BEAR PAW

Assembly Manual

Contributors: Marcus Battraw, Martin Croshaw, Pranav Tirumalai

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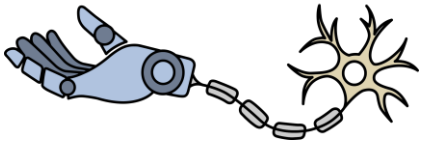


Contents

1. Introduction

While pediatric prosthetic devices are emerging on clinical and experimental horizons, researchers are missing a well-validated, robust device with open access to hardware and software. The straightforward and inexpensive Pediatric Assistive Ware designed at the UC Davis Bionic Engineering and Assistive Robotics Lab (BEAR PAW) provides an open-source platform to bridge this gap in knowledge. Dexterous, multiarticulate, and versatile in hand grasping patterns, the BEAR PAW will provide a platform for studies to improve understanding of how children will control prostheses. Ultimately, enabling such studies will improve the translation of dexterous multi-grasp prosthetic devices to the pediatric population. Complete with materials, definitions, and pictorial instructions, this guide allows any interested individual or team to create the BEAR PAW.

2. Nomenclature

2.1 Digits & Joints

Naming convention: **Digit-Position/Joint**
i.e. ***D3-JI*** (Digit 3 – Intermediate Joint) or ***D2-DI*** (Digit 2 – Distal and Intermediate)
Note that "I" is for Intermediate (i.e., the joint or phalanx in the middle of the finger, but since we couple the intermediate and distal components it is also the most distal component) and "P" for proximal (i.e., the joint or phalanx attaching the finger to the palm). The ability to rotate 90° into the page (assume palm down) is an additional degree of freedom provided to the thumb, and this joint is called out as ***D1-R***.

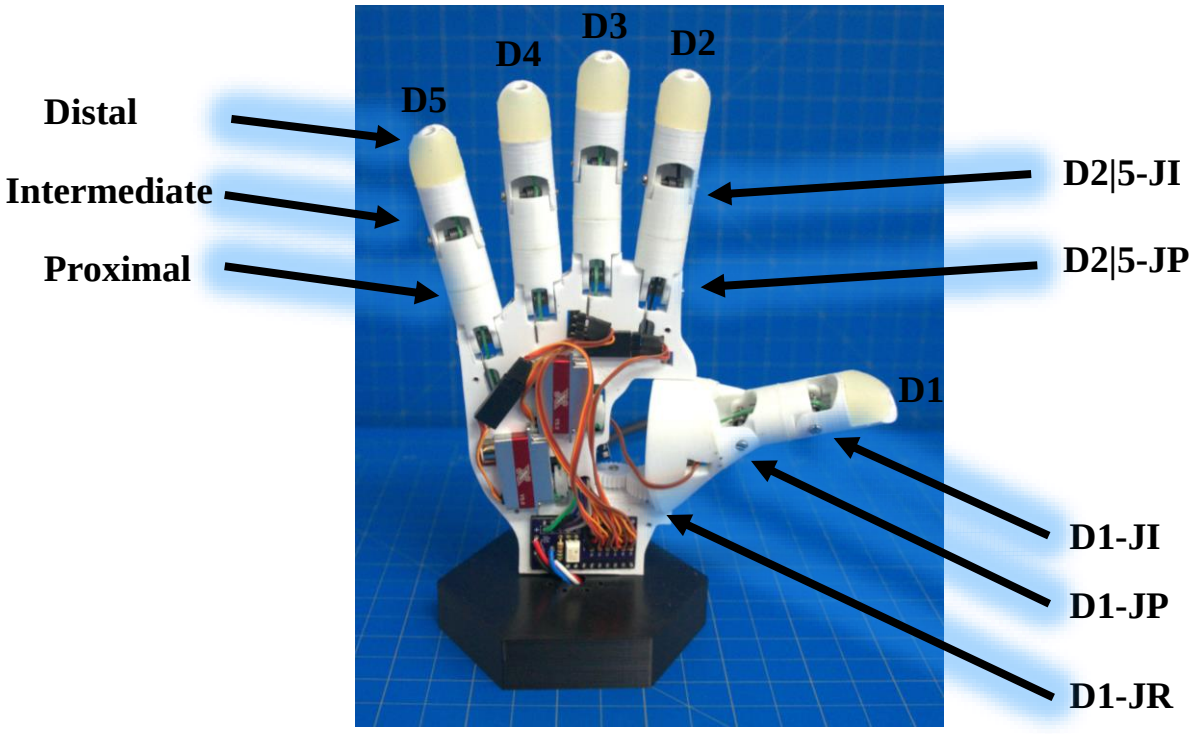


Figure 1: Digit and joint definitions.

NOTE: The distal joint in a child's hand poses a manufacturing obstacle due to its small nature. Additionally, it has a negligible range of motion. Thus, this design includes only two joints in each finger: the intermediate and proximal, with the distal and intermediate phalanges connected as a single part.

2.2 Naming Convention for 3D Printed Parts

3D-Printed Parts Code: **Hand-Digit(s)/Palm-Part**

Hand: Right (R), Left (L)

Digit(s): D1-D5. Since the parts and assemblies of D2, D3, D4 & D5 are identical, these are collectively called out as ***D2|5***.

Palm: Surface of the hand.

Part: The parts for each of the above designations.

- Digit Parts: D2-D5
    - Distal: (***DPhal***)
    - Intermediate: (***IPhal***)
    - Proximal: Comes in two parts, a distal and proximal part, for ease of printing.
        - Distal-most part of proximal: (***PPhal-DPart***)
        - Proximal-most part of proximal: (***PPhal-PPart***)
    - Tendon tightening mount: (***Tensioner***)
    - Negative of fingertip: Comes in two parts for easy removal of cured resin.
        - (***FTNeg1***) and (***FTNeg2***)
- Thumb Parts: D1
    - Distal: Comes in two parts—a distal and proximal part, for ease of printing.
        - Distal-most part of distal: (***DPhal-DPart***)
        - Proximal-most part of distal: (***DPhal-PPart***)
    - Intermediate: Comes in two parts—a distal and proximal part, for ease of printing.
        - Distal-most part of intermediate: (***IPhal-DPart***)
        - Proximal-most part of intermediate: (***IPhal-PPart***)
    - Proximal: Comes in five parts—for ease of printing.
        - Distal-most part of proximal: (***PPhal-DPart***)
        - Proximal-most part of proximal: (***PPhal-PPart-PalmGear***)
        - Door, to hide motor in proximal part: (***PPhal-PPart-PalmDoor***)
        - Gear, for motor to mesh with proximal gear for abduction: (***PalmGearWheel***)
        - Tendon tightening mount: (***Tensioner***)
    - Negative of fingertip: Comes in two parts for easy removal of cured resin.
        - (***FTNeg1***) and (***FTNeg2***)

- Palm Parts
    - Main interior frame for motor and digit mounting: (***InteriorFrame***)
    - Front of hand cover: (***PalmarCover***)
    - Back of hand cover: (***DorsalCover***)

Notes:

- Position/Location: If several parts make up a phalanx, they are referred to by location as being more proximal (closer to the palm) or distal (closer to the fingertip).
- Fingertip (FT) mold only needs to be printed once and can be reused.

3. Required Materials

3.1 3D Printed Parts

General printer settings used.

Printer	SigmaxR19
Hotend Nozzle	0.4 mm
Material	PLA
Global Layer	0.15 mm
Infill Density	25%
Speed	50 mm/s

3.1.1 Table 1: Parts for 3D Printing

Part Name	**Unique Print Settings**	**Print Length (meters)**	**Approximate Print Time**	**Part Mass**
R/L-D2|5-PPhal-PPart X 4	None	0.23 m X 4 = 0.92 m	26 min X 4 = 1 hr 44 min	2 g X 4 = 8 g
R/L-D2|5-PPhal-DPart X 4	None	0.21 m X 4 = 0.84 m	24 min X 4 = 1 hr 36 min	2 g X 4 = 8 g
R/L-D2|5-IPhal X 4	None	0.22 m X 4 = 0.88 m	26 min X 4 = 1 hr 44 min	2 g X 4 = 8 g
R/L-D2|5-DPhal X 4	None	0.12 m X 4 = 0.48 m	13 min X 4 = 52 min	1 g X 4 = 4 g
R/L-D2|5-Tensioner X 4	None	0.02 m X 4 = 0.08 m	3 min X 4 = 12 min	~ 0 g
R/L-D2|5-FTNeg1	None	1.00 m	1 hr 16 min	8 g
R/L-D2|5-FTNeg2	None	0.72 m	51 min	6 g
R/L-D1-PPhal-PPart-PalmGear	Infill 50% Global; 0.1 mm; Using Supports Advisable	1.33 m	2 hrs 50 min	11 g
R/L-D1-PPhal-PPart-PalmDoor	None	0.34m	34 min	3g
R/L-D1-PPhal-DPart	None	0.29m	28 min	2 g

R/L-D1-IPhal-PPart	None	0.24 m	25 min	2 g
R/L-D1-IPhal-DPart	None	0.21 m	20 min	2 g
R/L-D1-DPhal-PPart	None	0.15 m	20 min	1 g
R/L-D1-DPhal-DPart	None	0.15 m	15 min	1 g
R/L-D1-PalmGearWheel	None	0.08 m	11 min	1 g
R/L-D1-Tensioner	None	0.02 m	3 min	~ 0 g
R/L-D1-FTNeg1	None	0.98 m	1 hr 17 min	8 g
R/L-D1-FTNeg2	None	0.72 m	53 min	6 g
R/L-Palm-DorsalCover	Infill 35% Global; 0.12 mm; Use Supports	2.63 m	4 hrs 53 min	21 g
R/L-Palm-InteriorFrame	Infill 35% Global; 0.1 mm; Use Supports	2.75 m	6 hrs 39 min	22 g
R/L-Palm-PalmarCover	0.12 mm; Use Supports	1.67 m	3 hrs 10 min	13 g
R/L-Wrist-BaseMount	None	2.56 m	3 hrs 27 min	20 g
R/L-Wrist-HandAdapter	None	1.22 m	1 hr 44 min	10 g
R/L-Wrist-HandMount	None	1.02 m	1 hr 27 min	8 g
	Totals:	21.28 m	37 hrs 11 min	173 g

NOTE: Supports advised when there is an extensive hole or overhanging arch; alternatively, consider printing in a different orientation.

NOTE: X 4 on the finger part values to account for all fingers ***D2|5***.

NOTE: Printed several parts in 1 G-code file to speed up the process.

3.2 Ordered Parts

Table 2 below contains all the necessary items to build a complete BEAR PAW. This table was finalized on 8/25/2022; therefore, some items may be discontinued, or cost of items may have changed. The cost shown does not account for shipping/tax or any additional costs that may be incurred.

