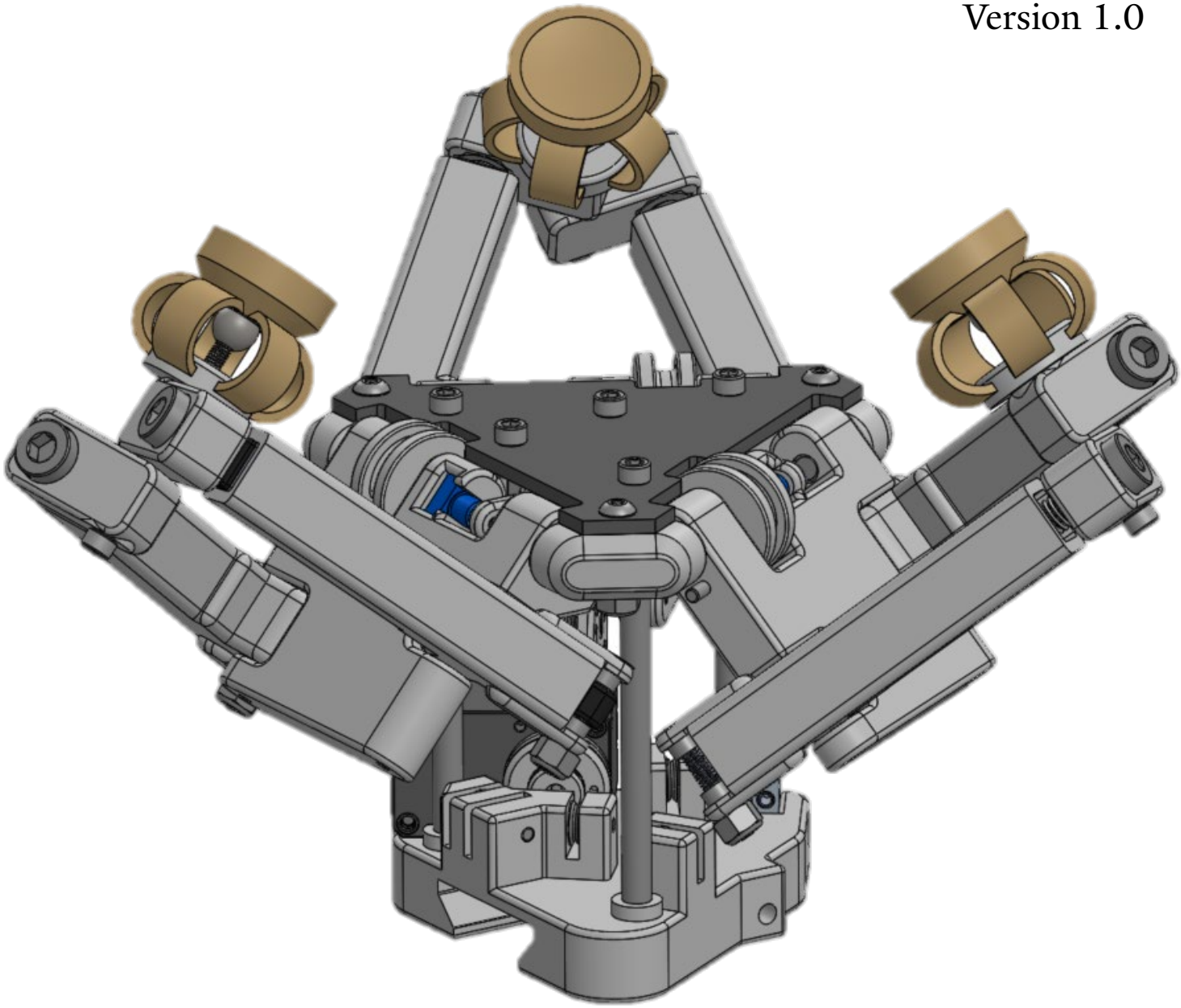
OpenHand

Stewart Hand

Version 1.0

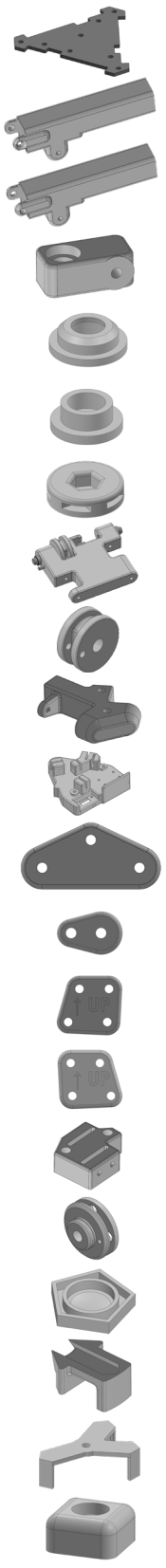


Assembly Instructions

Last updated: August 9, 2018

Custom Parts

Part Name	Usage	Fabrication	Quantity
w1.dxf	Palm plate (aluminum)	Waterjet/Mill	1
p1a.stl	Linear actuator mount (a)	3D print	3
p1b.stl	Linear actuator mount (b)	3D print	3
p2.stl	Fingertip pivot block	3D print	6
p3a.stl	Magnet holder (a)	3D print	3
p3b.stl	Magnet holder (b)	3D print	3
p4.stl	Leaf spring retaining ring	3D print	3
p5.stl	Finger base	3D print	3
p6.stl	Finger pulley	3D print	3
p7.stl	Finger axle block	3D print	3
p8.stl	Hand base	3D print	1
p9.stl	Double pulley block	3D print	2
p10.stl	Single pulley block	3D print	2
p11a.stl	Transmission pulley block (a)	3D print	1
p11b.stl	Transmission pulley block (b)	3D print	1
p12.stl	Stationary pulley block	3D print	1
p13.stl	Actuator pulley	3D print	1
m1.stl	Mold base	3D print	3
m2.stl	Mold insert	3D print	15
m3.stl	Mold top	3D print	3
f1.stl	Bearing press-fit fixture	3D print	1



Off-the-Shelf Parts (1/3)

Part Name	Quantity	Description	Vendor
Ø1/4” L1-5/8” steel dowel pin	3	Joint pin	McMaster [98381A547]
Ø1/4” L7/8” steel dowel pin	3	Joint pin	McMaster [98381A541]
Ø1/8” L2” steel dowel pin	3	Joint pin	McMaster [90145A480]
Ø1/8” L1-5/8” steel dowel pin	3	Tendon anchor pin	McMaster [90145A886]
Ø1/8” L1-1/2” steel dowel pin	3	Joint pin	McMaster [90145A884]
Ø1/8” L1” steel dowel pin	1	Pulley pin	McMaster [90145A475]
Ø1/8” L5/8” steel dowel pin	7	Pulley pin	McMaster [90145A472]
Ø1/8” L3/8” steel dowel pin	9	Pulley pin	McMaster [90145A470]
8-32 L1-1/8” countersunk screw	6	Fastener	McMaster [93085A201]
8-32 L1” countersunk screw	3	Fastener	McMaster [90585A233]
M2.5 x 16mm countersunk screw	4	Fastener	McMaster [92125A085]
8-32 L1” socket bolt	3	Fastener	McMaster [91251A199]
8-32 L5/8” socket bolt	2	Fastener	McMaster [90128A196]
4-40 L3/16” socket bolt	6	Spring anchor	McMaster [90128A105]
M8 L16mm socket bolt	6	Fastener	McMaster [91290A418]
M4 L55mm socket bolt	3	Fastener	McMaster [91292A268]
8-32 L7/8” button head screw	3	Fastener	McMaster [91306A267]
2mm L5mm self-tapping screw	2	Fastener	McMaster [96817A207]
Ø1/2” #6 countersunk washer	3	Spherical joint base	McMaster [90333A007]

Off-the-Shelf Parts (2/3)

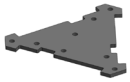
Part Name	Quantity	Description	Vendor
8-32 nylon lock nut	6	Fastener	McMaster [90631A009]
8-32 L 11/64” low-profile nut	3	Fastener	McMaster [90633A009]
M8 L4mm low-profile nut	6	Fastener	McMaster [90695A040]
M4 nylon lock nut	3	Fastener	McMaster [90576A103]
M4 nut	3	Fingertip mold	McMaster [90695A035]
8-32 heat set threaded insert	2	Bolt anchor	McMaster [93365A140]
4-40 heat set threaded insert	21	Bolt anchor	McMaster [93365A120]
8-32 L3” threaded standoff	3	Support	McMaster [93330A543]
M4 L4mm spacer ring	12	Spacer	McMaster [92871A006]
3/8” OD, 1/4“ ID, L1/8” ball bearing	6	Finger bearing	McMaster [57155K375]
Ø3/8” pulley	14	Tendon routing	McMaster [3434T310]
Extension spring	3	Finger spring	McMaster [9044K17]
Actuonix L12-50 (50mm stroke)	6	Linear servos	Actuonix [link]
Dynamixel XH-430-W350-R	1	Rotary servo	Robotis [link]
USB2Dynamixel or U2D2 adapter	1	Servo adapter	Robotis [link]
MiniMaestro 18	1	Servo Controller	Pololu [link]
D-Sub 9-pin connector	1	Serial Connector	Digikey [609-1483-ND]
10K ohm potentiometer	3	Finger angle sensor	Digikey [3310C-101-103L-ND]
Dragon Skin 30 silicone	1	Finger pad rubber	Smooth-On [link]

Off-the-Shelf Parts (3/3)

Part Name	Quantity	Description	Vendor
Ø3/8” L3/16” disk magnet	3	Fingertip magnet	K&J Magnetics [KJ_D63_N52]
Spectra line	1	Tendon	Amazon [link]
3-wire servo cable	3	Wiring	Various [link]
Mini-USB-B to Standard USB-A cable (any length)	1	Data cable	Various [link]
DB9 cable (at least one male end, choose length based on application)	1	Data cable	Various [link]
Ø10mm M4 threaded steel sphere (ferromagnetic but not magnetized)	3	Spherical joint	Various [link]
Electrical Wire (single-conductor and double-conductor)	N/A	Wiring	Various
Cyanoacrylate (i.e. superglue)	N/A	Adhesive	Various
Hot glue	N/A	Adhesive	Various
Heat shrink tubing	N/A	Insulation	Various

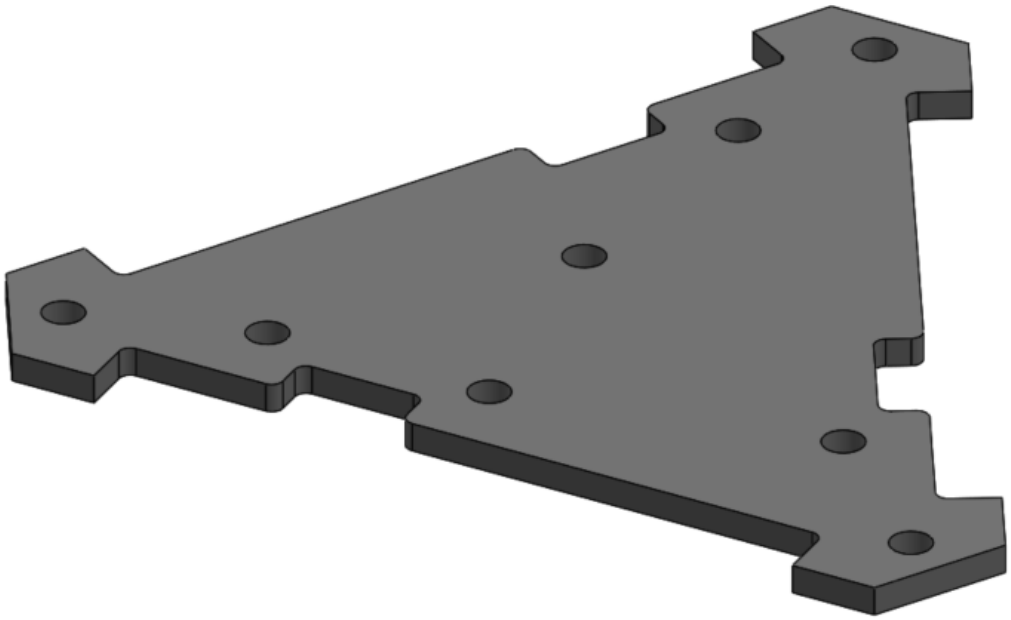
Note on Metal Components

Parts
`w1.dxf` **(x1)**



While most components in this hand are 3D printed or commercially available, the main palm plate must be made out of aluminum for strength. This component can be machined on a CNC mill or cut from 1/8” aluminum stock on a waterjet cutter.

