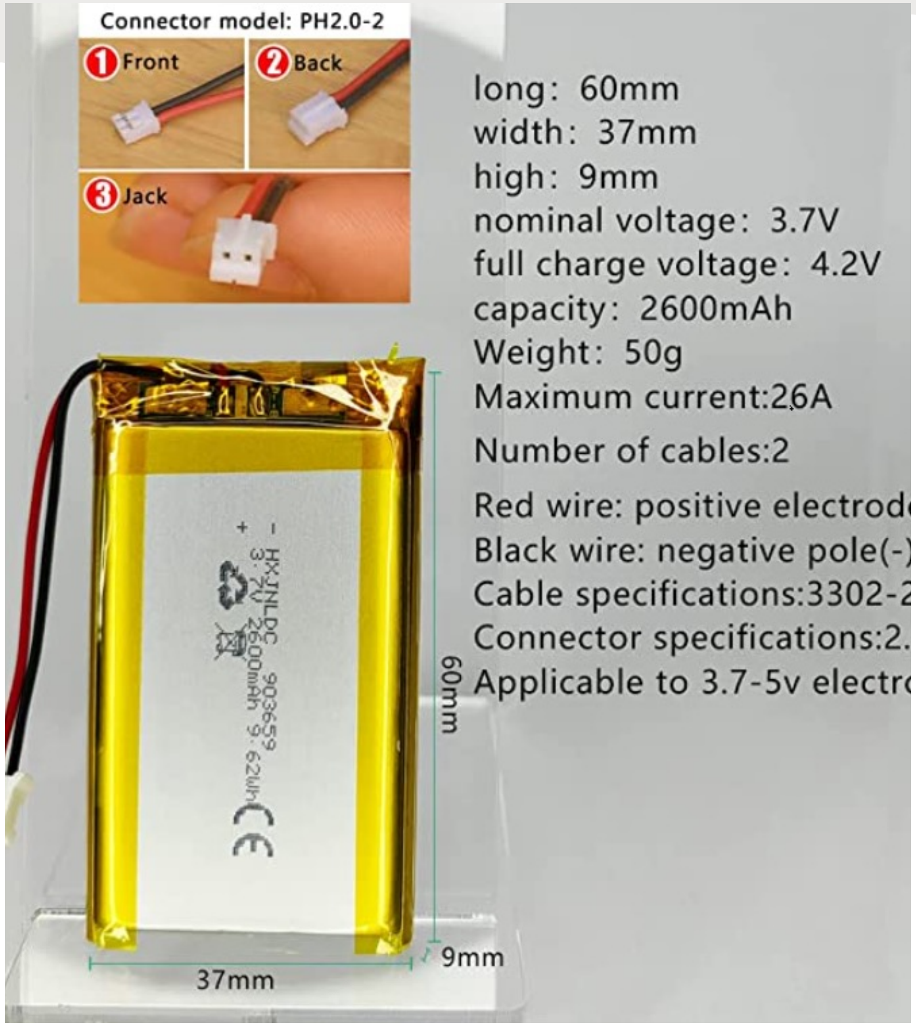
DFROBOT, “Metal DC Geared Motor – 6V 15RPM 10Kg.cm”, SKU:FIT0495-A datasheet, 2017.