Table 2: Parts for Ordering

Item	Description	Vendor	Part No.	Link	Qty.	Cost/Item	Ext. Cost
SENSORS/ELECTRONICS							
KST X08N V5.0	Micro Servo Motor with no mounting flanges	Alofthobbies	X08N	https://alofthobbies.com/kst-x08n.html	1	$46.00	$46.00
KST X08H V5.0	Micro Servo Motor with top mounting flanges	Alofthobbies	X08H	https://alofthobbies.com/kst-x08h-servo-2-8kg-38-oz-in-09-sec-8-grams-wide-voltage.html	1	$46.00	$46.00
KST X08 V5.0	Micro Servo Motor with side mounting flanges	Alofthobbies	X08	https://alofthobbies.com/kst-x08-servo-2-8kg-38-oz-in-09-sec-8-grams.html	4	$46.00	$184.00
Breakout Board	2 layer electronics breakout board, 17.8 x 33.0mm	OSHPARK	Find Gerber files on GitHub	https://docs.oshpark.com/services/two-layer/	1	$5.00	$5.00
Solid State Relay	Omron, Solid State Relay - PCB Mount, 3 A, 60 V	Mouser Electronics	653-G3VM-61AR1	https://www.mouser.com/ProductDetail/Omron-Electronics/G3VM-61AR1?qs=wnTfsH77Xs74FCx6Uqk9GQ%3D%3D	1	$6.91	$6.91
Resistor	5,600 Ohm Resistor, 5%, 0.5W Through Hole Resistor	DigiKey	S5.6KHCT-ND	https://www.digikey.com/en/products/detail/stackpole-electronics-inc/CFM12JT5K60/1741974?s=N4IgTCBcDaIMIDECyBGMApAKgVgNIDYAGEAXQF8g	1	$0.10	$0.10
Arduino Pro Mini 238 – 3.3V/ 8MHz	Micro Controller	Sparkfun	DEV-11114	https://www.sparkfun.com/products/11114	1	$10.95	$10.95
FTDI Mini USB to TTL	Mini USB to TTL Adapter Board for Arduino	Amazon	B00IJXZQ7C	https://www.amazon.com/HiLetgo-FT232RL-Converter-Adapter-Breakout/dp/B00IJXZQ7C/	1	$6.99	$6.99
Bluetooth Module	DSD Tech HC-05 Bluetooth Serial Module	Amazon	B01G9KSAF6	https://www.amazon.com/DSD-TECH-HC-05-Pass-through-Communication/dp/B01G9KSAF6/	1	$9.99	$9.99
Power Wires	22 Gauge Silicone wire spool red 25ft and black 25ft	Amazon	B07HGT44XY	https://www.amazon.com/BNTECHGO-Silicone-Flexible-Strands-	1	$9.98	$9.98

				Stranded/dp/B07HGT44XY/?th=1			
Extra Servo Wires	30 Gauge Silicone Wire Kit	Amazon	B01M70EDCW	https://www.amazon.com/dp/B01M70EDCW?th=1	1	$9.98	$9.98
Connector Kit	2.54 mm Crimp Pin Connector Housings, Single Row Male Headers, Male/Female Crimp Pins and Ribbon Cable	Amazon	B078RRPRQZ	https://www.amazon.com/Dupont-Connector-Kit-Connectors-Plusivo/dp/B078RRPRQZ/	1	$12.99	$12.99
Wall Adapter	AC/DC Wall Mount Adapter 5V, 20W	DigiKey	102-4196-ND	https://www.digikey.ca/en/products/detail/cui-inc/SWI25-5-N-P5/7070092	2	$27.89	$55.78
Wall Jack	DC Barrel Jack Adapter - Female	Sparkfun	10288	https://www.sparkfun.com/products/10288	2	$3.50	$7.00
CENTAURUS Servo Tester STV2.3	Steering Gear Rudder Detector Spare Parts for RC Aircraft Micro FPV DC 4.8V-6V	Amazon	B09LXTW19G	https://www.amazon.com/CENTAURUS-Steering-Detector-Aircraft-4-8V-6V/dp/B09LXTW19G	1	$3.50	$3.50
HARDWARE AND MISCELLANOUS							
Bearings	Bearing 2 mm Bore ID, 5 mm OD, 2.5mm	Amazon	B07X9T5F81	https://www.amazon.com/Donepart-MR52ZZ-Bearings-Miniature-Equipment/dp/B07X9T5F81	1	$9.99	$9.99
Pulley for KST X08 Servo	Pulley for KST Servo Pack of 4	Hyperflight	X08-PULLEY	https://www.hyperflight.co.uk/products.asp?code=X08-PULLEY&name=pulley-for-kst-x08-servos-4	2	$11.75	$23.50
Rotary Shaft 316 Stainless Steel	2 mm Shaft 200 mm long	McMaster Carr	1265K17	https://www.mcmaster.com/1265K17/	1	$14.27	$14.27
Torsion Spring	Torsion Spring 180 Degree Right-Hand Wound, 0.186" OD (Pack of 6)	McMaster Carr	9271K665	https://www.mcmaster.com/9271K665/	2	$5.19	$10.38
Strength Black Synthetic Cable	0.75mm (0.03") in diameter, 5 m long, 45kg strength	ServoCity	2908-0075-0005	https://www.servocity.com/synthetic-cable-black-0-75mm-diameter-5m-length/	1	$2.99	$2.99

M2 18-8 Stainless Steel Screw	Narrow Cheese Head Slotted Screws M2 x 0.4mm Thread, 25 mm Long (50 Pack)	McMaster Carr	91800A023	https://www.mcmaster.com/91800A023/	1	$10.15	$10.15
M3 18-8 Stainless Steel Pan Head Screw	M3 x 0.5mm Thread, 8mm Long	McMaster Carr	92000A118	https://www.mcmaster.com/92000A118/	1	$5.51	$5.51
#4 x 1/2" Flat Head Sheet Metal Screws	Screws for attaching the hand onto the wrist mount	Amazon	B08L23164W	https://www.amazon.com/Sheet-Screws-Phillips-Tapping-Stainless/dp/B08L23164W/	1	$9.49	$9.49
Heat Shrink Tubing Kit	Heat Shrink Tubing (650 pcs)	Amazon	B07QM8249H	https://www.amazon.com/625pcs-Shrink-Tubing-Tubes-Ratio/dp/B07QM8249H/	1	$8.79	$8.79
Textured Rubber	Multipurpose Neoprene with Crisscross Texture Adhesive-Back Sheet, 12" x 12", 1/32" Thick	McMaster Carr	8445K61	https://www.mcmaster.com/8445K61/	1	$16.67	$16.67
MATERIALS							
Smooth-On Dragon Skin	10 NV, 2 Pint Set, Trial Unit 2lbs (Moldable material for fingertips)	Reynolds Advanced Materials	MC-1244	https://www.reynoldsam.com/product/dragon-skin/	1	$35.37	$35.37
Gorilla Super Glue Gel XL	25 grams, clear	Amazon	B082XGL21J	https://www.amazon.com/Gorilla-Super-Glue-transparente-102433/dp/B082XGL21J/	1	$8.88	$8.88
						Total	$571.16

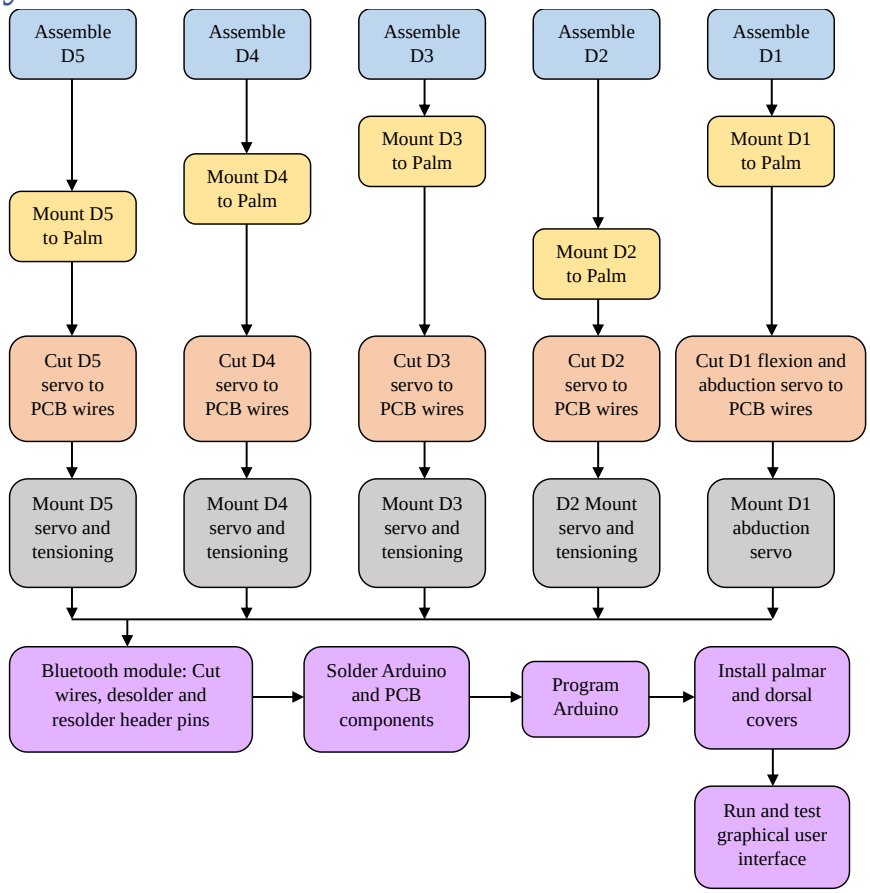
3.3 Tools

- SigmaX R19 (3D Printer)
- Crimping Tool

(https://www.amazon.com/dp/B087BGTH1Y)

- Sandpaper / Sanding Tool (Dremel)
- Screwdriver
- Wire Strippers
- Wire Cutter
- Tweezers
- Pliers
- Files
- Soldering Iron & Solder
- Knife
- Heat Gun

4. Assembly Flowchart



5. Fingers (D2|5)

5.1 Preparations

5.1.1 Sanding Parts in Order to Ensure Proper Fit:

- Sand all faces as shown in **Figure 2** above. Ensure minimal interference as to allow free sliding as at the joint connection of ***R\L-D2|5-PPhal-DPart*** and ***R\L-D2|5-IPhal***.
- Sand both the ***R\L-D2|5-Tensioner*** and ***R/L-D2|5-IPhal*** slot to allow smooth fit.

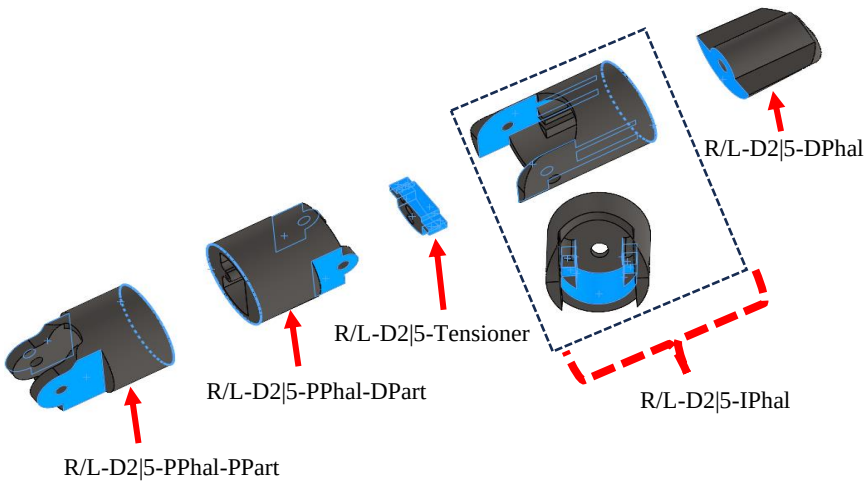


Figure 2: Sanding locations for D2|5

NOTE: May need to come back to re-sand these parts as needed for proper fit, and all holes may need to be lightly sanded.

5.1.2 Fingertip Mold

1. After the ***R/L-D2|5-FTNeg1*** and ***R/L-D2|5-FTNeg2*** are printed, slot together if possible or file to fit in.
2. Then, mix equal parts A and B of the Smooth-On Dragon Skin and pour into the mold. Wait for the recommended time suggested by the Smooth-On instructions.
3. If excess Smooth-On is at the top, cut off evenly with an X-Acto knife.
4. Afterwards, pull apart the mold and repeat the process over again until you have 4 fingertips (**Figure 3**).

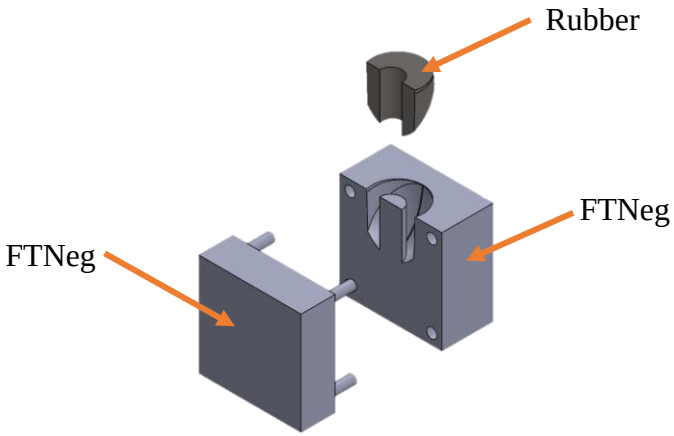


Figure 3: Negative molds for fingertips and thumb

5.1.3 Proximal Part (D2|5)

Orient the two proximal pieces as shown in **Figure 4** and glue them.

Proximal torsion spring slots may need to be cleaned so that the spring leg fits in.

This may be difficult even with a small file.

Suggestion: use gloves and a soldering iron. Heat up the spring leg and press the hot leg through the hole to clean it out. Remove before the plastic solidifies.