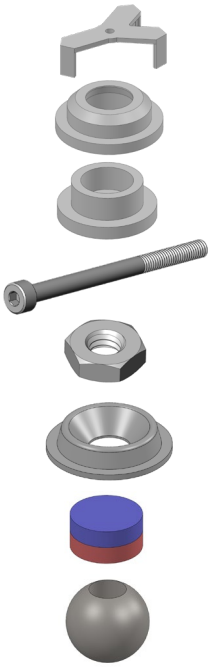
If the part is milled, it is recommended to first drill the hole pattern into the workpiece and a sacrificial fixture. The workpiece can then be securely fastened to the fixture to complete the milling.



Fingertips

Magnetic Fingertip Core

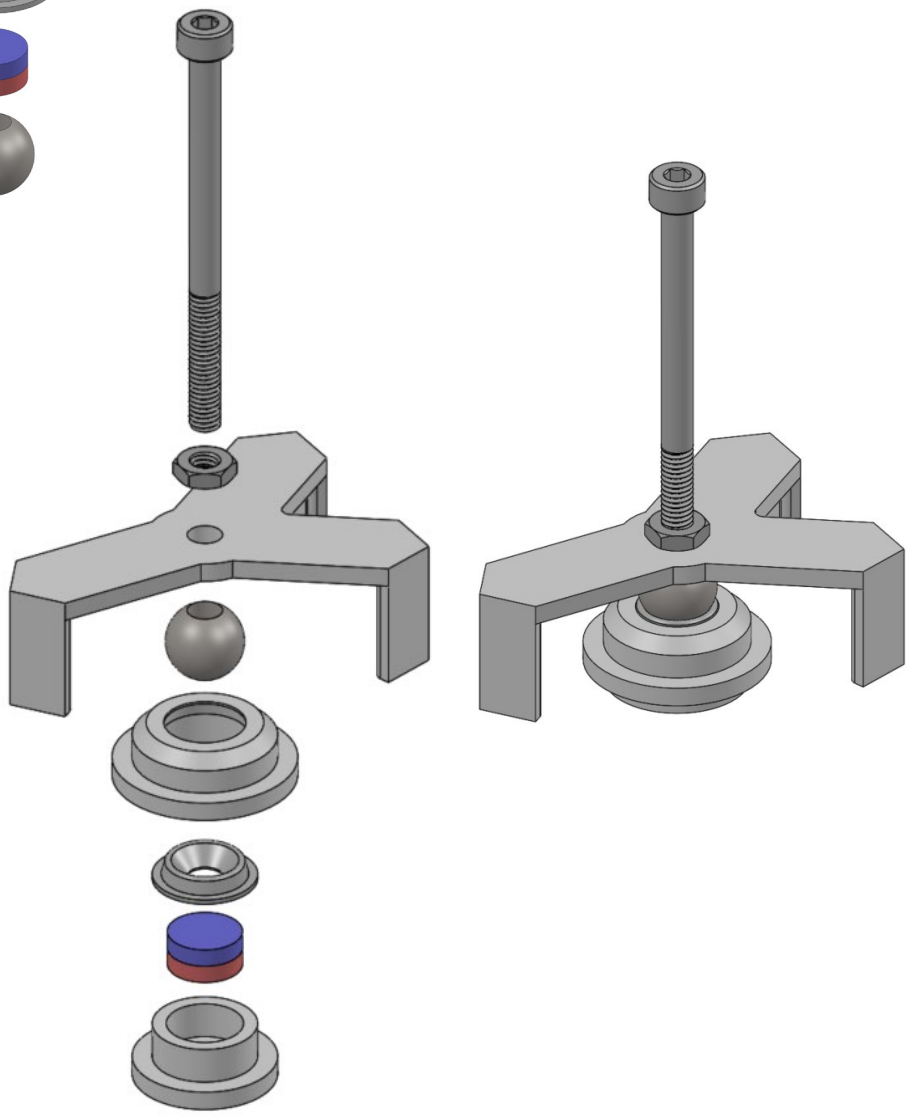
Parts
`m3.stl` (x3)
`p3a.stl` (x3)
`p3b.stl` (x3)
M4 L55mm socket bolt (x3)
M4 nut (x3)
Ø1/2” #6 countersunk washer (x3)
Ø3/8” L3/16” disk magnet (x3)
Ø10mm M4 threaded steel sphere (x3)



Insert the disk magnet and countersunk washer between `p3a` and `p3b` as shown in the figure. If they do not hold together snuggly, use a small amount of superglue to secure them.

Magnetize the assembly to the Ø10mm sphere and thread it onto the M4 bolt along with `m3` and the M4 nut, as pictured.

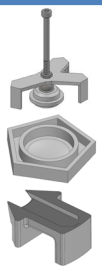
Repeat three times, once for each finger.



Fingertips

Fingertip Mold Assembly

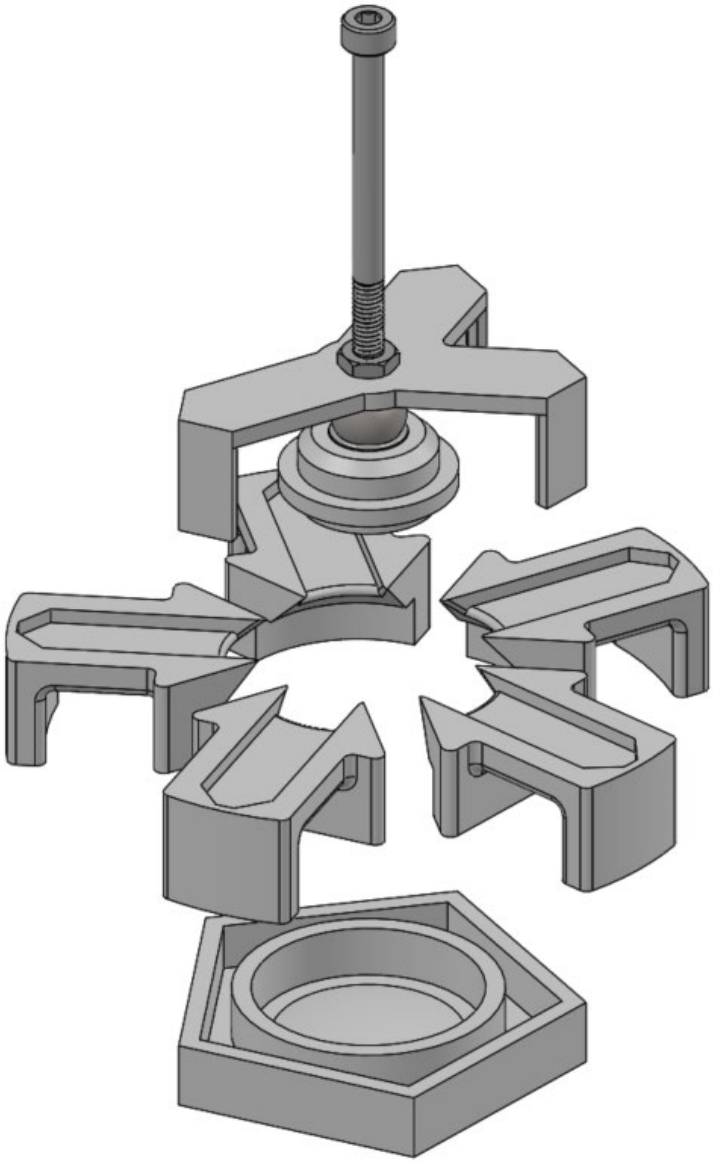
Parts
Assembly from previous page (x3)
`m1.stl` (x15)
`m2.stl` (x3)
Rubber bands

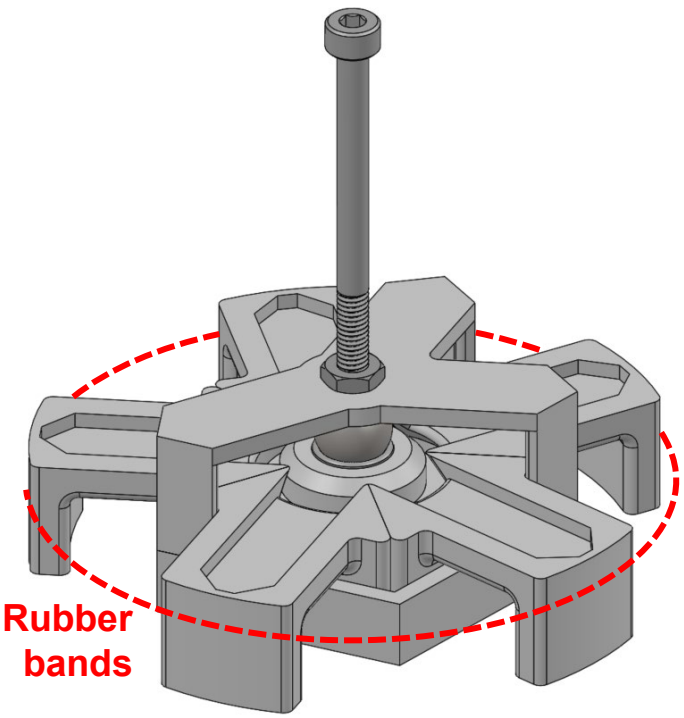


Combine each assembly from the previous page with one copy of `m1` and five copies of `m2`, as shown.

Secure the mold with rubber bands, wrapping ~3 of them around the m2 parts.

Repeat three times, once for each finger.

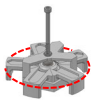




Fingertips

Fingertip Casting

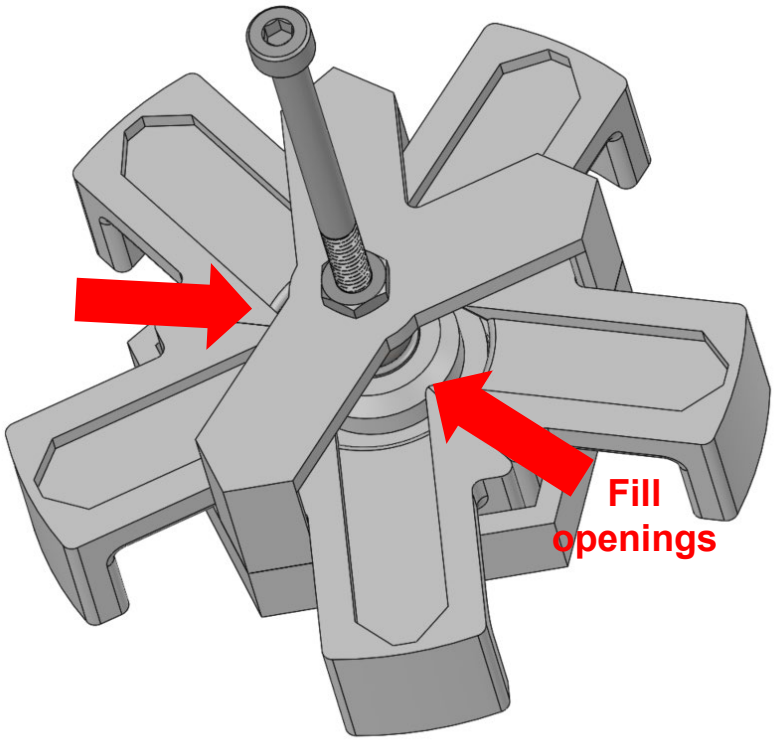
Parts
Assembly from previous page (x3)
Dragon Skin 30 silicone

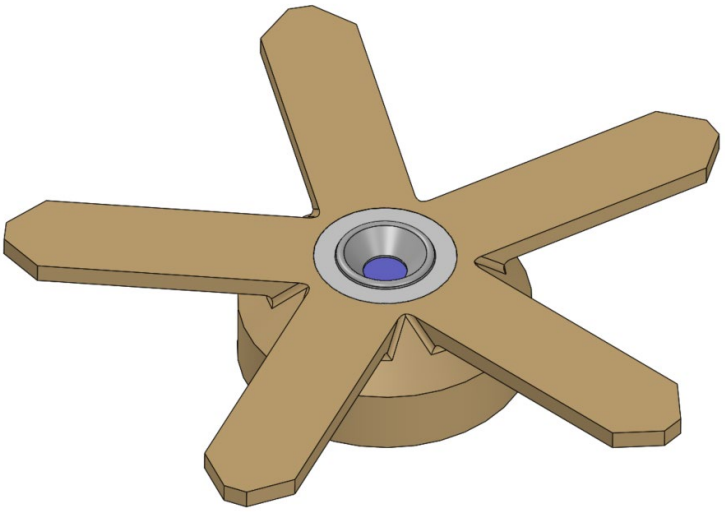


Ensure that the magnetized fingertip assembly is sitting flat within the mold. Mix the Dragon Skin silicone according to the package directions, using a vacuum chamber to de-gas the mixture before pouring to eliminate bubbles.