Jig SolidWorks Design and Assembly Drawing



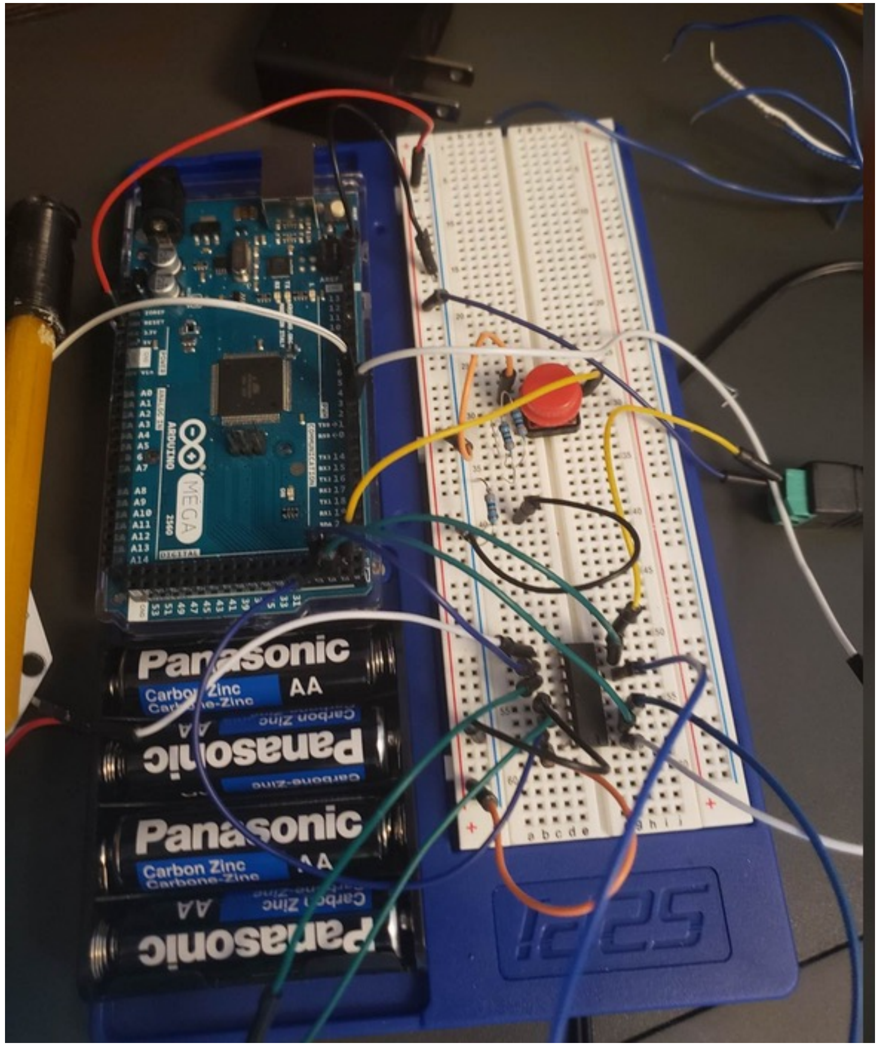


Battery Specs



HXJNLDC, "DC 3.7V 2600mah 903759 rechargeable lithium polymer replacement battery for DIY 3.7-5V electronic product, Mobile Energy Storage Power Supply," *Amazon.ca: Electronics*. [Online]. Available: https://www.amazon.ca/1600mAh-103048-Lithium-Replacement-Bluetooth/dp/B091YF4VH8/ref=sr_1_8?crid=IZFJ1HUZZ43X&keywords=drone%2Bbattery%2B5v&qid=1681077859&sprefix=drone%2Bbattery%2B5v%2Caps%2C118&sr=8-8&th=1. [Accessed: 10-Apr-2023].