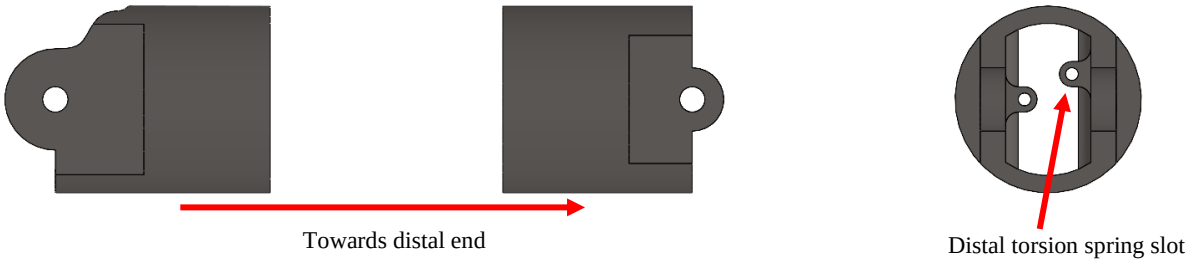


Figure 4: Distal torsion spring slot

5.1.4 Distal Part

Glue the ***R/L-D2|5-IPhal*** to the ***R/L-D2|5-DPhal***; then glue the rubber fingertip on last. See **Figures 5a** and **5b**.

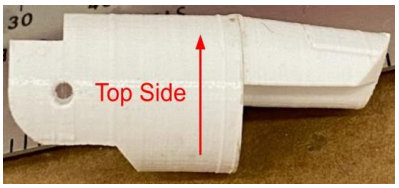


Figure 5a: Top side of distal

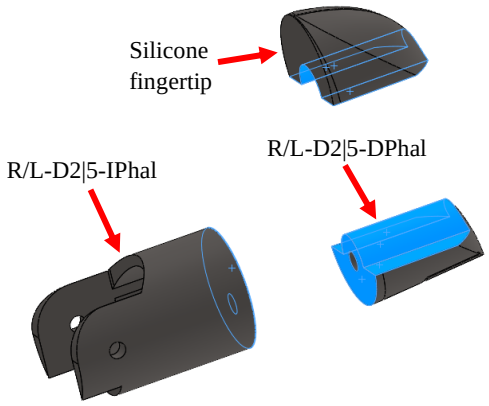


Figure 5b: Gluing distal surfaces for D2|5

NOTE: It is convenient to screw in the 25mm string tensioner screw when gluing these parts as it helps keep everything aligned.

A. Tendon preparation (D2-5)
   1. Prepare the tendon string (synthetic cable) by cutting a 150mm piece. The actual functional length of the string—once completed and assembled—is only about 60mm, but excess allows for error to be corrected. Cut this length of string, careful to do so with as little fraying as possible.
   2. Use the ***M2X25*** tensioner screw and screw into the distal part for the string tensioner (**Figure 6**).
   3. The hole for the torsion spring may be difficult to clean even with a small file. Suggestion: use gloves and a soldering iron. Heat up the spring leg and press the hot leg through the hole to clean it out. Remove before the plastic solidifies (**Figure 6**).
   4. Insert the tendon string through to the distal-facing side of the string tensioner and tie a simple knot to secure (knot should be on the side that points towards the fingertip). Remove any excess string.

5. Position the tensioner slightly within the ***R/L-D2|5-IPhal*** slot and screw the tensioner screw such that it is flush with the bottom of the tensioner (**Figure 6 & 7**). This will allow for maximum adjustment of tension within the finalized tendon.

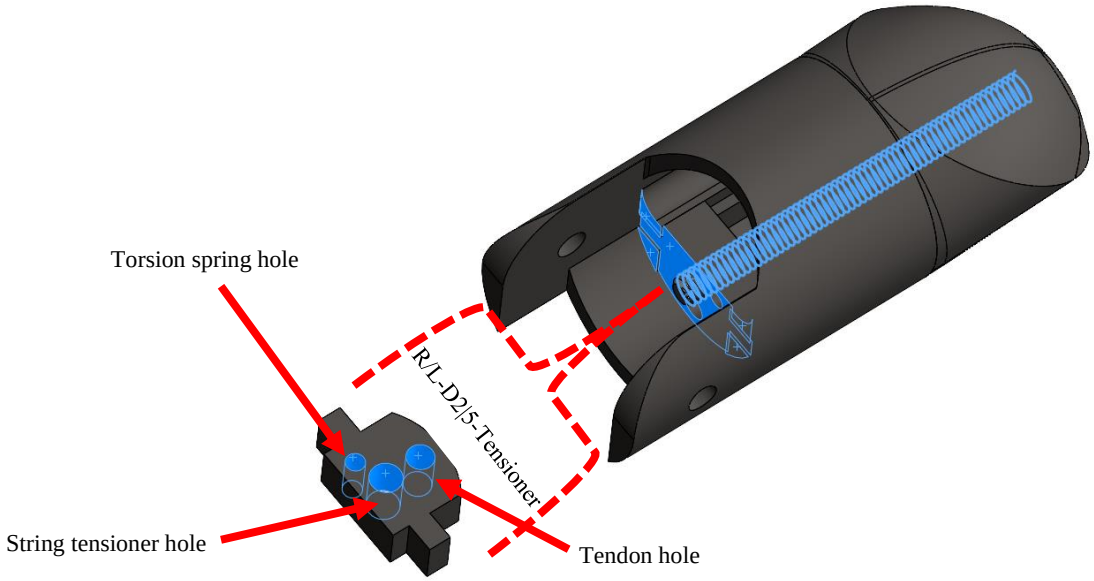


Figure 6: String tensioner layout

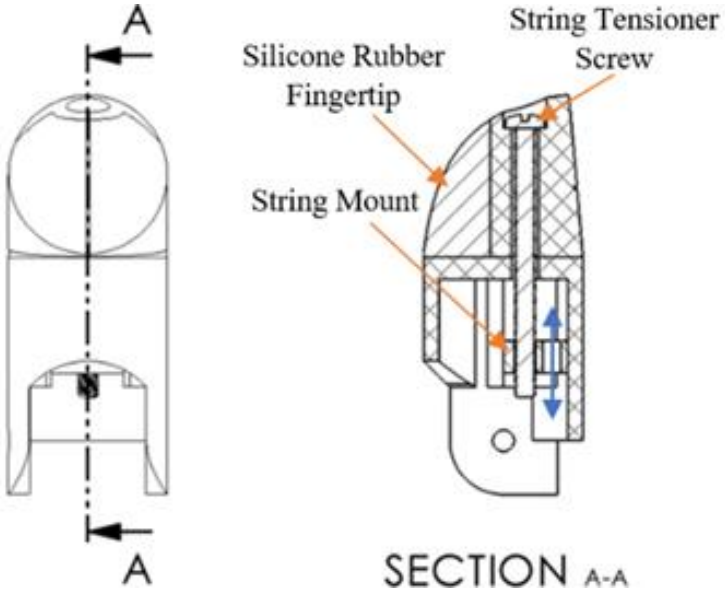


Figure 7: String tensioner cross-section

5.2 Assembly

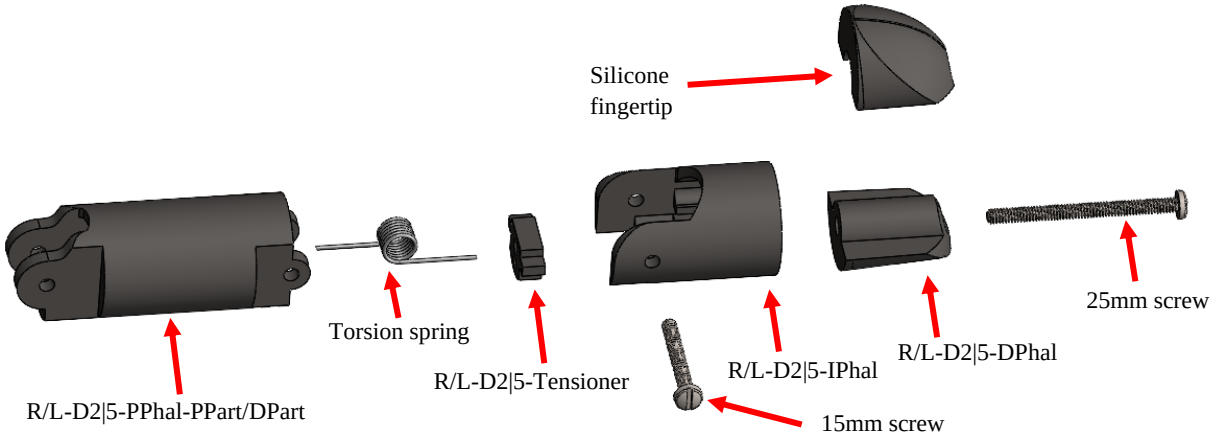


Figure 8: Digit general assembly

1. Cut the screws for joints ***D2|5-JI*** and ***D2|5-JP*** (15mm). The screw for ***D2|5-JP*** will be used later for assembling the digits to the palm.
2. Cut spring legs (they should be approximately 13mm) for joints ***D2|5-JI***.
3. Then with the torsion spring slotted in the torsion spring hole (**Figure 6**) and the ***R/L-D2|5-IPhal*** distal torsion spring slot (**Figure 4**) join them with the 15mm screw ensuring that the screw goes through the spring and that the tendon is on the palmar side of the digit.

NOTE: Refer to **Figure 8** for general layout.

NOTE: Fish the tendon through the palmar side of the finger.

6. Thumb (D1)

6.1 Preparations

6.1.1 Sanding Parts in Order to Ensure Proper Fit:

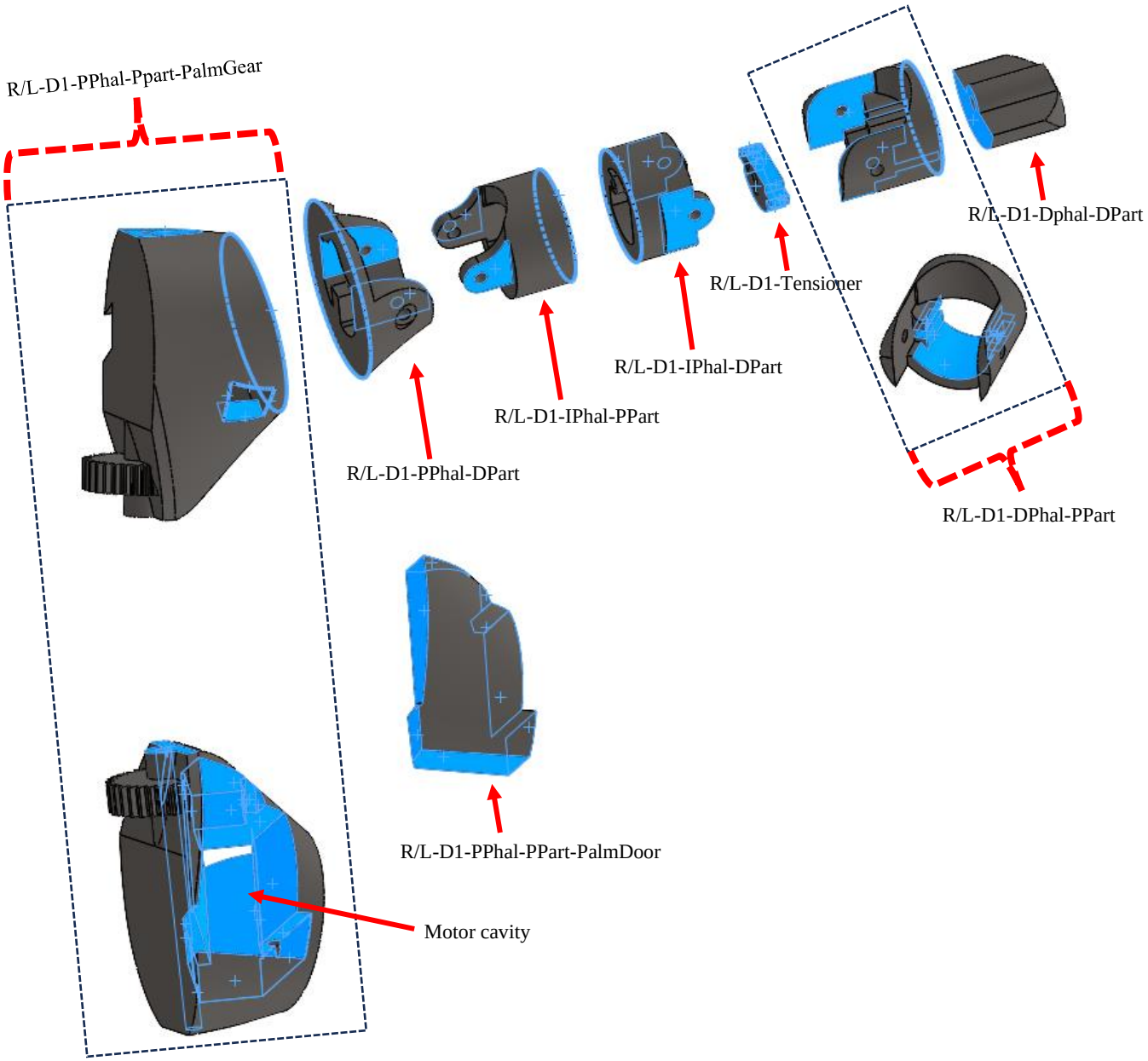


Figure 9: Thumb part locations for sanding

- Sand all faces as shown in **Figure 9** above. Ensure minimal interference to allow free sliding at the joint connection of ***R\L-D1-PPhal-DPart*** and ***R\L-D1-IPhal-PPart*** along with ***R\L-D1-IPhal-DPart*** and ***R/L-D1-DPhal-PPart***.
- Sand both the ***R\L-D1-Tensioner*** and ***R/L-D1-DPhal-PPart*** slot to allow smooth fit.