Fill all three molds through the two marked openings in the diagram below. The silicone should just overflow the top of the mold. Wait for the silicone to settle, and continue topping off the mold until it does not settle any further.

Leave the silicone to cure for up to 24 hours. Unscrew the M4 bolt and remove `m3`. Use a razor blade to trim the surplus silicone flush. Carefully free the cast part from the mold, being sure not to tear the silicone.

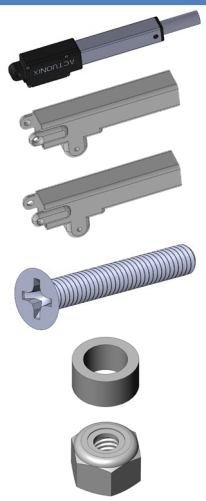




Fingers

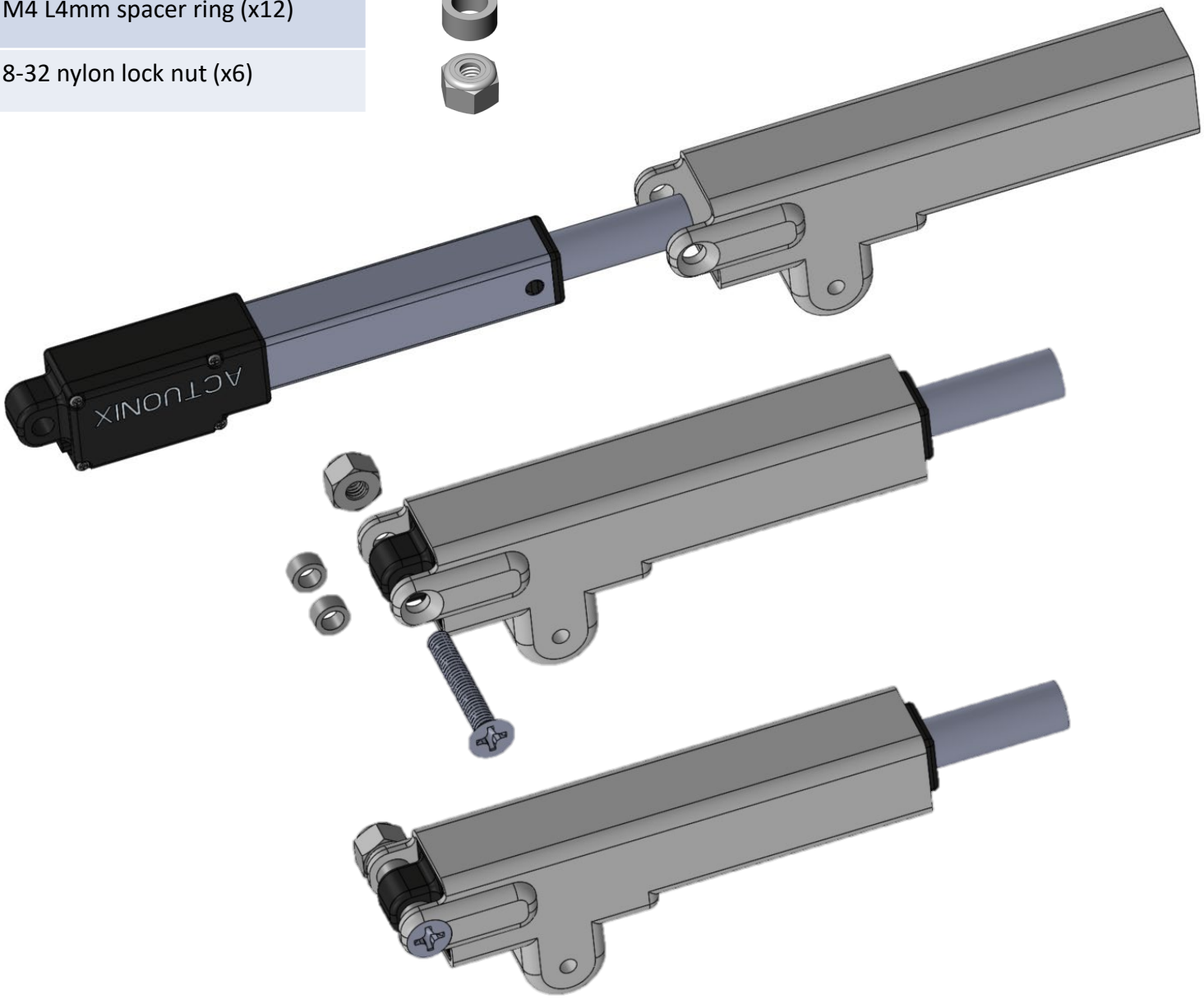
Actuator Assemblies (1/2)

Parts
Actuonix L12-50 (x6)
`p1a.stl` (x3)
`p1b.stl` (x3)
8-32 L1-1/8” countersunk screw (x6)
M4 L4mm spacer ring (x12)
8-32 nylon lock nut (x6)



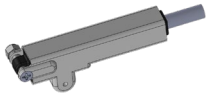
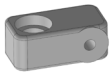
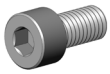
Insert the linear actuator into the `p1a` housing and secure it with the screw and nut, threading the 4mm spacers onto the screw to support the rear of the actuator.

Repeat three times for `p1a` and three times for `p1b`, which is a mirror-image component.



Fingers

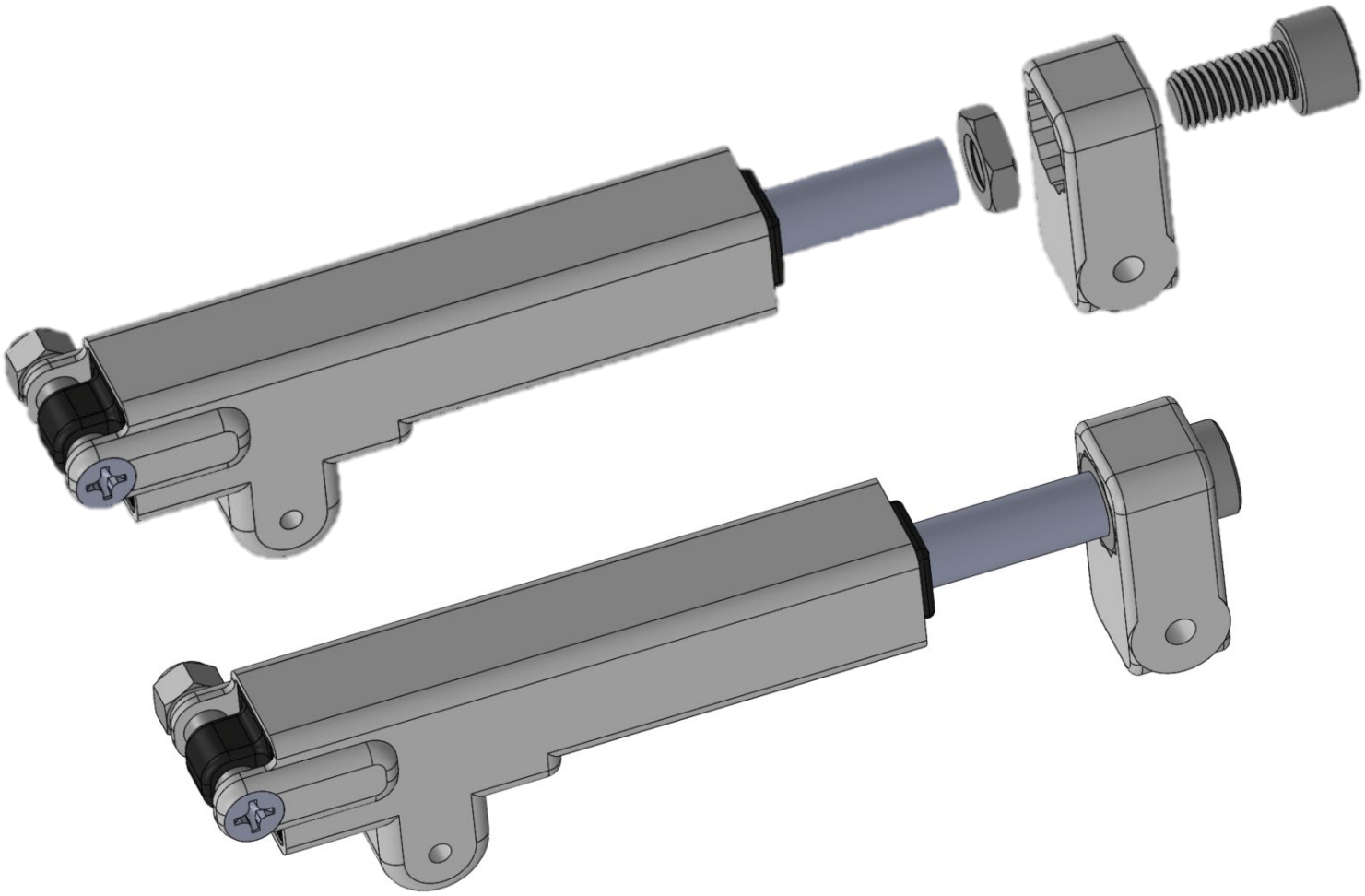
Actuator Assemblies (2/2)

Parts	
Assemblies from previous page (x6)	
`p2.stl` (x6)	
M8 L16mm socket bolt (x6)	
M8 L4mm low-profile nut (x6)	

Screw together each `p2` component with an actuator assembly using the M8 bolt and nut. Do not over-tighten the bolt, as it can damage the actuator.

In order to properly align `p2`, first tighten it down in any orientation, then mark a point on the M8 nut and a corresponding point it lines up with on the actuator rod. Unscrew the bolt and adjust the placement of the nut in `p2` to ensure that the parts line up up properly once re-tightened (see figure below for proper orientation).

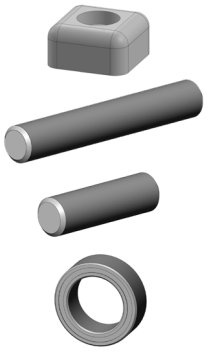
Repeat for all six actuators.



Fingers

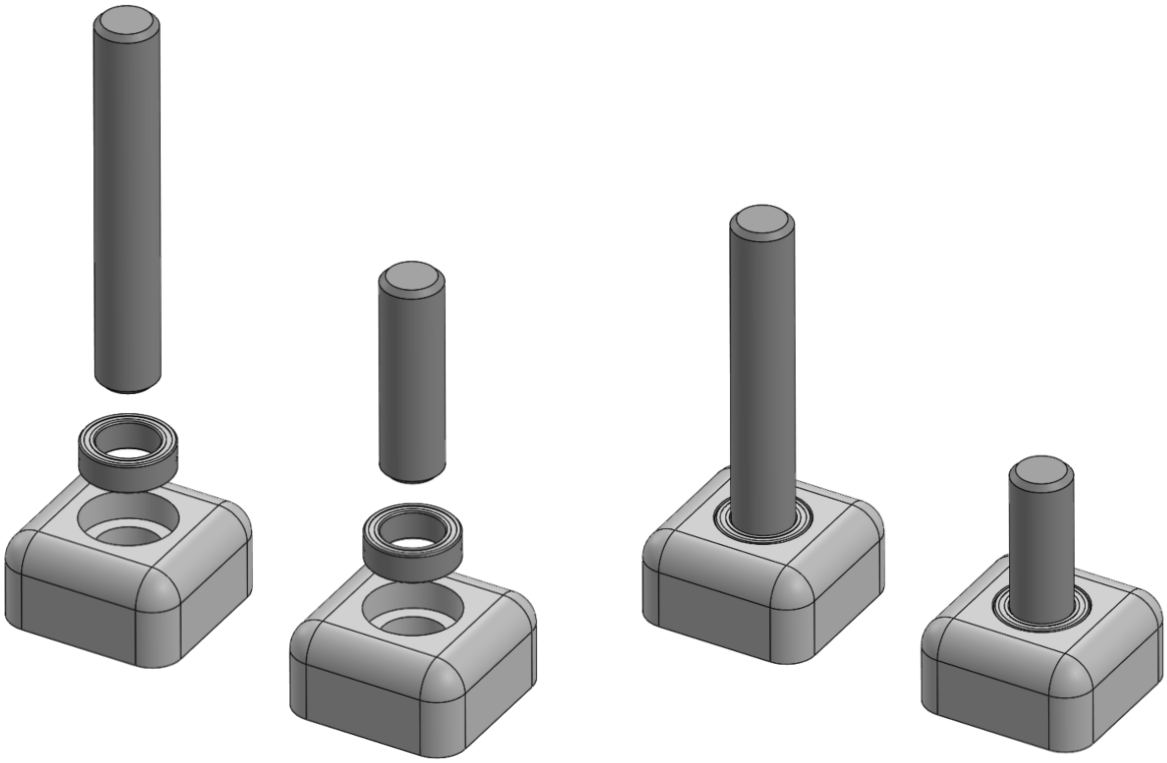
Ball Bearing Installation

Parts
`f1.stl` (x1)
Ø1/4” L1-5/8” steel dowel pin (x3)
Ø1/4” L7/8” steel dowel pin (x3)
3/8” OD, 1/4“ ID, L1/8” ball bearing (x6)



Use `f1` as a fixture to press-fit the ball bearings onto the dowel pins. Use an arbor press, a vice, or a hammer to install the pins. Be sure to not damage the bearings. The fixture will ensure that the bearing spacing is correct.