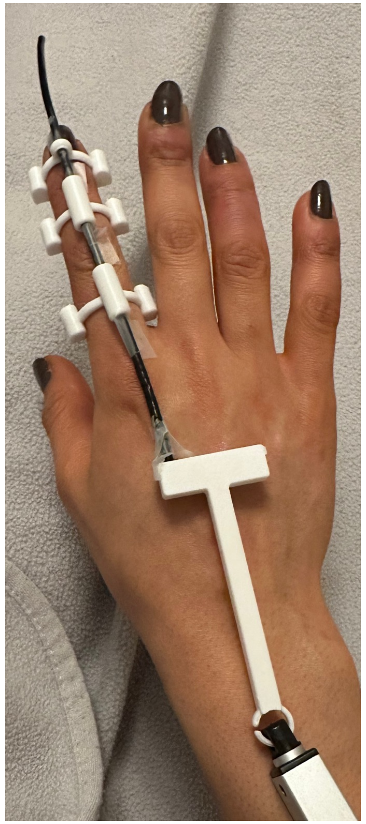
Motor Setup



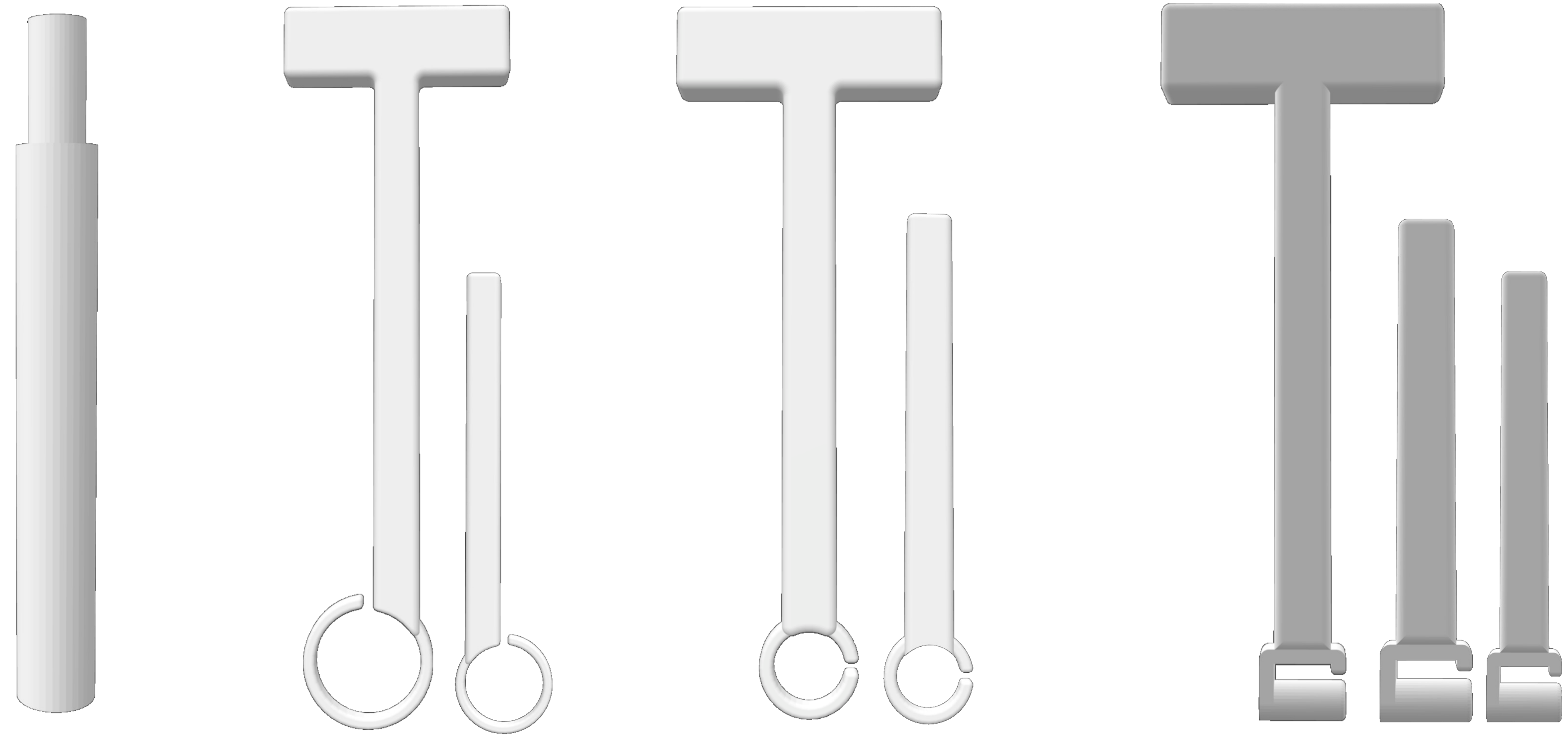
Frame

Actuation – Thumb DoF

Actuation – Cable/Connector Evolution

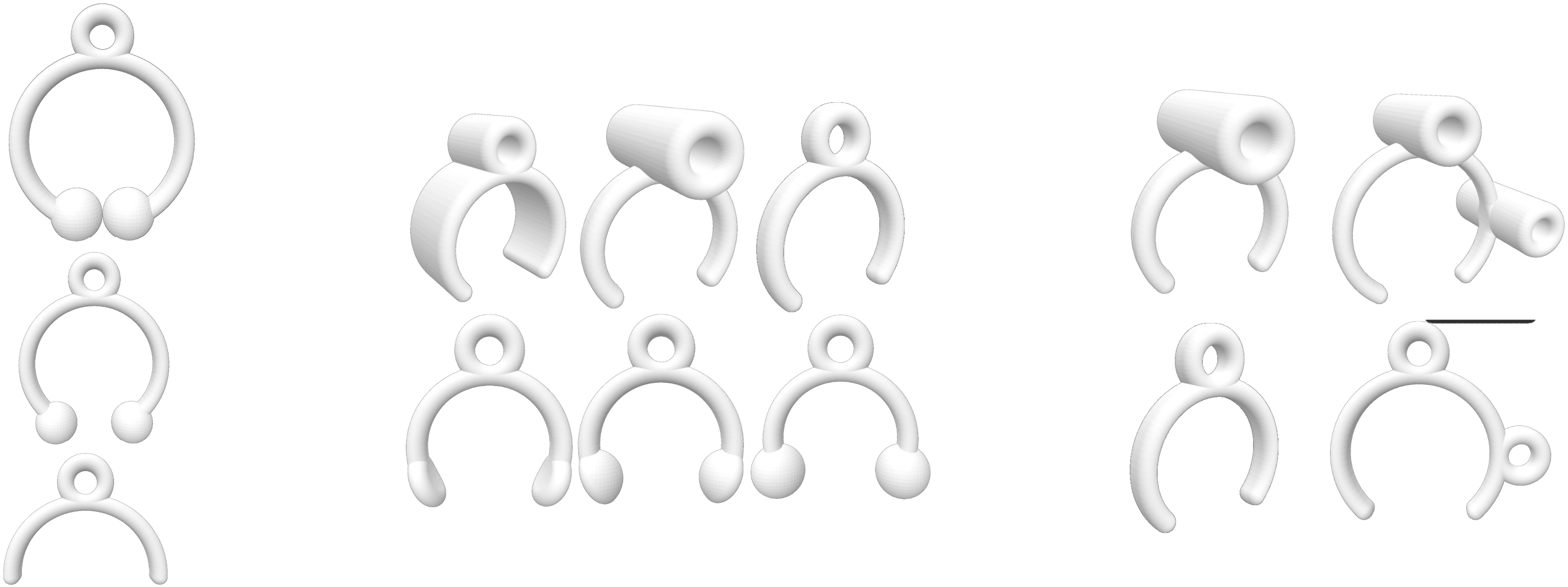