- Sand the ***D1-PPhal-PPart-PalmGear*** motor cavity so that the servo motor with no flanges fits inside.
- Cut the rod to 57mm. Then, sand the thumb abduction rod to ensure that it fits into the 2mm inside diameter of the bearings. This can be done using a hand drill and sandpaper. (See hand drill used in **Figure 10** to the right.) Attach the rod as you would a drill bit and pull the trigger while you sand the rod back and forth with the sand paper. Take out the rod and repeat again on its opposite side. Do this until the rod fits in the bearing with some resistance.

Figure 10: Hand drill used.

NOTE: May need to come back to re-sand these parts as needed for proper fit.

6.1.2 Thumb-tip Mold

Refer to **Figure 3**, Section 5.1.2—similar mold cast for the thumb.

6.1.3 Proximal Part:

1. Ensure the hole on the flat face of the proximal piece goes all the way through to the interior motor cavity (sand if needed), as the tendon string will pass through this hole. The proper hole pathway can be seen in the SolidWorks model provided (**Figure 11a**).
2. Glue the two parts together in the orientation shown in **Figure 11b** to the right.

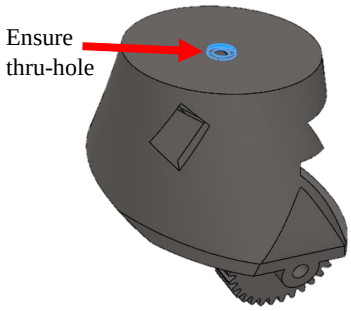


Figure 11a: View 1 – Thru-hole

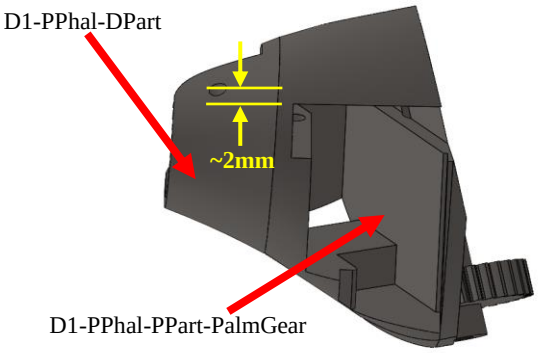


Figure 11b: View 2 - Mounting

6.1.4 Distal Part:

A. Glue together ***D1-IPhal-DPart*** and ***D1-IPhal-PPart*** such that the interior slots meant for the torsion springs are on opposite sides as shown in **Figure 12**. Complete the same process for ***D1-DPhal-DPart*** and ***D1-DPhal-PPart*** (**Figure 13**). Additionally, glue the rubber fingertip to the distal part.

Proximal torsion spring slots may need to be cleaned so that the spring leg fits in. This may be difficult even with a small file.

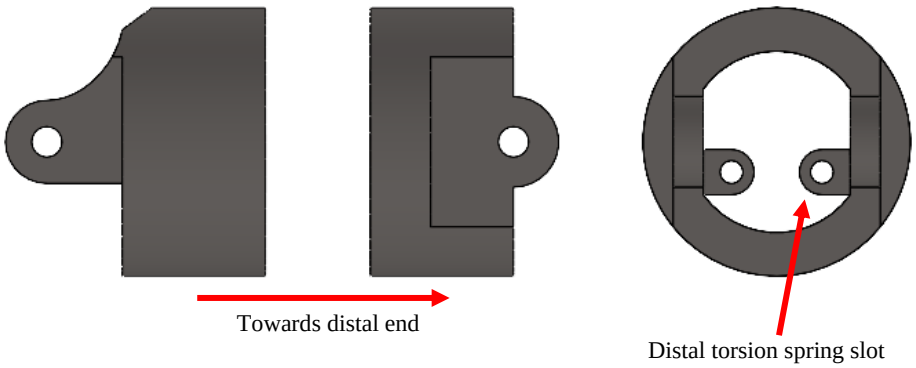


Figure 12: Distal torsion spring slot

Suggestion: Use gloves and a soldering iron. Heat up the spring leg and press the hot leg through the hole to clean it out. Remove before the plastic solidifies.

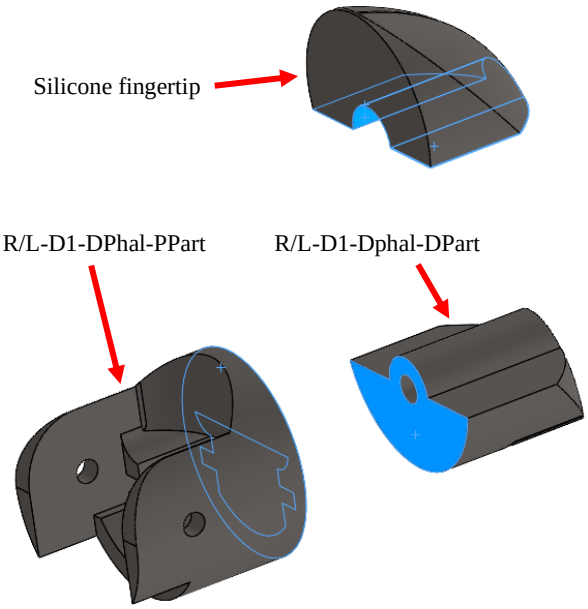


Figure 13: Gluing distal surfaces for thumb

B. Tendon preparation (D2-5)
    1. Prepare the tendon string (synthetic cable) by cutting a 150mm piece. The actual functional length of the string once completed and assembled is only about 60mm, but excess allows for error to be corrected. Cut this length of string, careful to do so with as little fraying as possible.
    2. Pass the tendon through the ***D1-PPhal-PPart-PalmGear*** through-hole as seen in **Figure 11a** (should be sticking through on both sides).
    3. Use the servo motor with no mounting flanges and zero it out with the servo tester (make sure that the zero position is correct such that when the servo is in the thumb it will wind the tendon in the correct direction to flex the thumb). The motor will be installed inside the ***D1-PPhal-PPart-PalmGear*** with the pulley side going in first.

4. Using a pointed-nose file, expand the slotting hole (**Figure 14**) such that the tendon string can pass through with little fraying and resistance. Take care not to completely file away the exterior wall of the slotting hole. Filing of the surrounding features of the pulley may be necessary.
5. Using a lighter or heat gun, burn the 10-15mm of excess string to reduce length, ensuring it sticks to the pulley.
6. Mount the pulley to the servo arm with the servo screw.
7. Place the servo motor inside the ***D1-PPhal-PPart-PalmGear*** motor cavity with the pulley side in first. Ensure that the servo wire goes through the slot on the back side.
8. Pull the tendon through the top lightly making sure not to rotate the servo motor. If so, re-zero with the servo tester.

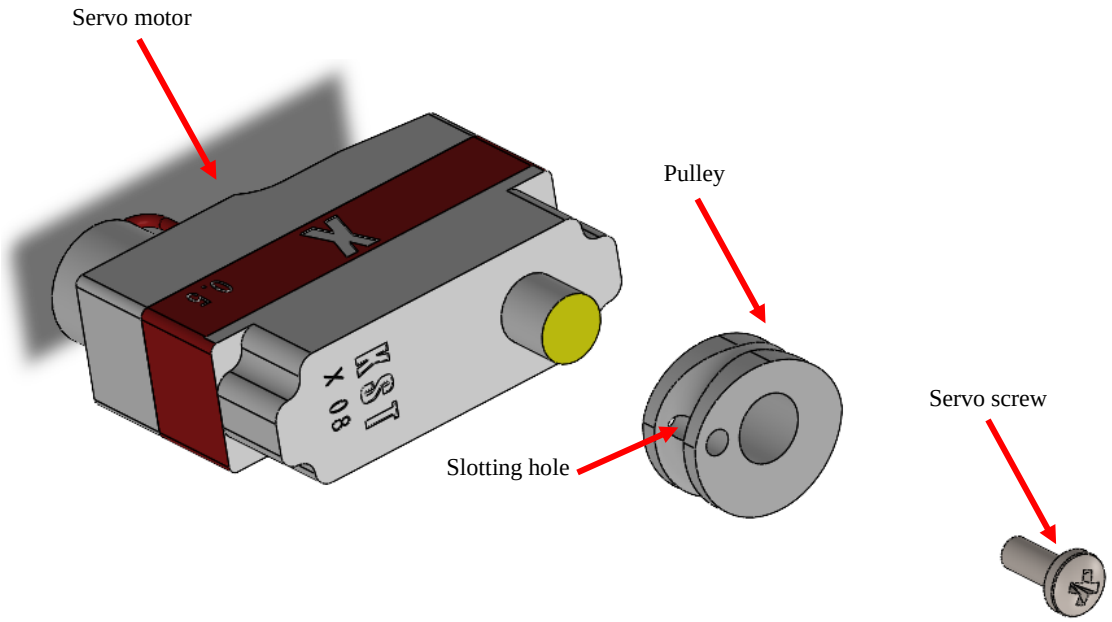


Figure 14: Pulley assembly

6.2 Assembly

1. Cut and file the end of three ***M2X25*** screws; one should be 21mm (proximal joint) ***D1-JP***, the other two should be 18mm (distal joint ***D1-JI*** and tensioner screw).
2. At this point, the proximal, intermediate, and distal parts should be completed, along with a string/tendon attached to the installed servo motor and coming out of the thru-hole on part ***D1-PPhal-PPart-PalmGear.***
3. Cut and bend the torsion spring legs so that they fit in the ***R/L-D1-PPhal-DPart*** spring slot (90°) and the ***R/L-D1-IPhal-PPart*** spring slot. Then use the 21mm screw to attach these two parts while ensuring the screw goes through the center of the torsion spring.
4. Use the 18mm tensioner screw and screw into the now-assembled distal thumb for the string tensioner.

5. Fish the tendon through the glued intermediate part (***R/L-D1-IPhal-PPart/DPart***) ensuring it is on the palmar side of the spring. Insert the tendon string through to the proximal-facing side of the ***R/L-D1-Tensioner***.
6. (This is the difficult part.) Move the distal thumb assembly of the thumb into position as if you were going to attach it. Observe the length of the tendon needed such that the tensioner can reach the tensioner slot. Remember to provide an extra 2-3mm to the string/tendon as it will have to go over the spring once it is fully assembled. Now tie a simple knot to secure the string/tendon, and place the tensioner in the ***R/L-D1-DPhal-PPart*** tensioner slot of the distal thumb assembly. Finally, screw the tensioner screw just enough to grab the tensioner.
7. Now cut the torsion spring legs (approximately 13mm) for ***D1-JI*** and place within slots of ***R/L-D1-IPhal-DPart*** spring hole and ***R/L-D1-Tensioner*** spring hole (remember the tendon should be on the palmar side of the spring). Now join these two parts with the second 18mm screw ensuring it goes through the torsion spring center.
8. Zero out the motor again because it may move during this process. Check to see if the tendon is too loose. You can tighten the tensioner screw, but it may be very loose even after tightening. At this point, you may have to remove the screw at ***D1-JI*** and make the string a little shorter (reassemble and try again).
   NOTE: This process may take some time, be very careful you don't rush it or you will remove too much string!

NOTE: Refer to **Figure 15** below for general layout.