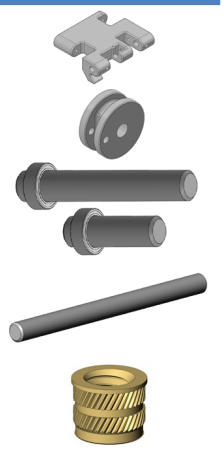
Repeat for all six pins.



Fingers

Finger Base

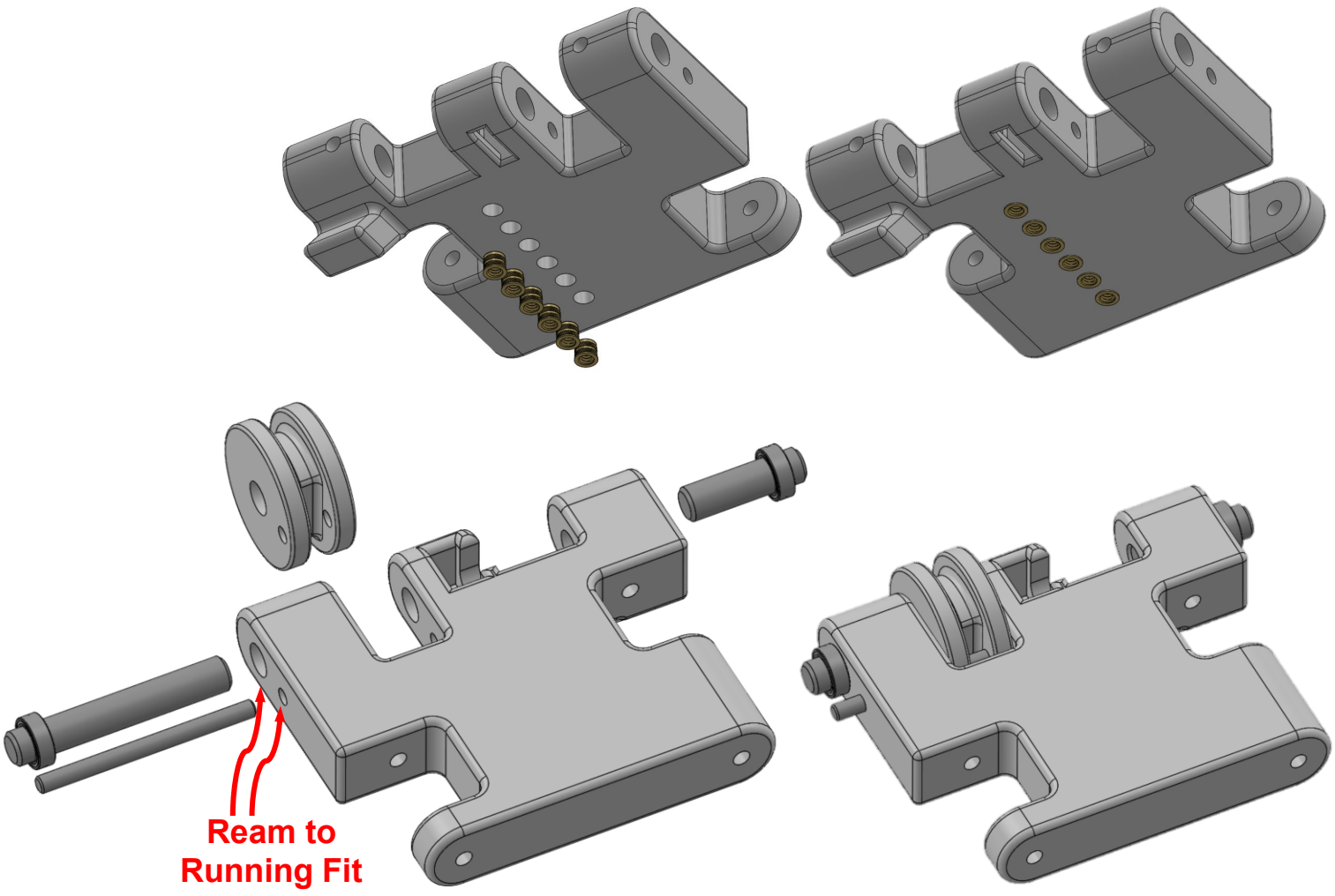
Parts
`p5.stl` (x6)
`p6.stl` (x3)
Pin assemblies from previous page (x6)
Ø1/8” L1-5/8” steel dowel pin (x3)
4-40 heat set threaded insert (x18)



Install the heat press inserts into the bottom of `p5` with a soldering iron.

Ream out the indicated holes to be a running fit (to ease pin installation) and press fit the dowel pins into `p5` and `p6` as shown. Stop right before the ball bearings make contact with `p6`, to prevent the bearings from binding.

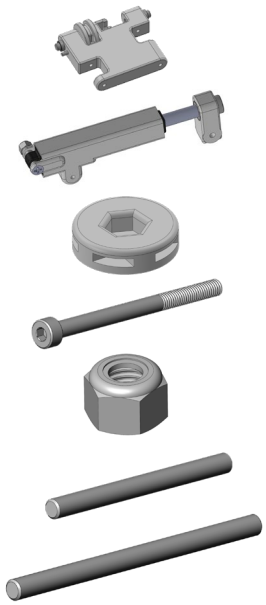
Repeat for all three fingers.



Fingers

Finger Assembly

Parts
`p5` assembly from previous page (x3)
`p1a` assembly (x3) and `p1b` assembly (x3) from page 9
`p4.stl` (x3)
M4 L55mm socket bolt (x3)
M4 nylon lock nut (x3)
Ø1/8” L1-1/2” steel dowel pin (x3)
Ø1/8” L2” steel dowel pin (x3)

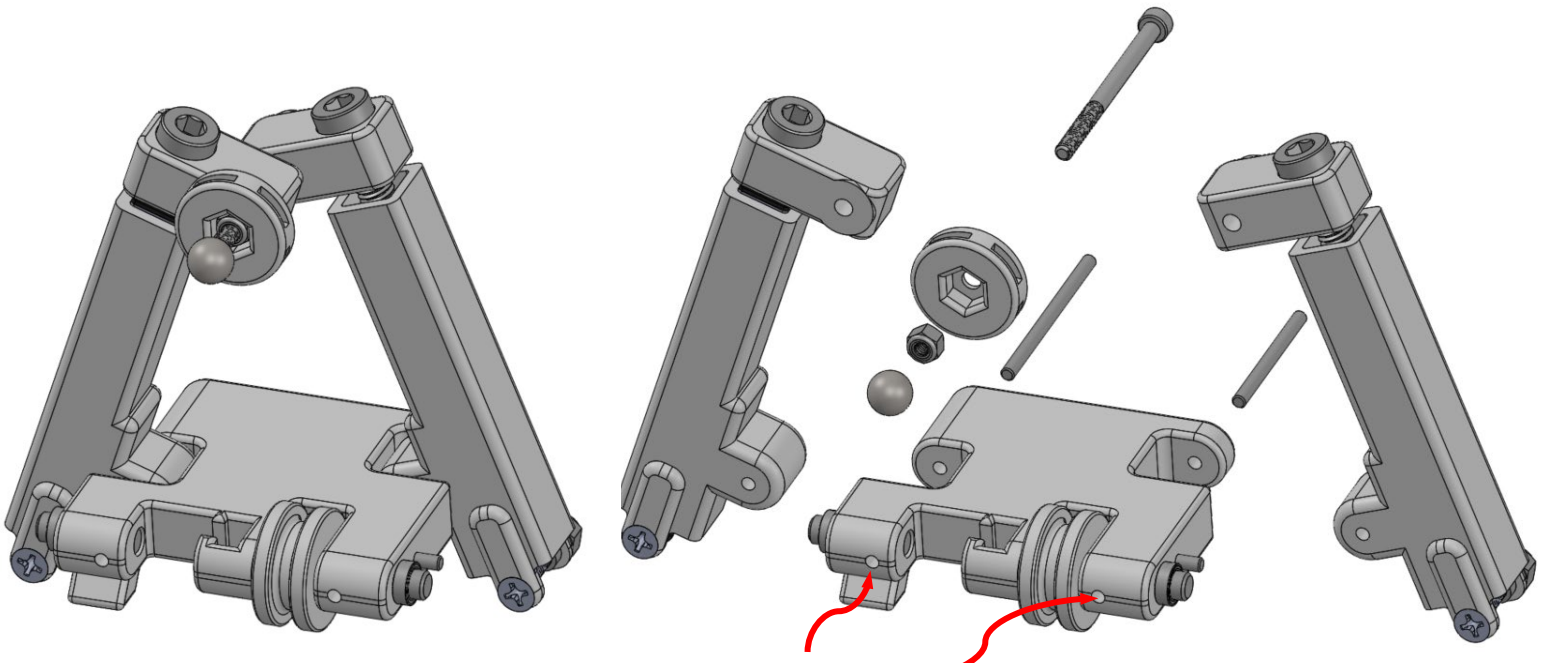


Attach two actuator assemblies to each copy of the `p5` assembly using the dowel pins as pictured below.

NOTE: Be sure to attach one `p1a` assembly and one `p1b` assembly to each finger, as they are mirror images. Both actuators on a given finger should have the lock nuts on the bottom facing backwards away from the fingertip.

Connect the actuator assembles at the top with the bolt, threading it onto `p4`, the lock nut, and the threaded sphere. Use `p4` as a wrench to tighten the lock nut so that the actuators cannot move out-of-plane but are also not so tight that `p4` can no longer rotate about the bolt’s axis.

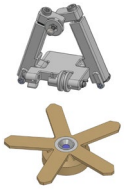
Repeat for all three fingers.



Fingers

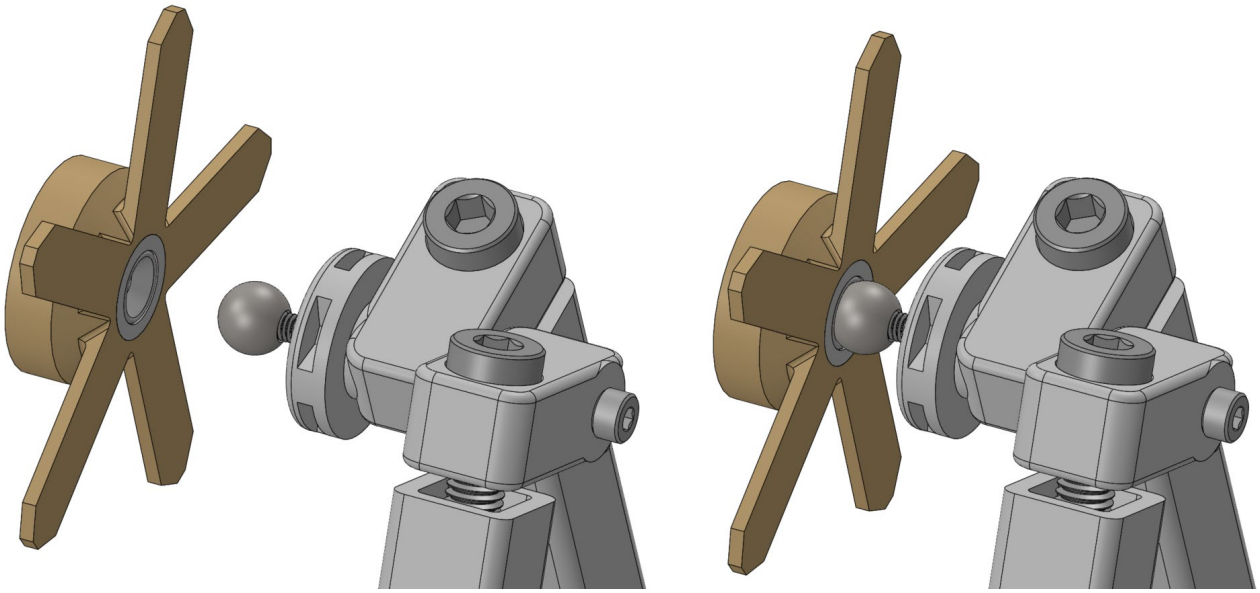
Fingertip Installation

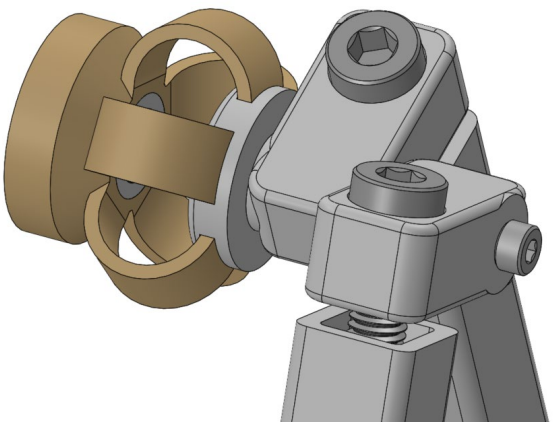
Parts
Finger assembly from previous page (x3)
Fingertip assembly from page 7 (x3)
Superglue



Magnetize the each fingertip to the threaded sphere at the end of the finger. Wrap the flexible leaf springs around so they sit in the corresponding pockets on `p4`, and superglue them in place. Be sure to not adhere `p4` to the frontmost copy of `p2`, as it must still be free to rotate.