Actuation – Cable/Connector Evolution

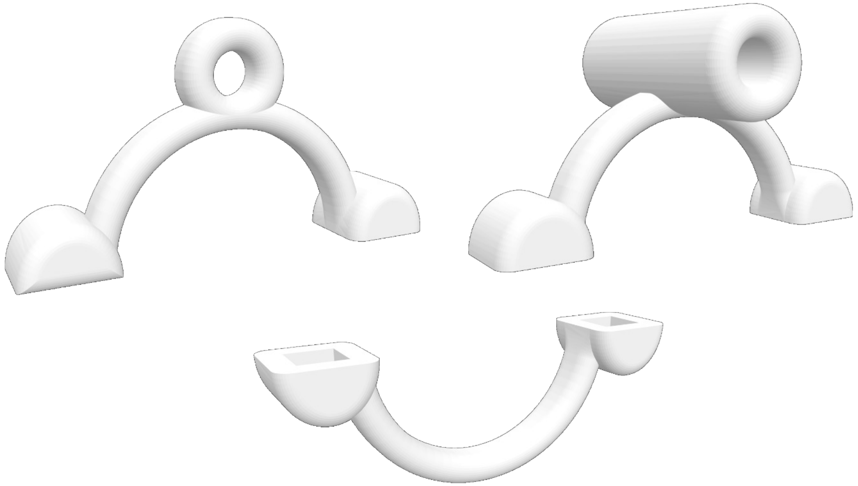


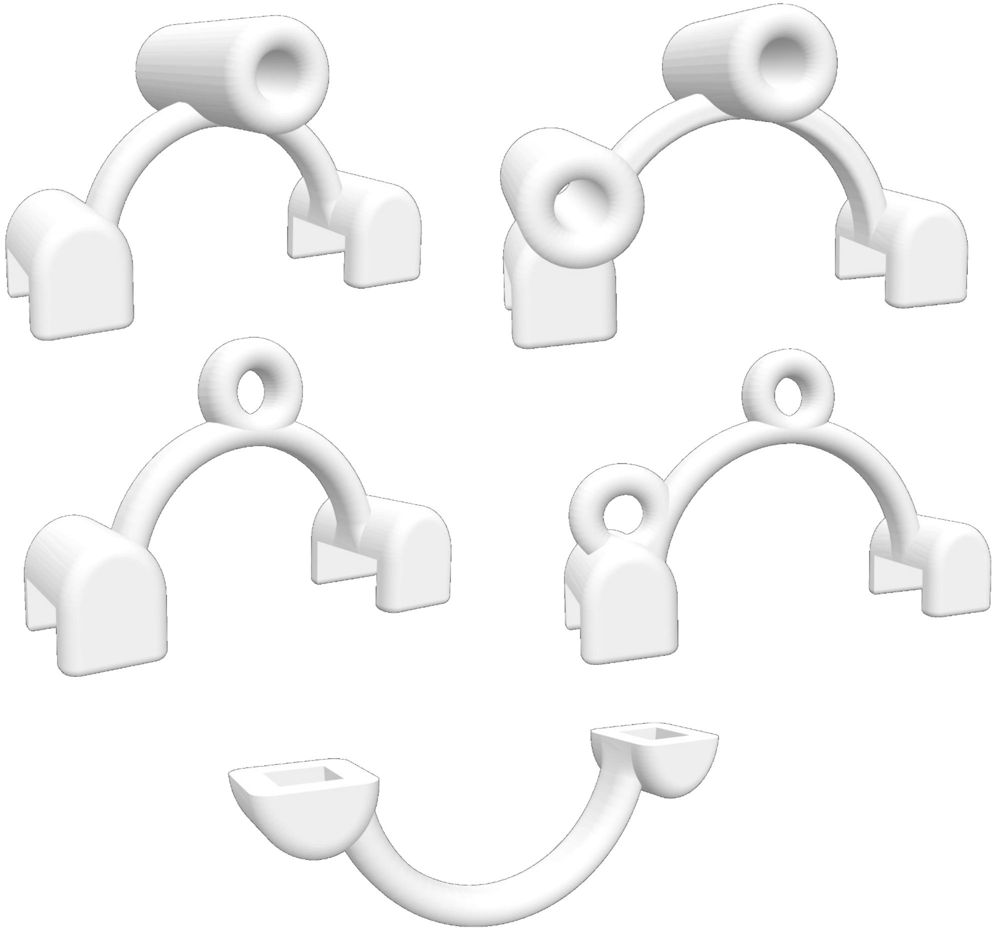
Actuation – Finger Attachment Evolution

Actuation – Finger Attachment Evolution

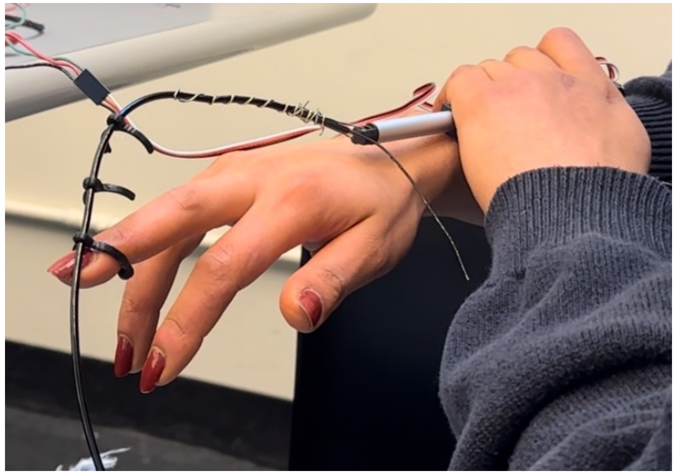