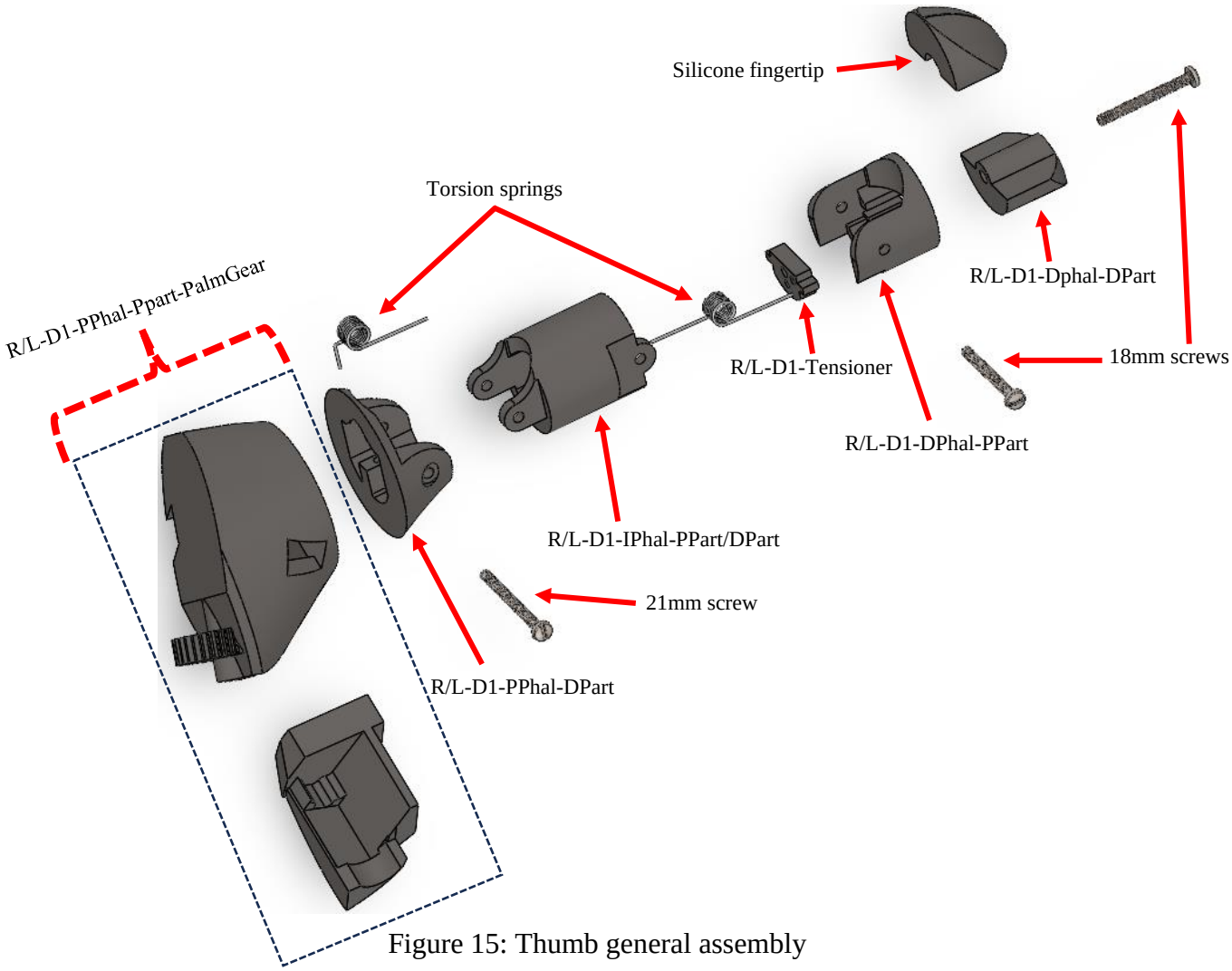


Figure 15: Thumb general assembly

7. Palm

7.1 Preparations

- Sand, file & perform deep clean of slits in ***R\L-Palm-DorsalCover*** after removing supports.
- Sand the ***R\L-Palm-DorsalCover*** and ***R/L-Palm-PalmarCover*** where ***D2|5*** will sit and interact to ensure smooth fit.
- Sand and file the ***R/L-Palm-InteriorFrame*** where servo motors mount to ensure a tight snap fit. Sand where the ***D2|5*** will be mounted to ensure smooth fit. Sand thumb abduction bearing mount to ensure bearing fit. See **Figure 16** for sanding surfaces.

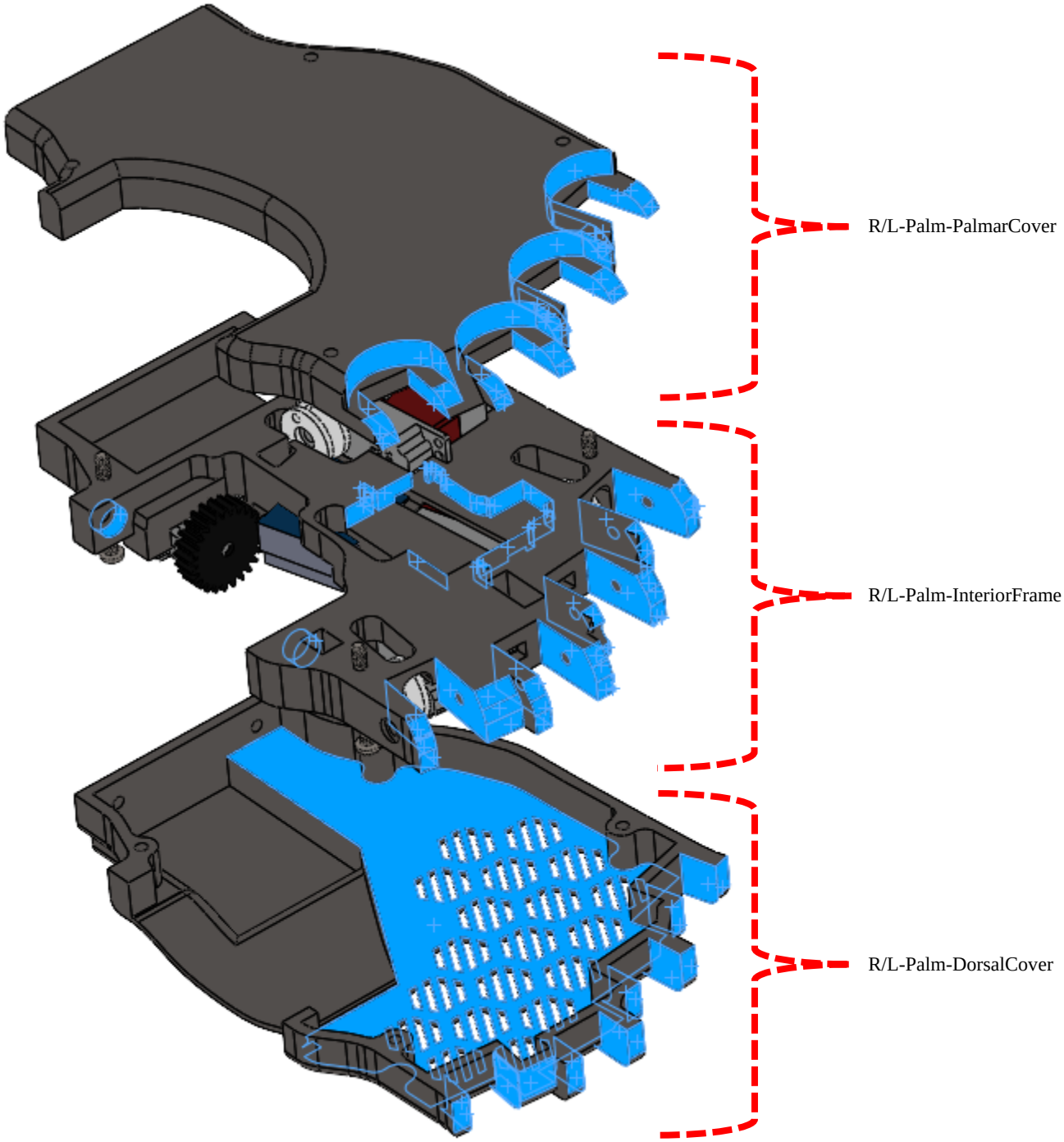


Figure 16: Sanding locations for palm parts

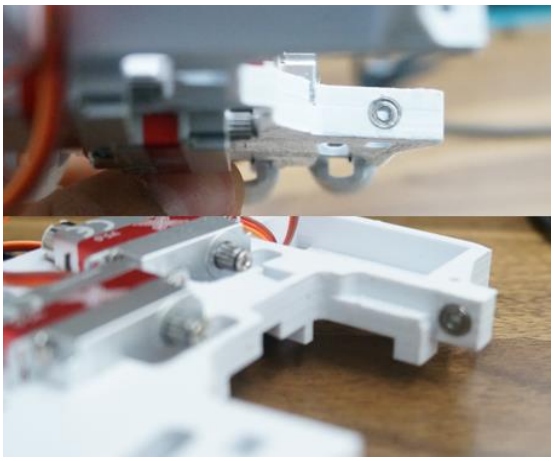


Figure 17: Motor placement

- Insert bearings into ***R/L-Palm-InteriorFrame*** as shown in **Figure 17**.

8.2 Mount the Digits D1|5 to the Palm

1. General digit attachment to palm can be seen in **Figure 18**.
2. Cut the torsion springs for ***D2|5-JP***. The leg that goes up into the proximal ***R/L-D2|5-PPhal-PPart*** will need to be trimmed to approximately 13mm.
3. Assemble the digits in the following order: D3, D4, D5, D2.
4. Place the torsion spring up in the given digit spring slot. Make sure the tendon is on the palmar side of the spring. Put the digit in place with the other end of the torsion spring pressing against the palm. Screw in the 15mm ***D2|5-JP*** screw that was cut earlier in the digit assembly section.
5. The leg of the torsion spring that presses against the palm will need to be cut short and pressed into the palm by heating with a soldering iron. (See figure to the right.)
6. Repeat steps 3 and 4 until digits ***D2|5*** are secured.
7. Now align the thumb on the palm and slot the 2mm rod through the bearings and the proximal part ***D1-PPhal-PPart-PalmGear***.