Repeat for all three fingers.

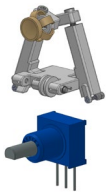




Fingers

Potentiometer Installation

Parts
Finger assembly from previous page (x3)
10K Ohm potentiometer (x3)
3-wire servo cable (x3)

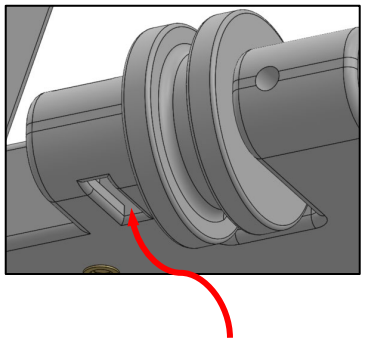


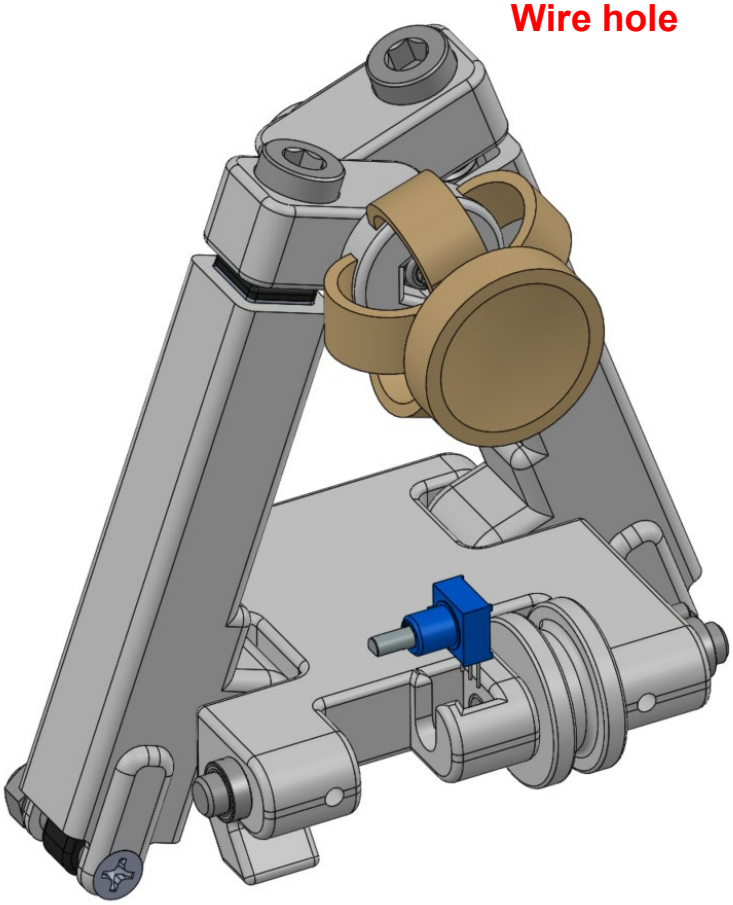
Strip one end of the cables (leaving a female connector on the other end). Thread the cable through the hole in `p5` indicated below (with the stripped leads pointing upwards) and then thread a piece of heat shrink tubing over the cable.

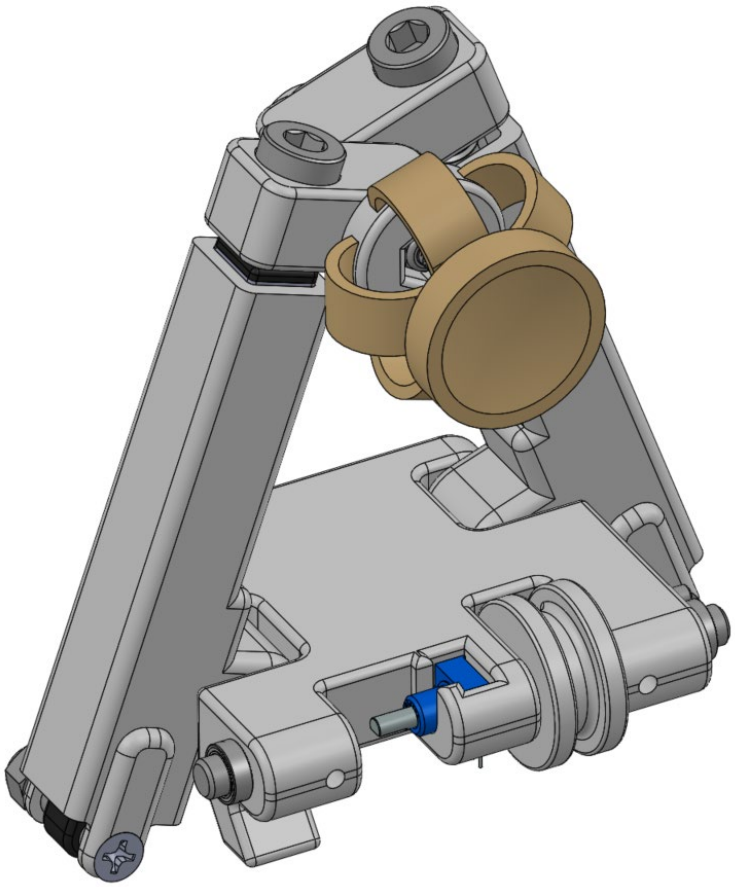
Solder the wires to the potentiometer, with the white signal wire going to the center pin (the red/black wires may attach to either outer pin). Use a heat gun to shrink the heat-shrink tubing around the solder joints.

Seat the potentiometer in `p5` and secure with the included nut.

Repeat for all three fingers.



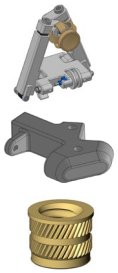




Palm

Palm Assembly (1/2)

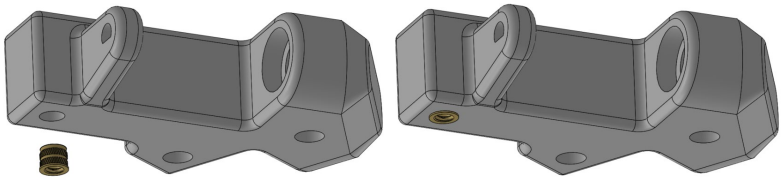
Parts
Finger assembly from previous page (x3)
`p7.stl` (x3)
4-40 heat set threaded insert (x3)

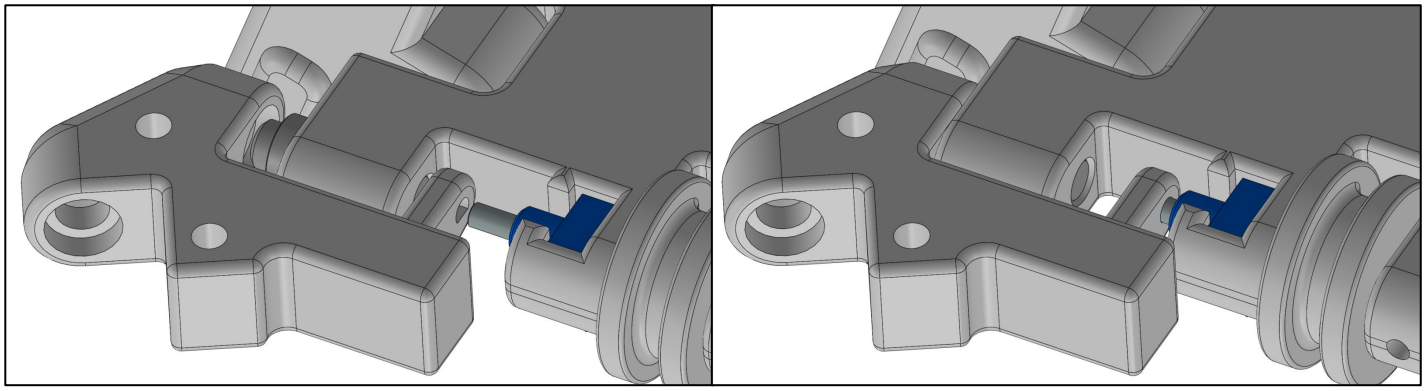


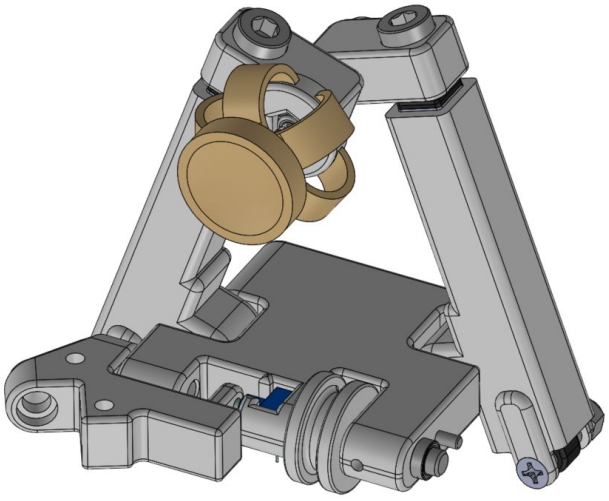
Install the heat press insert into the bottom of `p7` with a soldering iron.

Slide `p7` onto the finger assembly, ensuring that the potentiometer shaft is captured by the D-profile hole in `p7`.

Repeat for all three fingers.