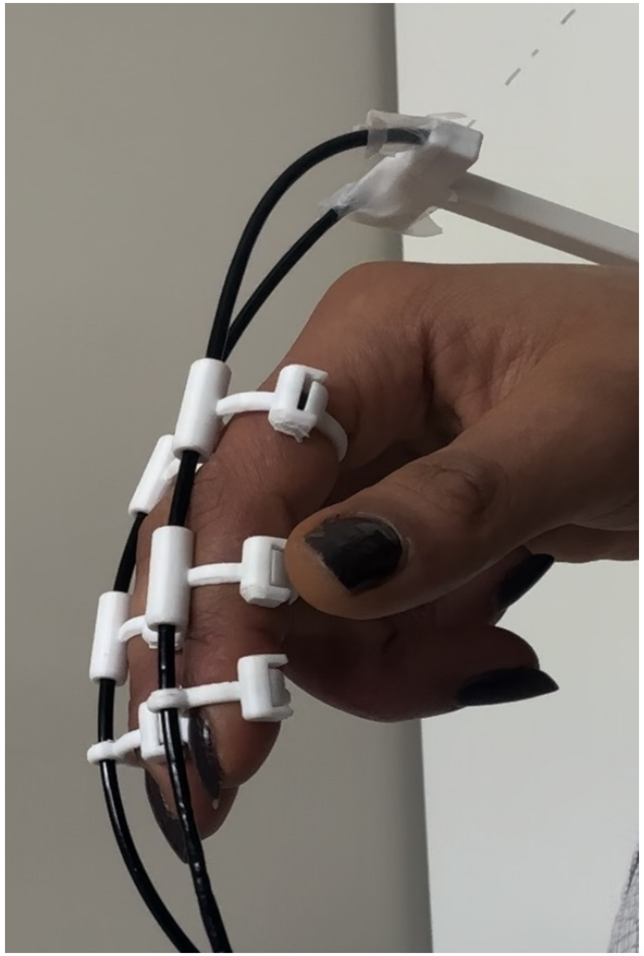
Actuation – Finger Attachment Evolution

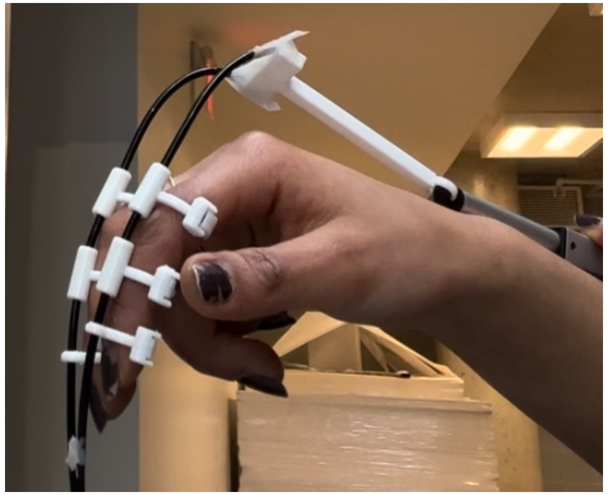


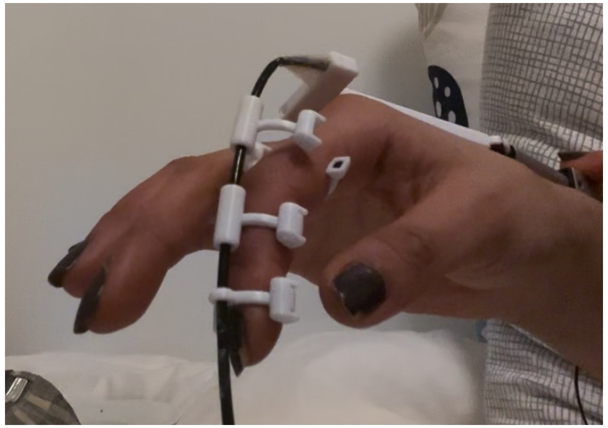


Actuation – Challenges