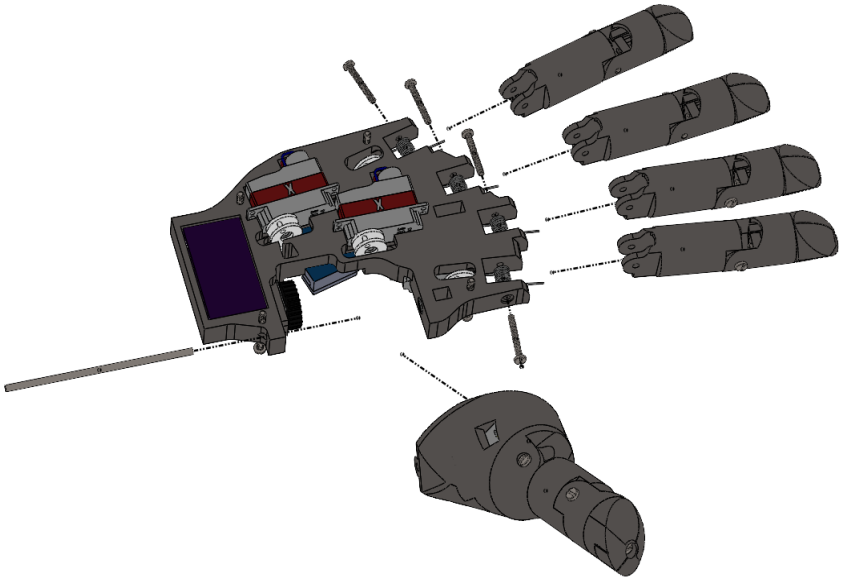


Figure 18: Digit attachment

7.3 Motor Placement

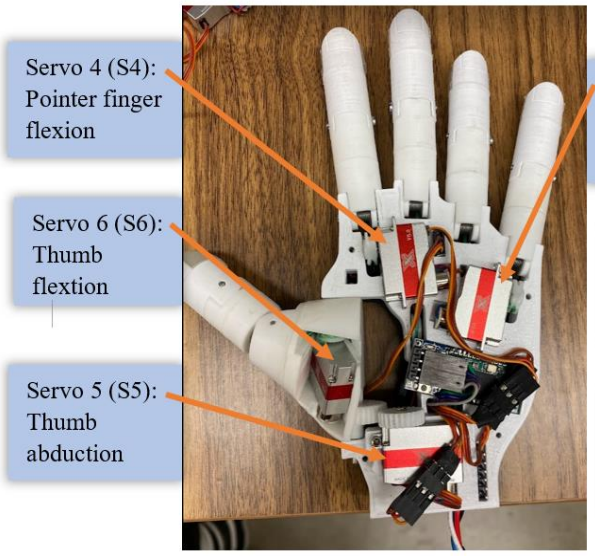


Figure 19a: Dorsal side servo motor reference

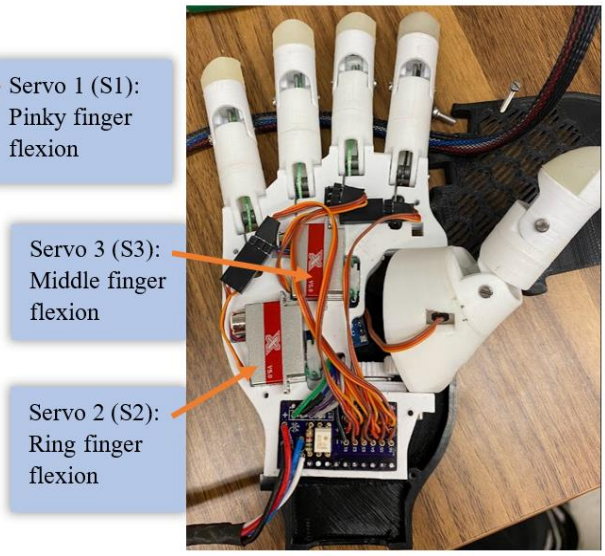


Figure 19b: Palmar side servo motor reference

Table 3. Servo motor number, pin on PCB, and wire cut lengths

Servo Pin on Breakout PCB	Digit	Flange type	Wire length from motor (mm) – Female end	Wire length from PCB (mm) – Male end
(Servo 1) S1	Pinky Flex	Vertical flange	60	80
(Servo 2) S2	Ring Flex	Vertical flange	40	100
(Servo 3) S3	Middle Flex	Vertical flange	50	90
(Servo 4) S4	Pointer Flex	Vertical flange	80	60
(Servo 5) S5	Thumb Abduction	Horizontal flange	65	75
(Servo 6) S6†	Thumb Flex	No flange	95	100

† There will not be enough wire left over from the servo motor (S6) after it is cut so you will need to use the Extra Servo Wires to accommodate the length from the PCB.

Each servo motor needs to be cut and have male/female ports added to the junction to allow for disconnection without disassembly. See **Table 3** for servo wire cut list.

7.3.1 Wire Cutting

Wire Cut Procedure (Female End): This is the wire still attached to the servo motors.

The cut list is designed to account for errors in cutting, so if done as in **Table 3** above, the system will have a slight amount of slack in the final assembly.

Figure 20a:

Figure 20b:

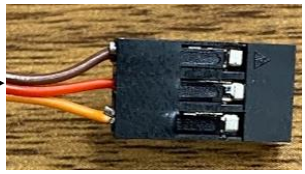


Figure 20c:

Cut the servo wires to the appropriate length as given in **Table 3**.

Section below explains how to use the crimping tool.

1. Strip 2-3mm of insulation off each of the three wires to expose the proper amount of conductor. Twist conductor to prevent splaying, or "frizzing."
2. Make sure each wire is separated 10mm to allow for ease in crimping.
3. Load a 10mm connector piece into the small end of the crimping device (https://www.amazon.com/dp/B087BGTH1Y). Make sure the larger set of wings is flush with the surface of the crimping tool.
4. Insert one servo wire such that the first set of connector wings may anchor into the insulation of the wire and the second set of wings touches the exposed conductor. Squeeze the device to the tightest setting and release.
5. Inspect the connector: lightly pull back and forth. If some movement occurs, use needle-nose pliers to adjust the connection to make it more fit. Make sure the smaller wings are in good connection with the conductor.
6. Repeat connections for the remaining two wires.
7. Once all three connectors are attached, carefully insert all three connectors into a three-slot plastic housing receptacle. Make sure all connectors are top-side up (should see a small square facing up on each connector).
8. Insert connectors into housing until you hear 3 clicks, one for each wire. Repeat for each wire of every servo motor.

Wire Cut Procedure (Male End): This is the wire that will attach to the PCB.

1. Remove the existing female-adapter and connector pieces off the three wires. Do this by cutting midway along the housing unit to break the plastic and expose the connector pieces at the end of each wire. Pull the connector pieces off using the pliers, exposing the conductor.
2. Break off a set of 3 header pins using the pliers. Cut off three 10mm pieces of heat-shrink insulator and load onto each of the newly cut wire ends. Separate the wires, giving about 50mm of range between the soldering gun and the loaded heat shrink (to avoid premature shrinking).
3. Solder each wire to the shorter end of a header pin, and ensure the order of wires remains consistent (i.e., Brown-Red-Orange). Once a connection has been made between two

wires, load the heat-shrink insulator over the exposed conductor and apply a conservative amount of heat to the area (**too much heat can melt the solder underneath and disrupt the connection**).

4. Complete this process for male-ended wires S1-5. For wire S6, complete the same steps as listed above, however, use a set of 3 right-angled header pins.

7.4. Mounting Tendons and Motors

7.4.1 Fingers - D2|5

NOTE: Zero out the servo motor before attaching tendon using the servo tester. The zero direction of the servo depends on the location of the servo motor.

A. Servo pulley preparation (applicable for ***D2|5***):
   1. Attach a servo pulley to the servo arm such that the flat side of the pulley is facing away from the palm and the curved side is facing into the palm. Identify the hole in the pulley that is furthest from the distal finger joint and facing into the servo. We will call this hole the slotting hole (see **Figure 21** below).
   2. Take the pulley off and using a pointed-nose file, expand the slotting hole such that the tendon string can pass through with little fraying and resistance. **Take care not to completely file away the exterior wall of the slotting hole.** Filing of the surrounding features of the pulley may be necessary.
   3. Pass the tendons through their appropriate pathways in the palm.
   4. Then slot the tendon string through the slotting hole of the servo pulley such that the string passes over the pulley's track. When the pulley is lined up to be mounted to its servo, the string should be in the gap between the pulley and the servo.
   5. Pull the string through the pulley hole as it is aligned with its actual placement. To do this, you may need the servo motor in position.
   6. Once the appropriate length for the tendon is determined, cut any excess leaving about 10-15mm.
   7. Using a lighter or heat gun, burn the 10-15mm excess string to reduce length, ensuring it sticks to the pulley.
   8. Mount the pulley to the servo arm. Using the servo tester, bend the finger. If a large amount of slack is present during the initial bend of the finger, remove the pulley and remount it in a configuration that has less slack. If a small amount of slack is present, tighten the pulley onto the servo with the servo screw and put the servo in place.
   9. Then, tighten the tensioner via the flathead screw on the tip of the finger. Adjust until optimal tension is acquired, such that when using the servo tester only a small movement of the knobs starts moving the finger.

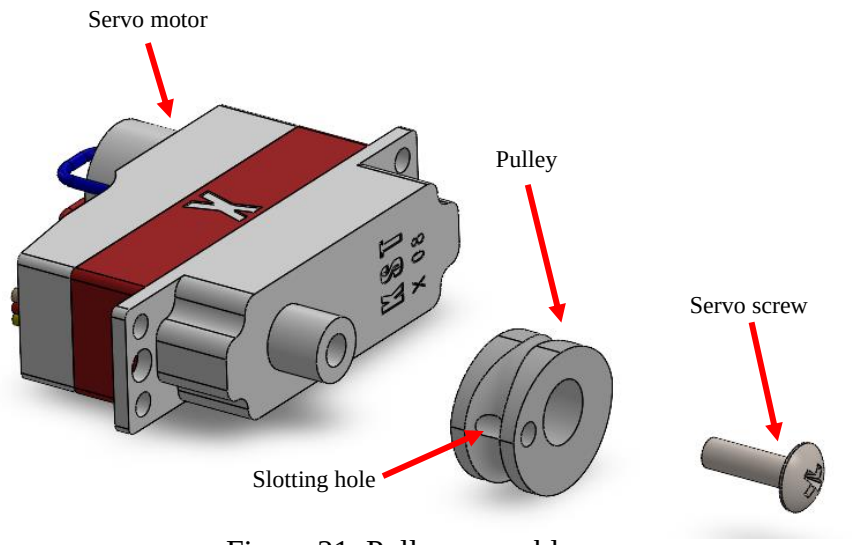


Figure 21: Pulley assembly

7.4.2 Thumb - D1

1. Zero out the motor for the thumb abduction (Servo 5).
2. Place the ***R/L-D1-PalmGearWheel*** on the servo and screw in.
3. Move the thumb just under parallel with the palm and place the servo with the gear into its position. If it does not go in you may need to take the 2mm rod out of the thumb to adjust. If it is too close to the ***R/L-D1-PPhal-PPart-PalmGear*** you may need to shim Servo 5. (Place a few small sheets of paper under the motor to raise it up for a good gear mesh to prevent gear binding). Screw the servo motor to its place with the screws provided with the servo motor. (See **Figure 22** below.)

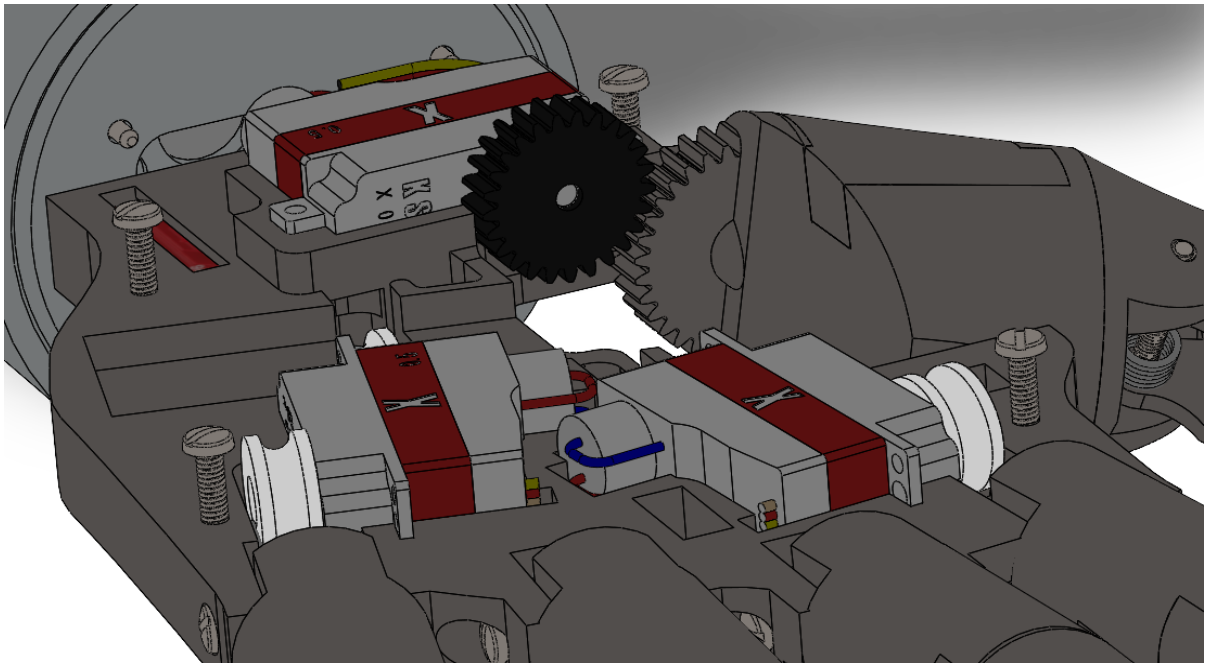


Figure 22: Thumb abduction gear mounting

7.5 Covers and Wrist

*****NOTE: Leave dorsal palm covers off—install after hardware & software section**

1. After the motors have been wired, electronics soldered, board has been programed and Bluetooth module inserted, proceed with cover and wrist installation.
2. Cut 4 ***M2X25*** screws to an 18mm thread length. Install palmar and dorsal covers ensuring not to pinch any of the wires. Then screw in from the dorsal side to the palmar side (see **Figure 23** below).
3. After this you can install the wrist mounts. Make sure the power wires are routed through the wrist and proceed to screw in the ***R/L-Wrist-HandMount*** using four of the #4 x 1/2" Flat Head Sheet Metal Screws.
4. Fish the wires through the ***R/L-Wrist-HandAdapter*** then mount it to the ***R/L-Wrist-HandMount*** with four M3 x 0.5mm bolts.
5. Print rubber grip template found on the next page; use template to cut Neoprene textured adhesive rubber and attach to the palm.