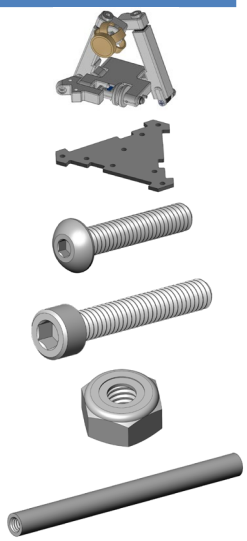




Palm

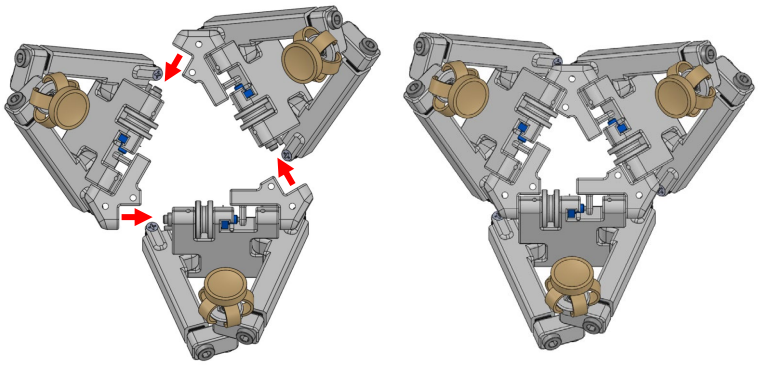
Palm Assembly (2/2)

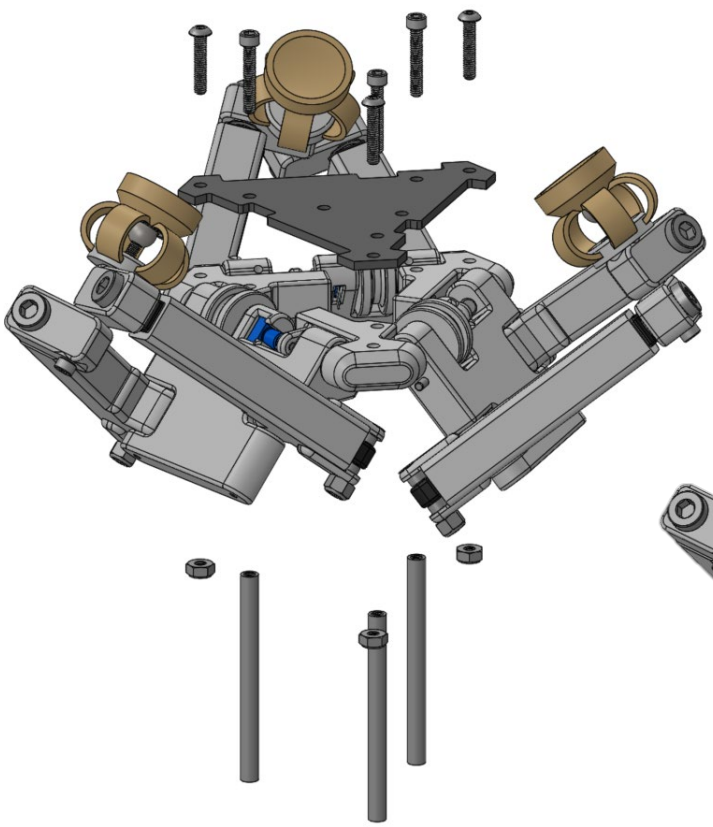
Parts
Finger assembly from previous page (x3)
`w1.dxf` (x1)
8-32 L7/8” button head screw (x3)
8-32 L1” socket bolt (x3)
8-32 L 11/64” low-profile nut (x3)
8-32 L3” threaded standoff (x3)

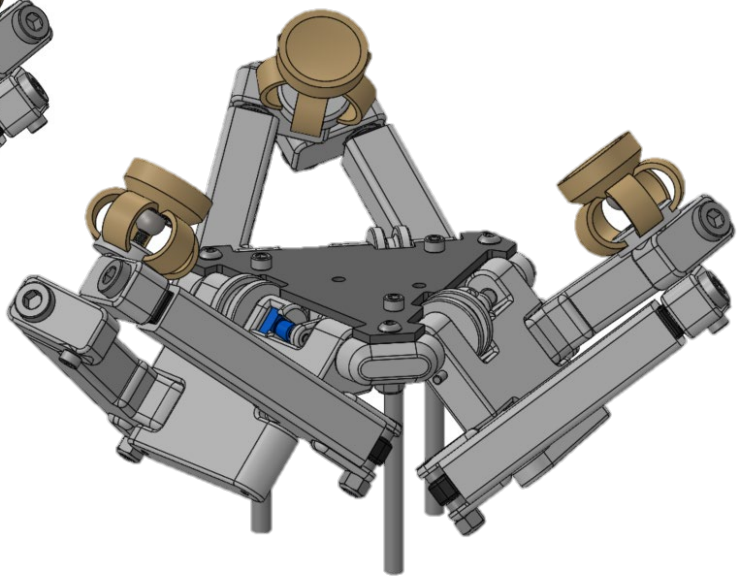


Slide the three fingers together so each ball bearing seats into the neighboring `p7` component.

Secure the fingers to `w1` with the bolts, low-profile nuts, and standoffs. The nuts and socket head bolts pass through the outermost holes in `w1` while the socket bolts and standoffs connect through the innermost holes, as pictured.







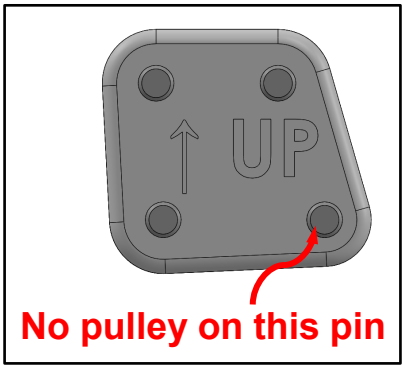
Pulleys

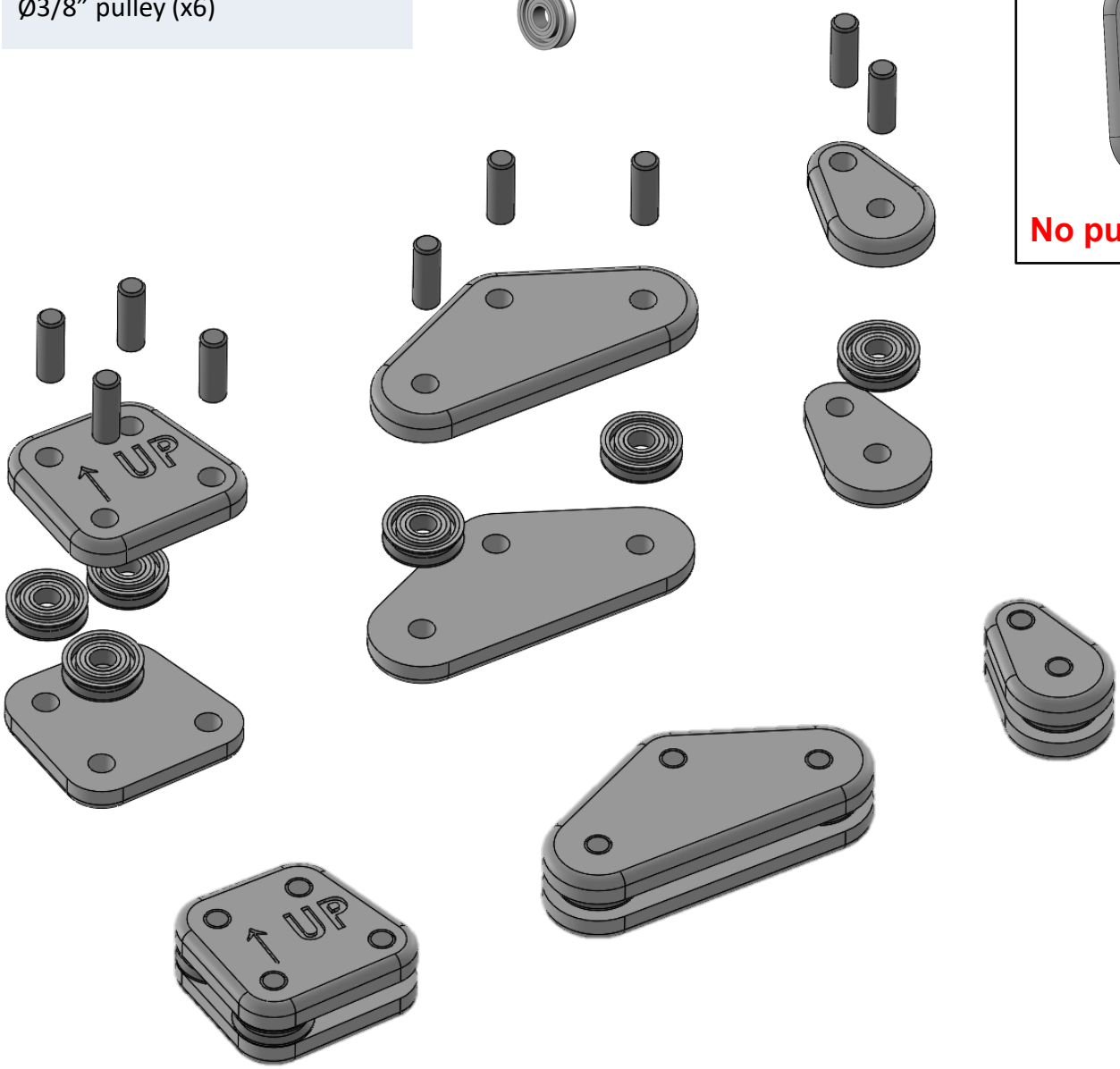
Floating Pulley Blocks

Parts
`p9.stl` (x2)
`p10.stl` (x2)
`p11a.stl` (x1)
`p11b.stl` (x1)
Ø1/8” L3/8” steel dowel pin (x9)
Ø3/8” pulley (x6)

Assemble the three floating pulley blocks as pictured below, press fitting the dowel pins into the printed parts with an arbor press, vice or hammer. The pulleys should be free to rotate with minimal friction.

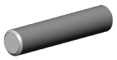
Note the orientation of `p11a` and `p11b` to ensure the pulleys are installed on the proper pins.





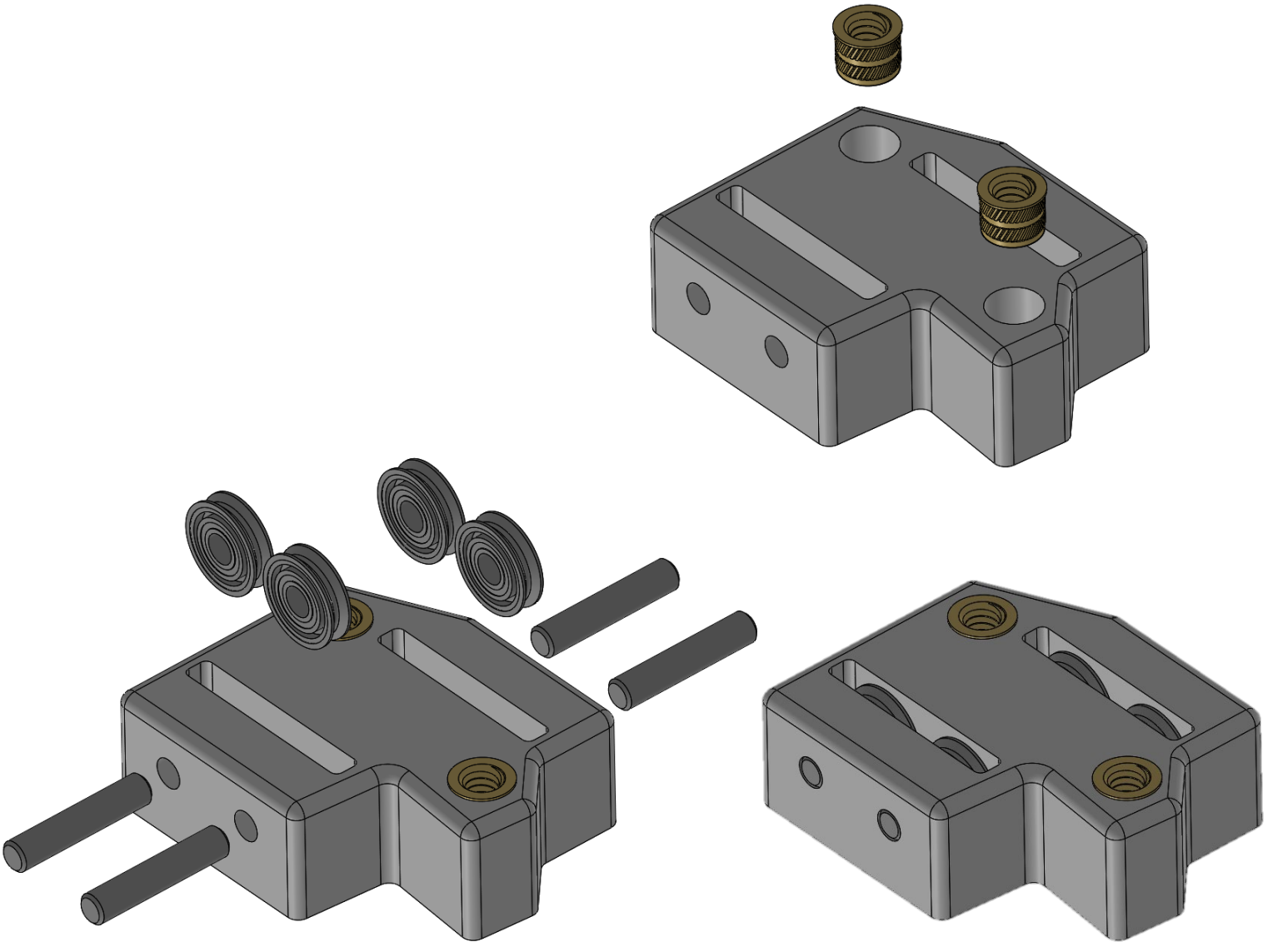
Pulleys

Stationary Pulley Blocks (1/2)

Parts	
`p12.stl` (x1)	
Ø3/8” pulley (x4)	
Ø1/8” L5/8” steel dowel pin (x4)	
8-32 heat set threaded insert (x2)	

Install the heat press insert into the bottom of `p12` with a soldering iron.