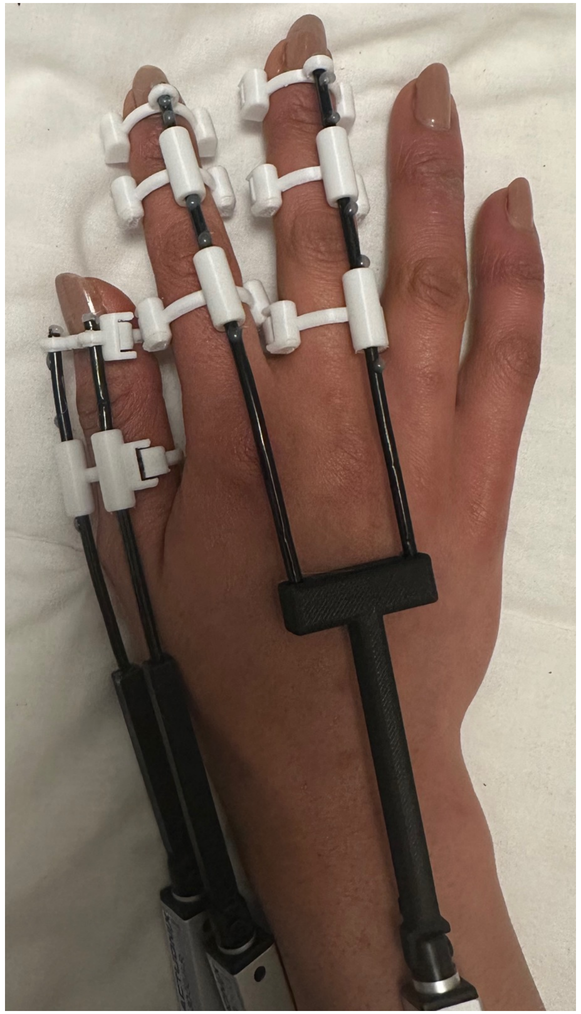




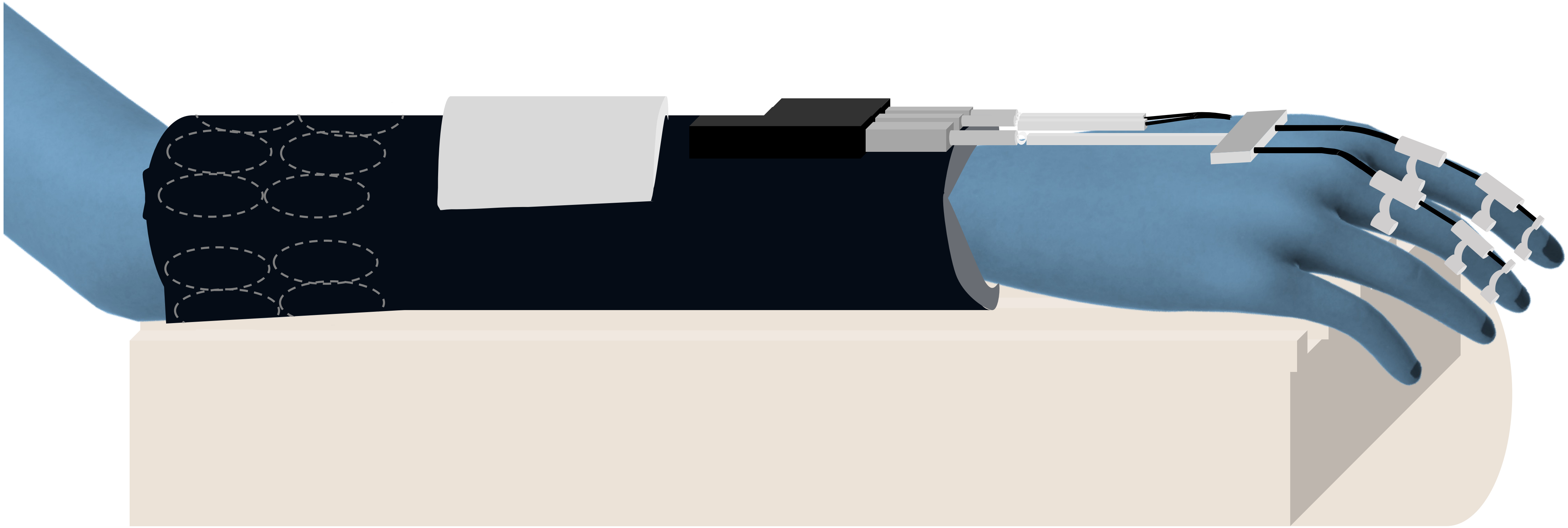




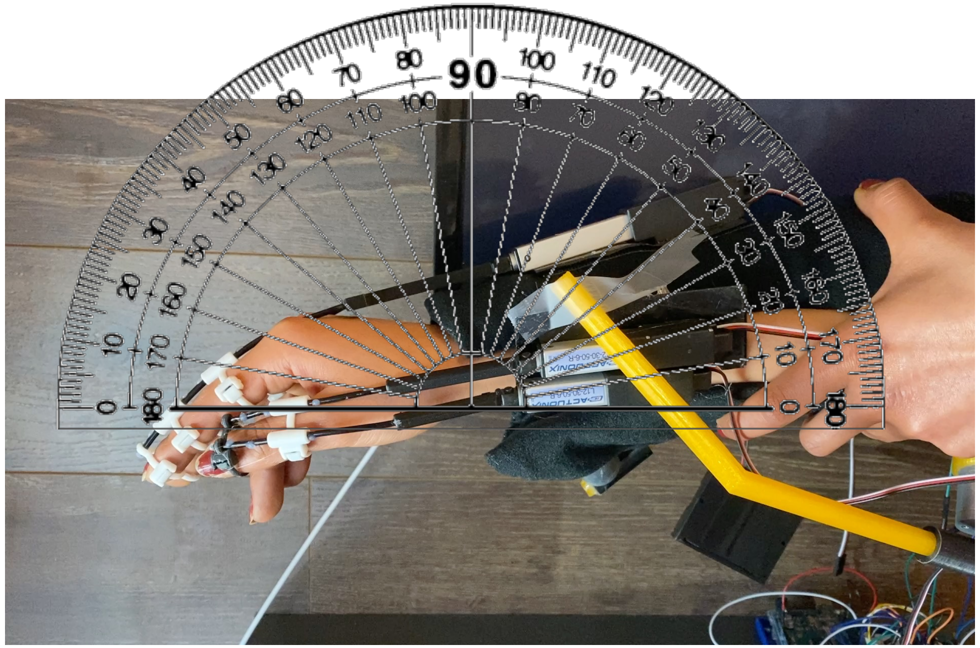
Actuation – Final



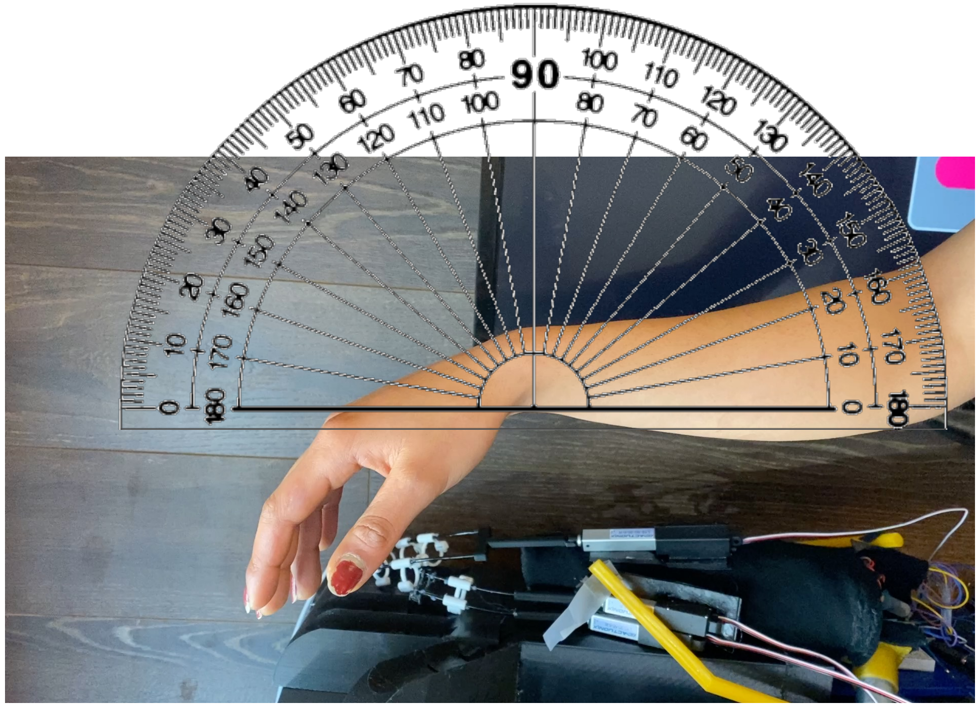
Designed Solution Graphic



Validation – Wrist ROM Videos



With ~ 25 degrees



Without ~ 60 degrees

Trigger Component – Hyperparameter Results

Parameter	Range	Selected
Learning Rate	0.001-0.01	0.009
Dropout Rate	0.3-0.7	0.35
Conv Filters	[32, 64, 128, 256]	128