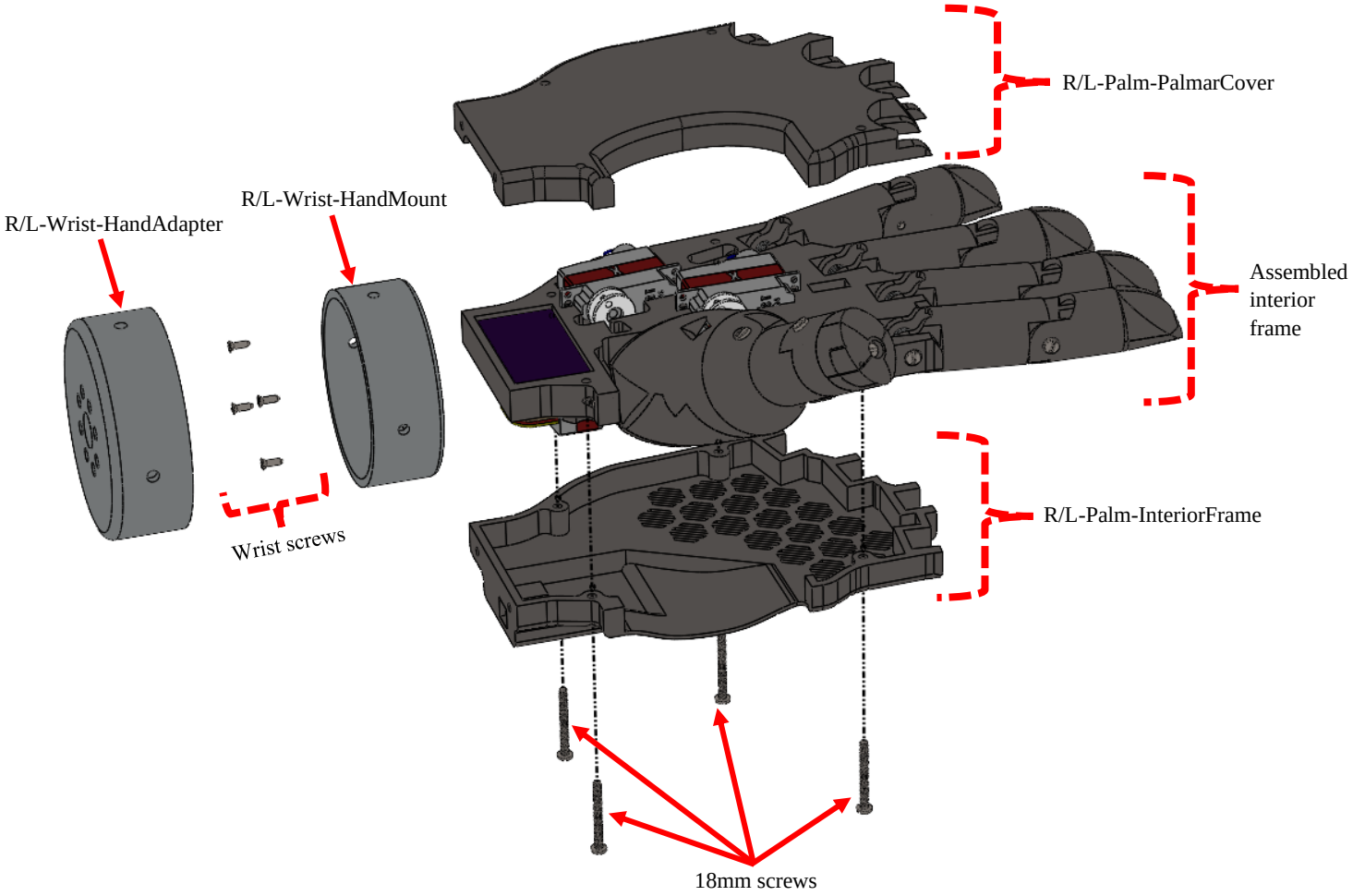
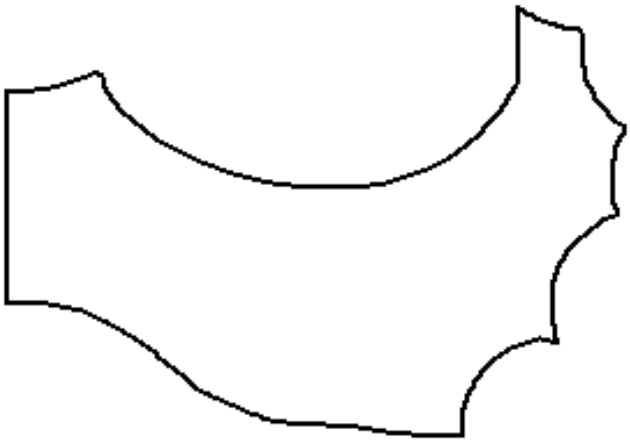
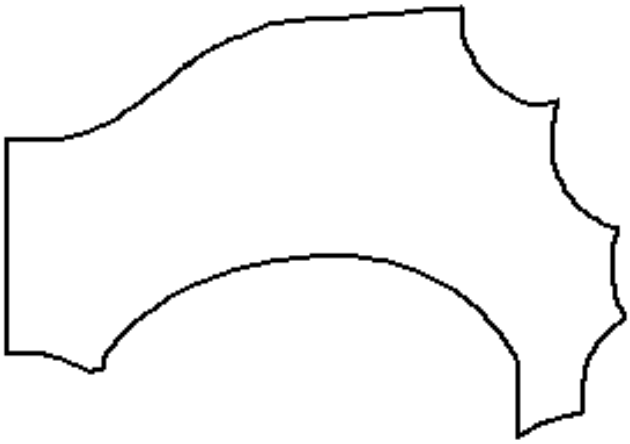


Figure 23: Thumb abduction gear mounting

Left Hand



Right Hand



Drawings are to scale: Print out and use as a template to cut the textured rubber for the palm grip.

8. Hardware and Software

8.1 Soldering

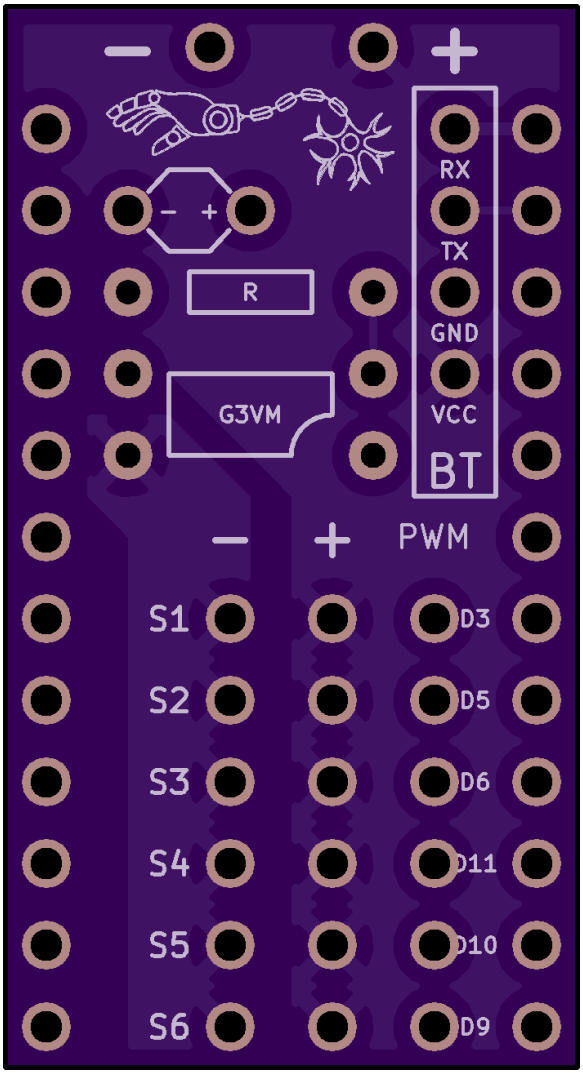


Figure 24a: PCB front

Figure 24b: PCB back

1. Solder the resistor to the PCB where the ***R*** location is (**Figure 24a**).
2. Solder the relay to the PCB where the ***G3VM*** location is, in the orientation of the dot present on the relay itself, aligning it with the cutout on the PCB drawing (**Figure 24a**).
3. Cut 4 pieces of the power wire about 2-3 feet (or to your desired length) and solder them to the thru-holes shown in **Figure 25** below.
4. Connect the other end of these wires separately to the two DC Barrel Jack Adapter – Female parts following the positive and negative wire labeling (these will need to be removed and reinstalled when placing the palm covers on at the end).

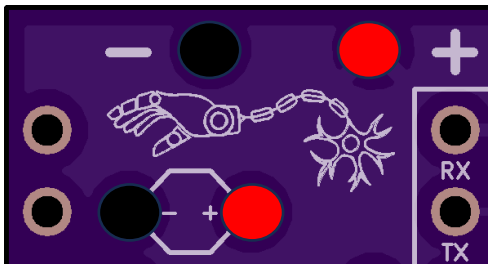


Figure 25: Power mount thru-holes

5. Solder the other half of the servo wires to the below thru-holes. Brown is negative, red is positive, and yellow is PWM (**Figure 26**).

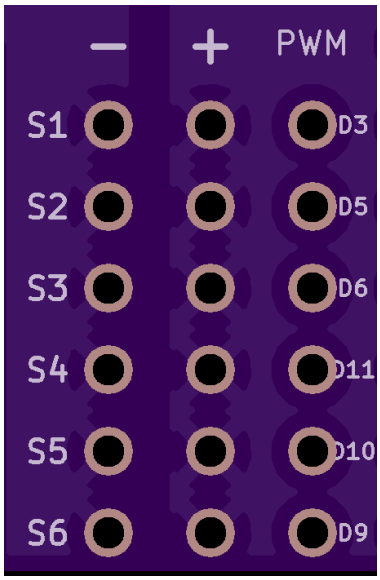


Figure 26: Servo mount thru-holes

6. Create a 4 pin female connector as described in **Section 7.3.1** (Wire Cutting) with 4 equal length wires of 85 mm. Then solder the end onto the RX, TX, GND and VCC thru-holes as shown in **Figure 27** below.

Figure 27: Bluetooth mount thru-holes

7. Desolder the Bluetooth header pins and resolder new 90° header pins in the opposite direction (into the board), as this saves space. **It is difficult to desolder so buying an extra Bluetooth module may be needed.**
8. Clean up any large amounts of solder on the back of the PCB with wire cutters.
9. Solder the header pins to the Arduino ProMini around the outside: two 12-pin headers, and one 6-pin header (see **Figure 28a** below).
    a. For the two 12-pin headers, the pins should be soldered with the short end going into the back face (underside) of the Arduino ProMini, and the longer ends sticking downwards (see **Figure 28b** below).
    b. For the 6-pin headers, the short end should be going into the front face of the Arduino, and the long ends sticking upwards (see **Figure 28b** below).

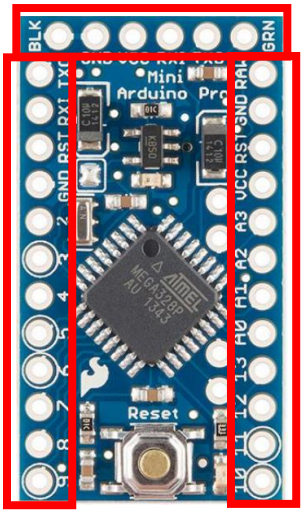


Figure 28a: Arduino ProMini header pin location.

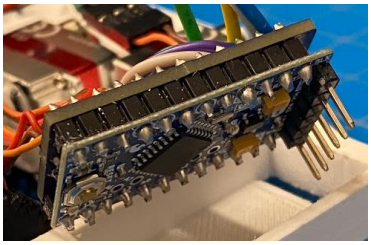


Figure 28b: Arduino ProMini header pins mounted.

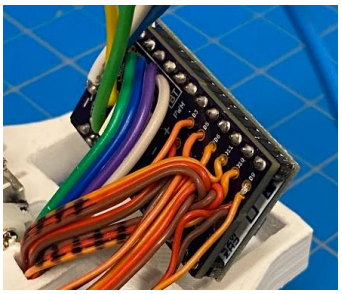


Figure 28c: Arduino ProMini and PCB mounted.