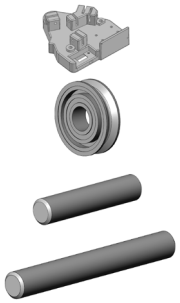
Install the four pulleys in `p12` as shown in the figure, press fitting the dowel pins into the printed parts with an arbor press, vice or hammer. The pulleys should be free to rotate with minimal friction.



Pulleys

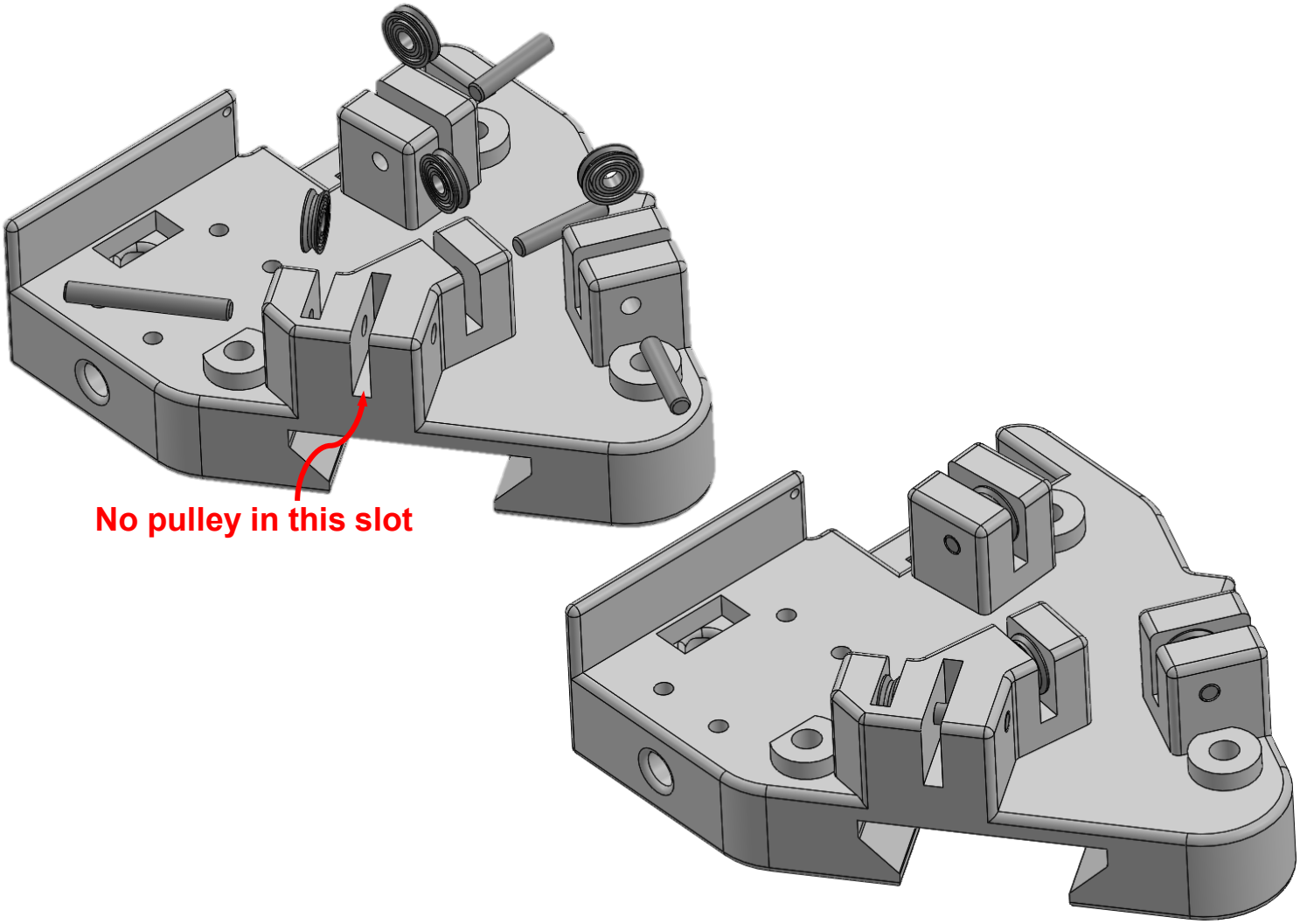
Stationary Pulley Blocks (2/2)

Parts
`p8.stl` (x1)
Ø3/8” pulley (x4)
Ø1/8” L5/8” steel dowel pin (x3)
Ø1/8” L1” steel dowel pin (x1)



Install the four pulleys in `p8` as shown in the figure, press fitting the dowel pins into the printed parts with an arbor press, vice or hammer. The pulleys should be free to rotate with minimal friction.

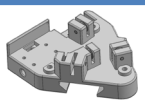
Note That one of the slots in `p8` (at the center-bottom of the figure) does not receive a pulley, but instead simply has the 1” dowel pin passing through it.



Electronics

Wire routing

Parts
Assembly from previous page (x1)
Mini-USB-B to Standard USB-A cable (x1)
Dynamixel cable (x1)
Single-conductor wires

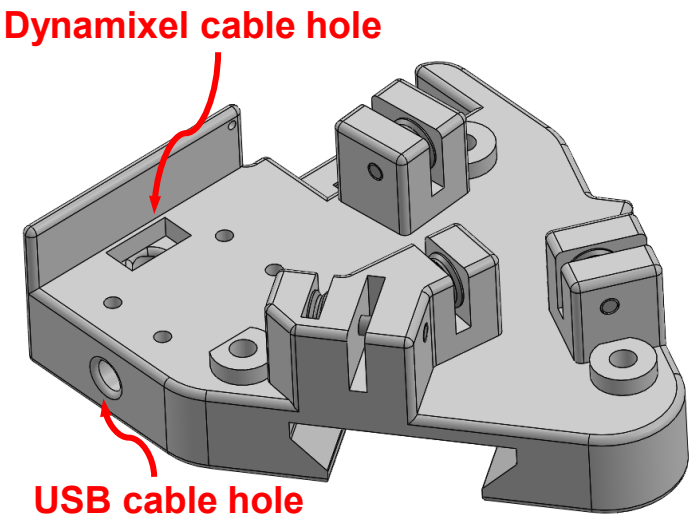


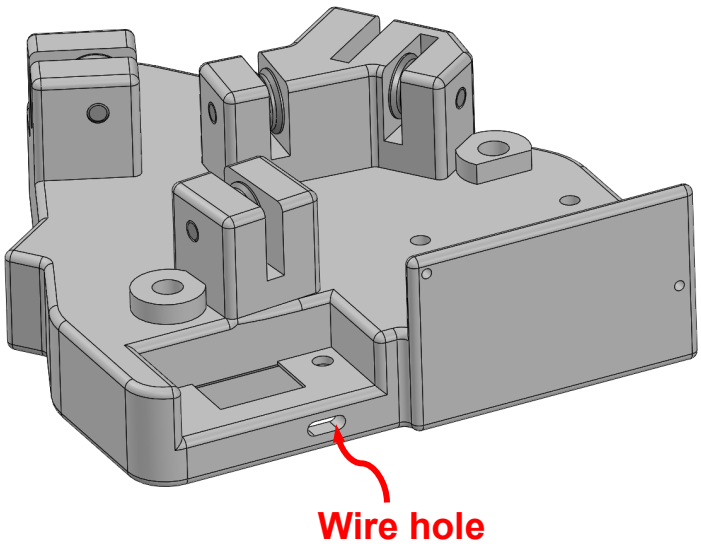
Separate the Mini-USB B end of the USB cable, leaving approximately 5 to 6 inches of length attached to it. Strip the wires. Pass the stripped end of the cable through the hole in `p8` as pictured.

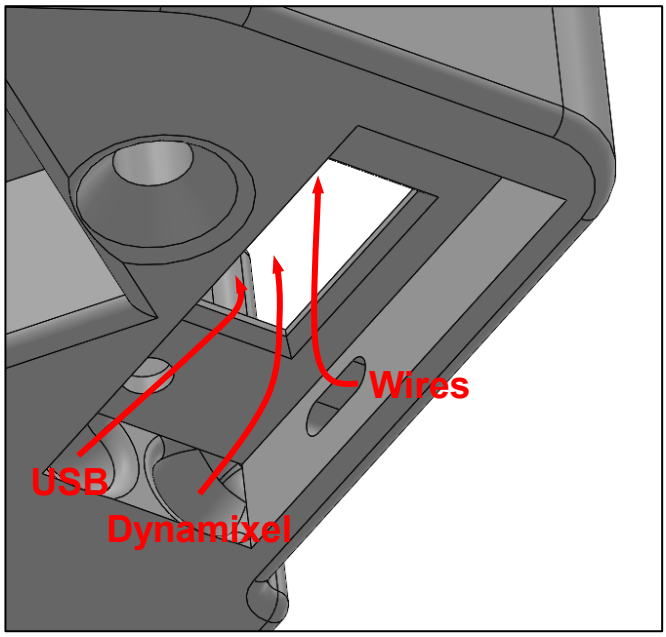
Cut the Dynamixel cable (included with the Dynamixel servo) in half. Strip the wires. Pass the stripped end through the hole in `p8` as pictured.

Cut and strip two short lengths of wire (approximately 1 to 1.5 inches in length). Pass them through the hole in `p8` as pictured.

All 10 of these wires will now be located in the rectangular pocket on the underside of `p8`. Pass them all up through the labeled hole in the figure below.





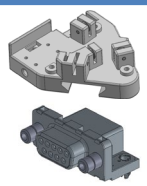


Pass all wires through rectangular hole

Electronics

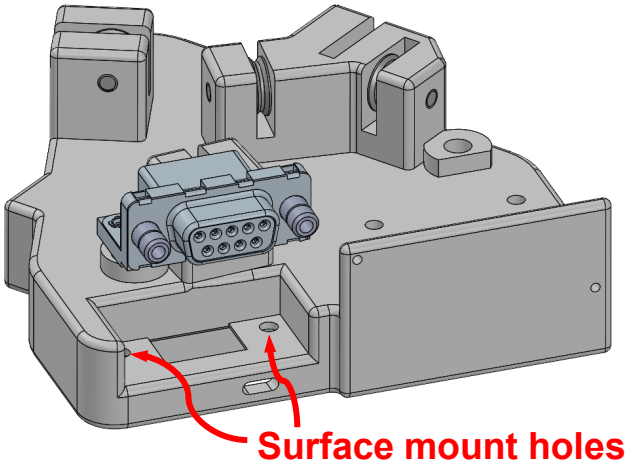
Electrical Connector

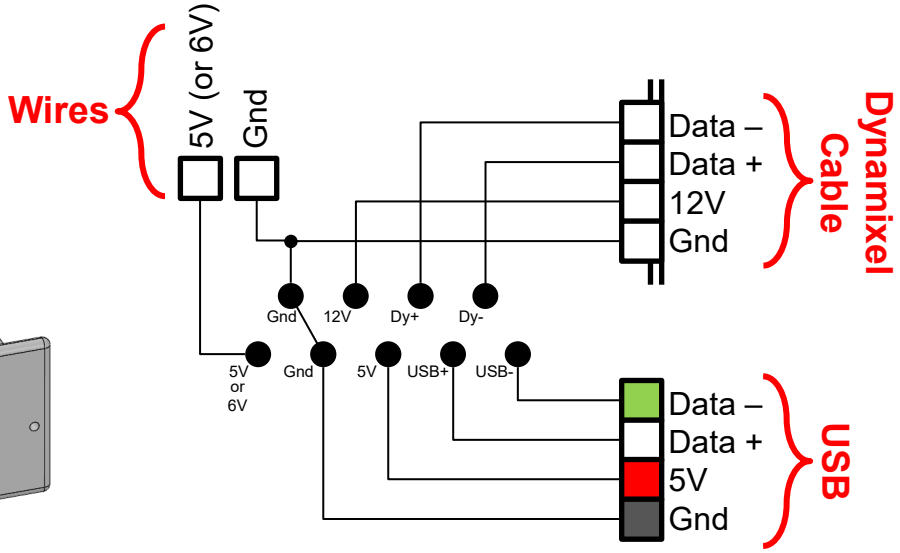
Parts
Assembly from previous page (x1)
D-Sub 9-pin connector (x1)
Hot glue
Single-conductor wires

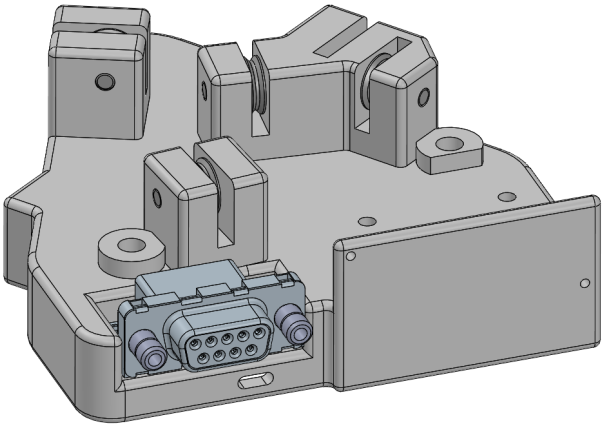


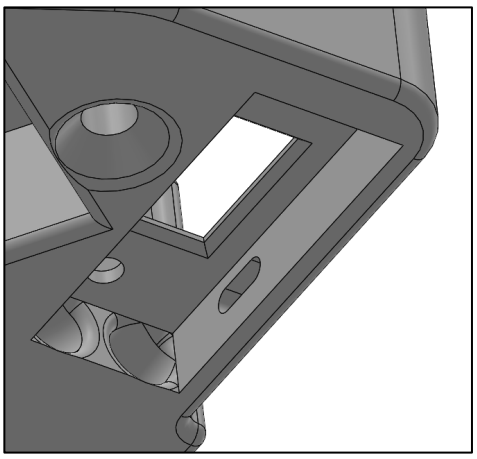
Solder the wires from the previous page to the DB9 connector, wiring them as shown in the figure below.