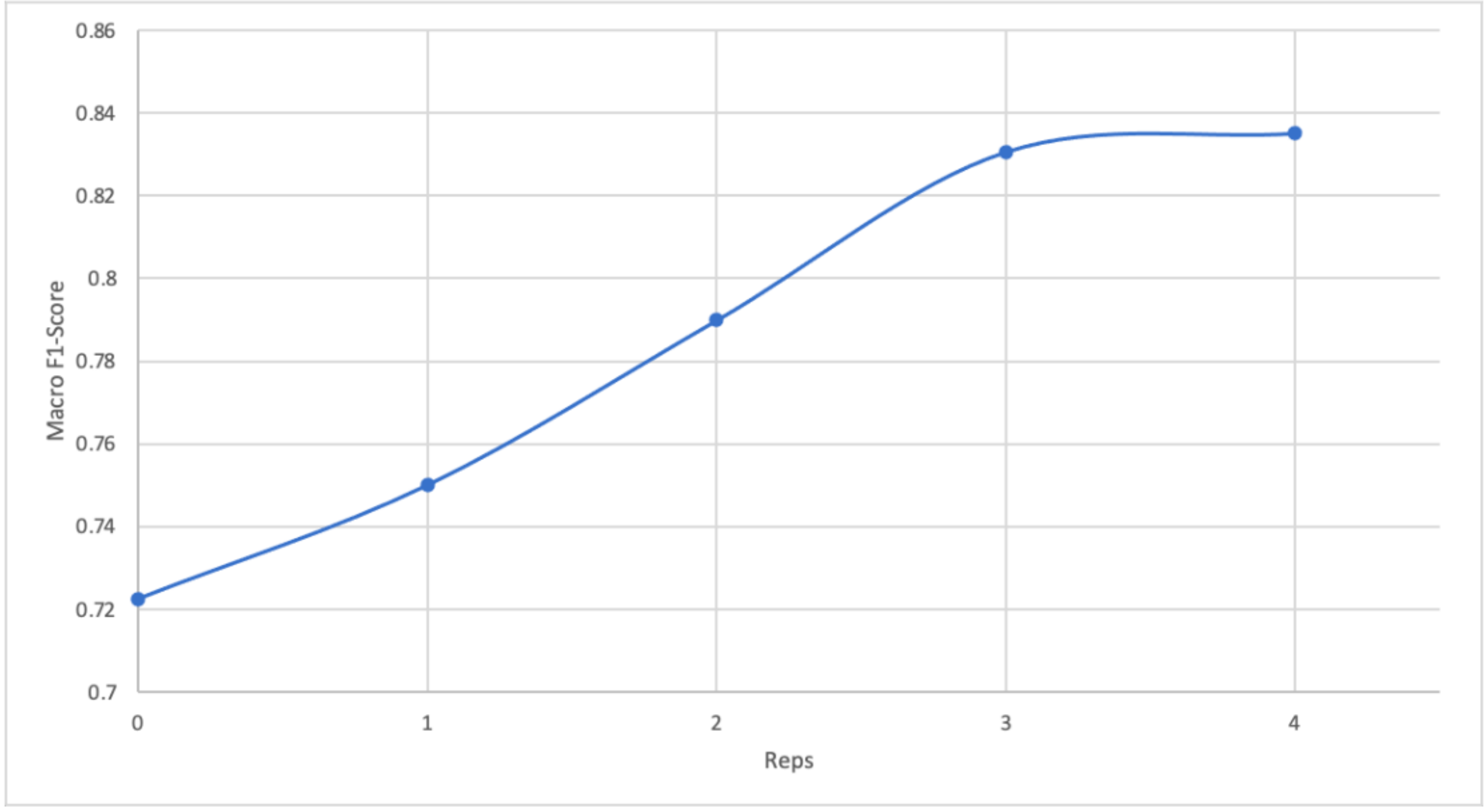
Trigger Component – Objective Function

$$J = -\sum_{c=1}^{M} \alpha_c y_{i,c} \log(\hat{y}_{i,c})$$

Where:

- i is the current input sample
- c is the current class
- M is the total number of classes
- α_c is class-specific weight that penalizes misclassifications based on proportion of the class in the dataset
  - 1 – proportion of that class in dataset
- $y_{i,c}$ is the ground-truth label for the class
- $\hat{y}_{i,c}$ is the predicted label for the class

Trigger Component – Fine-Tuning Ablation



OpenBCI Cyton Main Specs

Cyton Board Technical Specifications

OpenBCI 32bit Board:

- 8 differential, high gain, low noise input channels
- Compatible with active and passive electrodes
- Texas Instruments ADS1299 ADC (link to datasheet)
- PIC32MX250F128B microcontroller w/chipKIT™ bootloader (50MHz)
- RFduino™ Low Power Bluetooth™ radio (Link to datasheet)
- 24-bit channel data resolution
- Programmable gain: 1, 2, 4, 6, 8, 12, 24
- 3.3V digital operating voltage
- +/-2.5V analog operating voltage
- ~3.3-12V input voltage
- LIS3DH accelerometer (link to datasheet)
- Micro SD card slot
- 5 GPIO pins, 3 of which can be Analog

OpenBCI Dongle:

- RFD22301 radio module from RFdigital™
- FT231X USB-to-serial converter from FTDI
- Can upload code to the OpenBCI board or the dongle
- Fully broken out and pin-compatible w/ RFduino form factor

Note: If you want a back-up (optional) battery, we recommend this rechargeable JST 2-pin Lithium Ion Polymer Battery - 3.7v. **and** its USB-battery charger

DO NOT EXCEED A 6V Battery