10. Now solder the PCB to the Arduino. The back face of the Arduino should be facing the back face of the PCB (see **Figure28b and c**). **Make sure everything is done because you can't go back from this step.**

8.2 Wiring

1. Wires for servos 1, 4 and 5 go through port 1 (**Figure 29**) of the palm frame, from the dorsal side through to the palmar side. **Servo 2 will need to be popped out of its place momentarily while wires are passed through.**
2. Wires for the Bluetooth module will go through port 1 (**Figure 29**) of the palm frame, from the palmar side to the dorsal side where the Bluetooth module is located. **Servo 2 will (again) need to be popped out of its place momentarily while wires are passed through.**

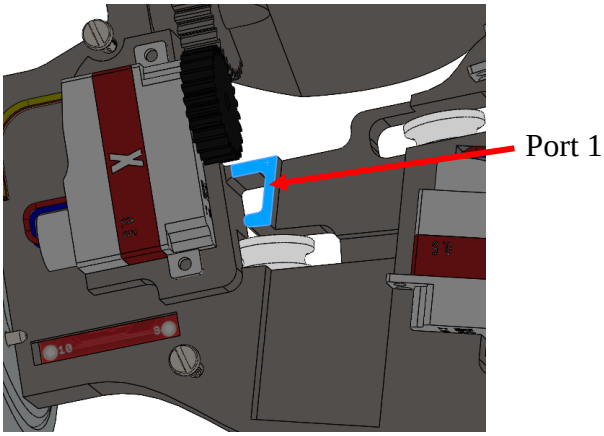


Figure 29: Port 1 – Wire routing

3. Servo 6 wire will go through port 2 of the palm frame on the dorsal side, and the female connector will stay inside this port (see **Figure 30** below).

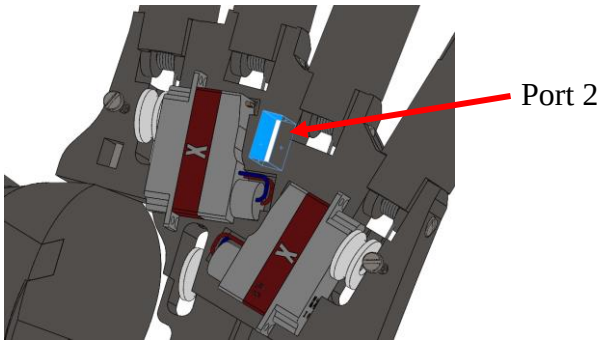


Figure 30: Port 2 – Wire routing

4. Follow **Figures 31a** and **31b** below for wire routing and Bluetooth module placement.

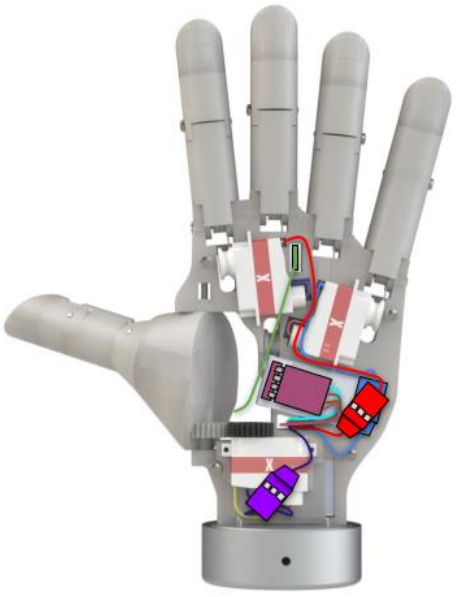


Figure 31a: Servo wire routing - Dorsal

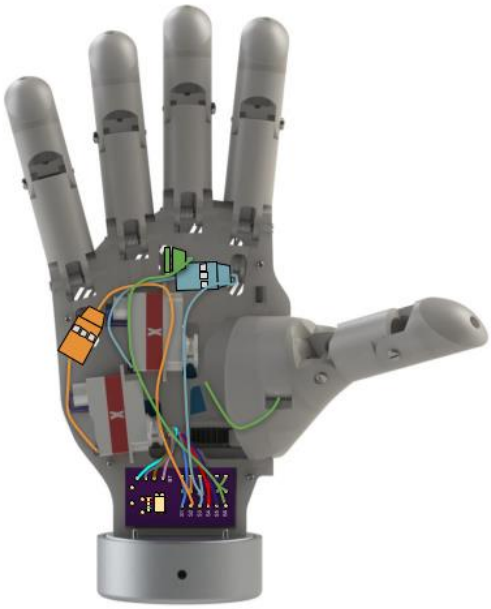


Figure 31b: Servo wire routing - Palmar

8.2 Programming

1. Leave the Bluetooth module unconnected and connect the FTDI cable to program the hand (**make sure jumper on the FTDI is on the 3.3V setting**).
2. The FTDI board will require that you download the drivers. Link can be found below: https://ftdichip.com/drivers/d2xx-drivers/
   The **driver version** used was the **2.12.28** but this is no longer supported. It can be found at the link above but newer version should still work.
3. Download and install Arduino IDE: https://www.arduino.cc/en/software.
   Then make the following board selections: see **Figure 32** below.

   Board: Arduino Pro or Pro Mini

   Processor: ATmega328P(3.3 V, 8 MHz)

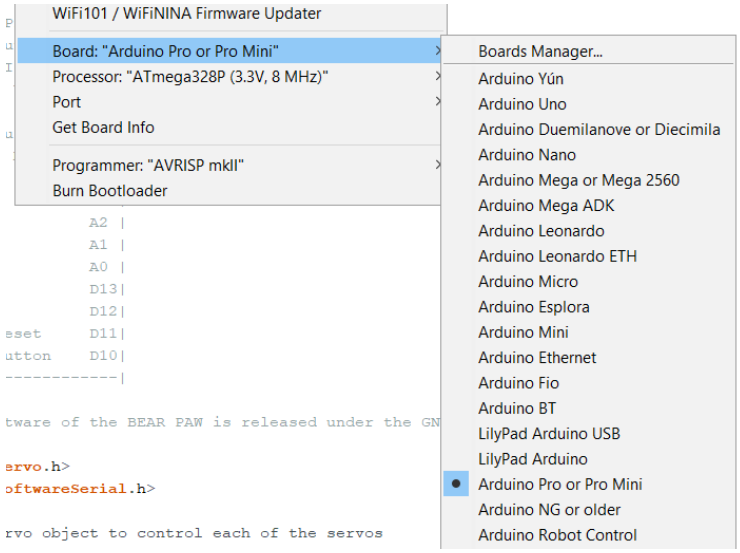


Figure 32: Arduino board and processor settings

4. Download the Arduino script from GitHub and upload to the board.
5. Now download Processing (currently using **version 3.5.4**) from the following link: https://processing.org/de/download/
   Under the ***Sketch tab***, go to ***Import Library*** then ***Add Library***. Search and add ***ControlP5 library*** by Andreas Schlegel. See **Figure 33** below.

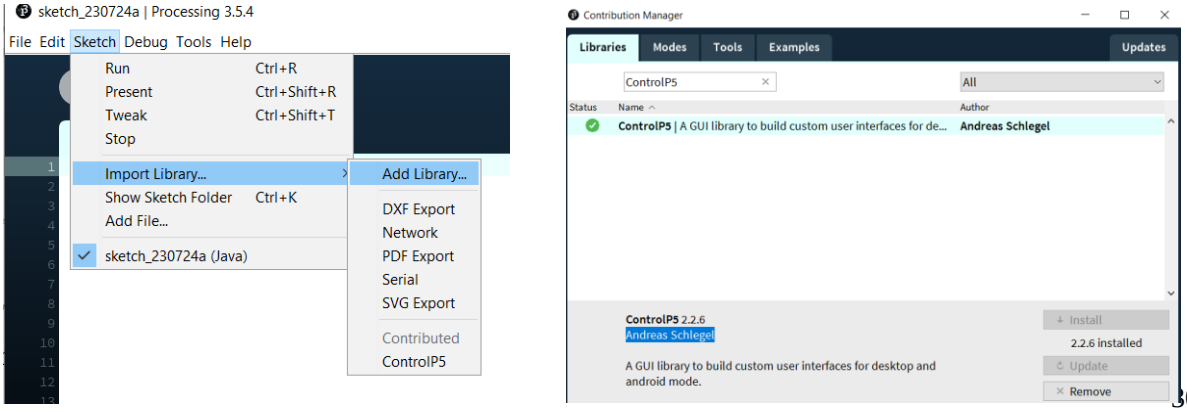


Figure 33: ControlP5 library installation procedures

6. Now you can plug in the two Wall Adapters into mains power and connect the two DC Barrel Jack Adapter – Female parts to them.
7. Then download the GUIProcessing script from GitHub and run it.
8. Upon first run, the script will likely give an error because the wrong port is selected and the GUI will remain black. The code should have provided a list of the available communication ports in the Console. Cycle through these on line 50 shown below ("COM5") until the GUI successfully runs.

```
43
44 void setup(){
45
46   size(1100, 530); // window size
47  //Comunication Port Setup
48        //Uncomment to control via bluetooth
49        printArray(Serial.list()); // prints all available serial ports
50        port = new Serial(this, "COM5", 9600); //Select the USB port the SAMD is conn
51
52   cp5 = new ControlP5(this);
```

Figure 34: Communication port setup

9. Now you can turn the virtual knobs and press the virtual buttons to make sure everything works. See the GUI **Figure 35** below.
    a. To go into any grasp, toggle the virtual button (press it twice). To go back to Grasp 1 (i.e., rest), toggle it.

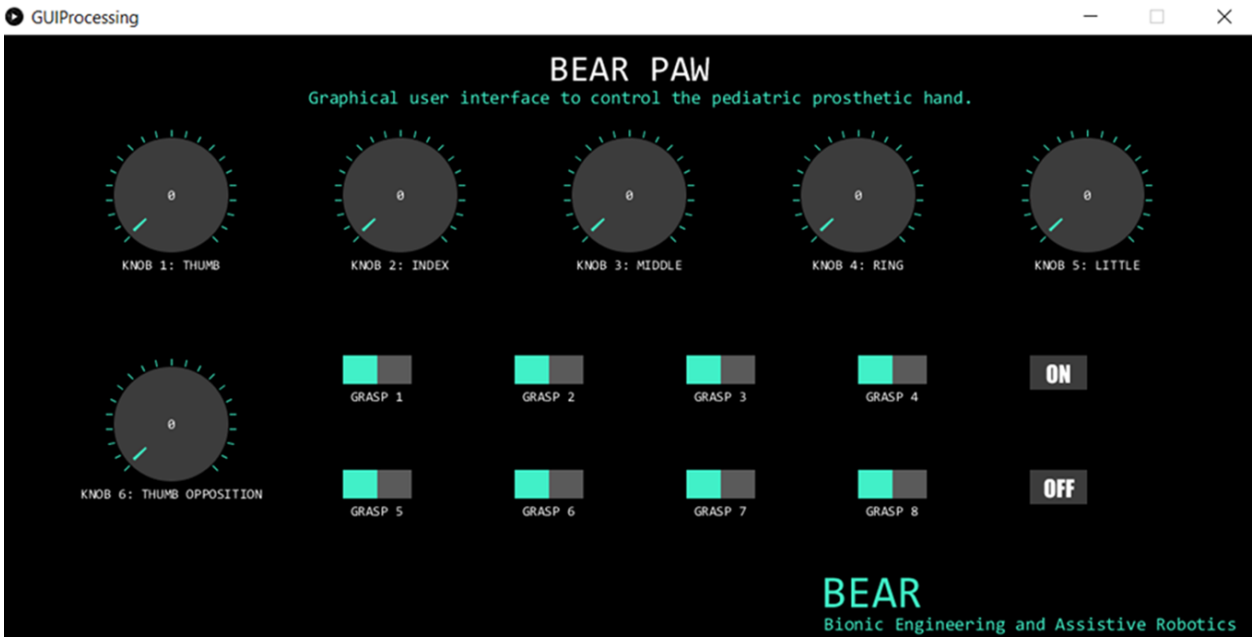


Figure 35: Graphical User Interface

10. Once you successfully run the GUI in Processing, you can take the FTDI out and plug in the Bluetooth module. You will have to select the Communication port again. **Make sure everything works again before you put the palm covers on.**

    If successful you can now put on the palm covers and wrist mounts.