Seat the connector into the two surface-mount holes in `p8` and use hot glue to fill the rectangular cavity on the bottom of `p8`, securing the connector and insulating the wires to prevent shorting. Ensure the hole glue does not extend below the bottom of `p8`.









Fill rectangular cavity with hot glue to secure/insulate wires

Electronics

Electrical Cable

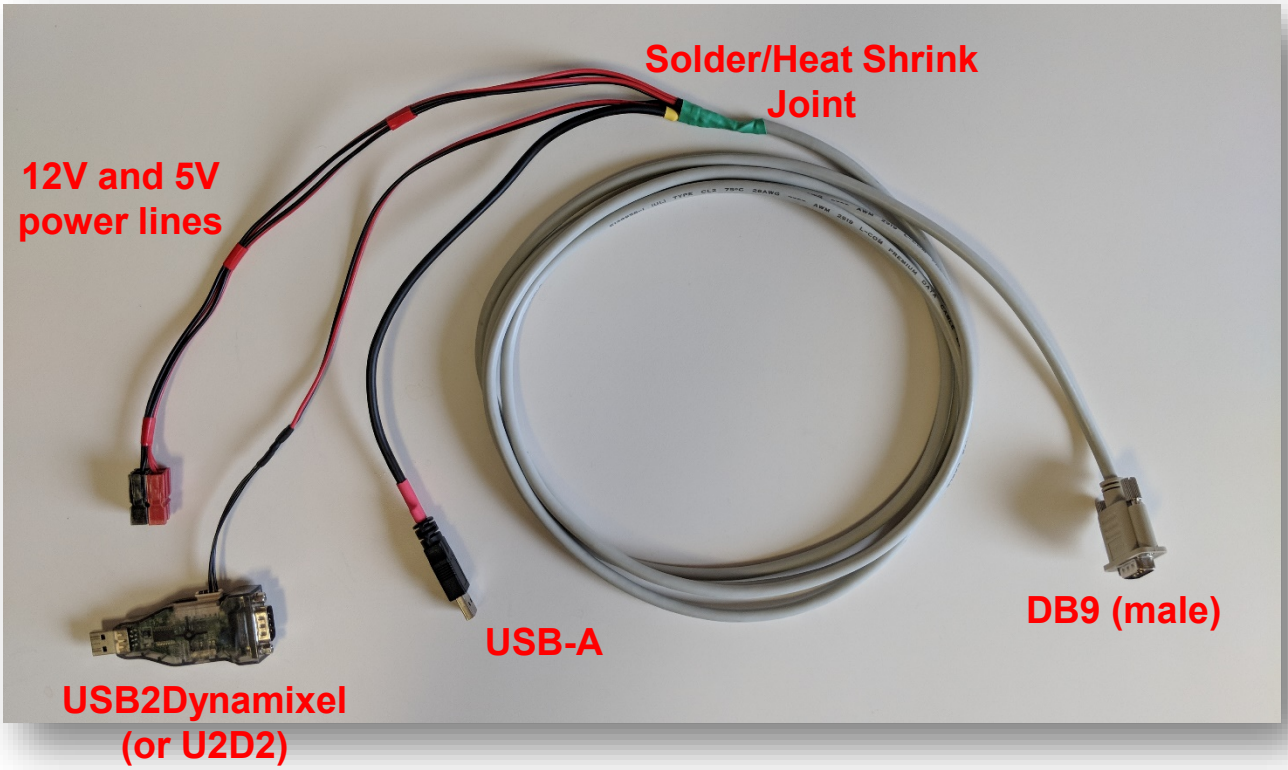
Parts
DB9 cable (x1)
Mini-USB B to Standard USB A cable (x1)
Double-conductor wires
USB2Dynamixel adapter (x1)

Remove one end of the DB9 cable, leaving a male connector on the other end. Strip the nine internal wires. Cut the USB-A side of the USB cable from page 21 down to a more reasonable length and strip its wires, as well.

Solder and heat-shrink the USB cable along with three pairs of double-conductor wires to the end of the DB9 cable.

Terminate one of the pairs with the data wires of the leftover Dynamixel cable from page 21. Plug this cable into the USB2Dynamixel adapter

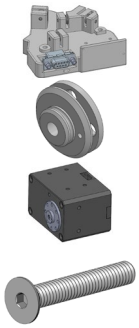
Terminate the remaining two pairs with power connectors for 5V (or 6V) and 12V power supplies. In the cable pictured below, Anderson connectors were used.



Base

Dynamixel Installation

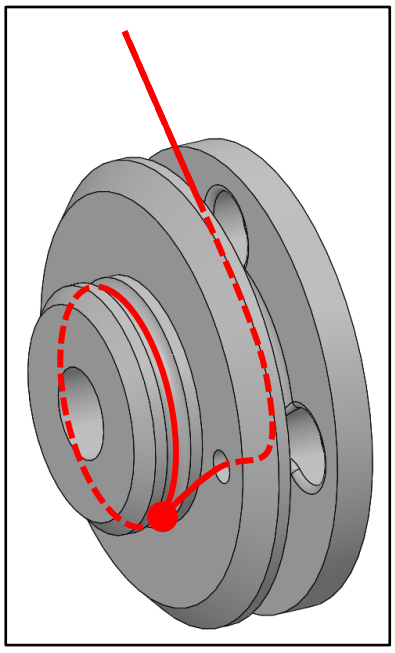
Parts
`p8` assembly from page 22 (x1)
`p13.stl` (x1)
Dynamixel XH-430-W350-R
M2.5 x 16mm countersunk screw (x4)
Spectra Line
Super glue

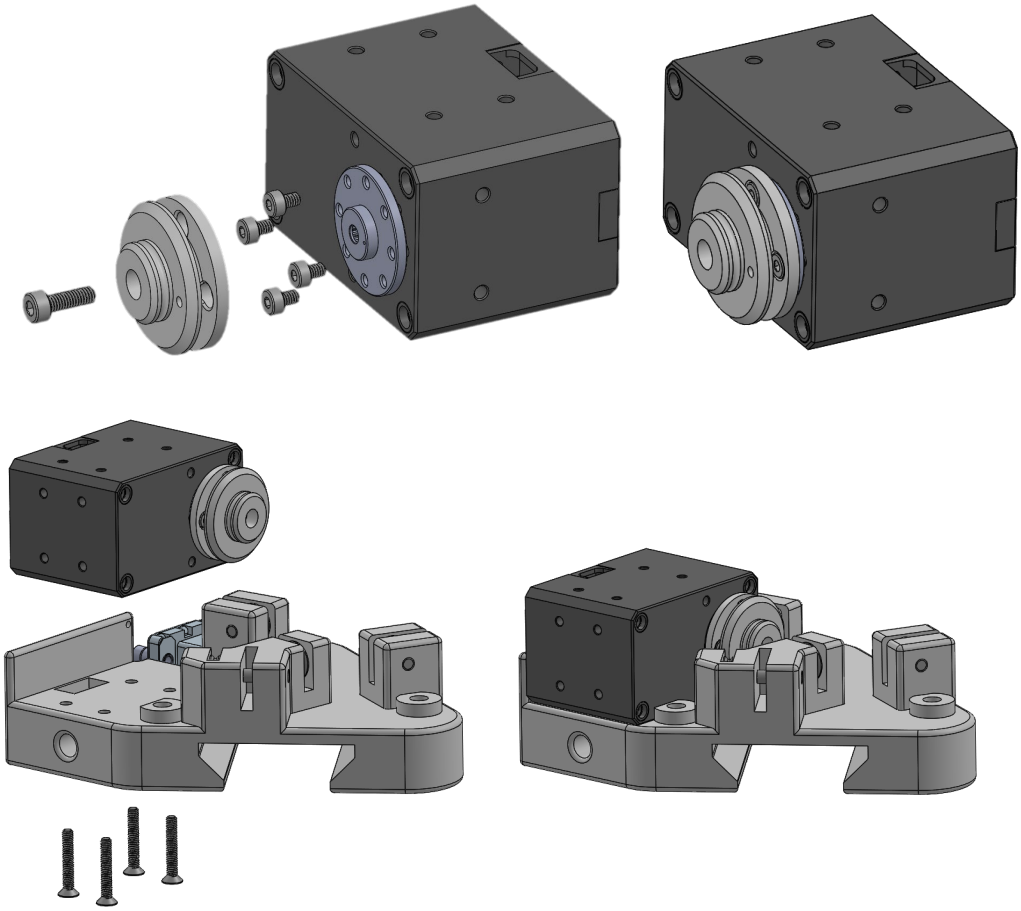


Route a 10-inch segment of Spectra line around `p13` as shown in the picture, passing it out from the inside of the pulley groove, wrapping it around the exterior hub, and securing it in place with a knot. To lock the knot in place, apply a small amount of super glue.

Install four of the M2 bolts included with the Dynamixel around the perimeter of the motor horn to act as shear pins. Attach `p13` using the M2.5 bolt included with the Dynamixel.

Mount the Dynamixel to the p8 assembly using the M2.5 countersunk screws. Plug in the Dynamixel cable installed on page 21.

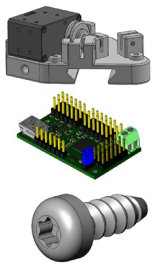




Base

Servo Controller Installation

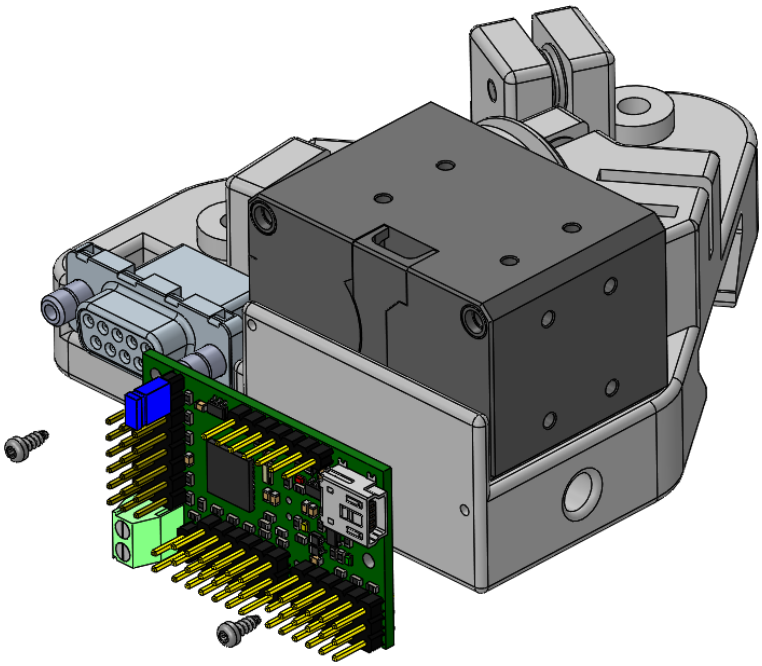
Parts
Assembly from previous page (x1)
MiniMaestro 18 (x1)
2mm L5mm self-tapping screw (x2)

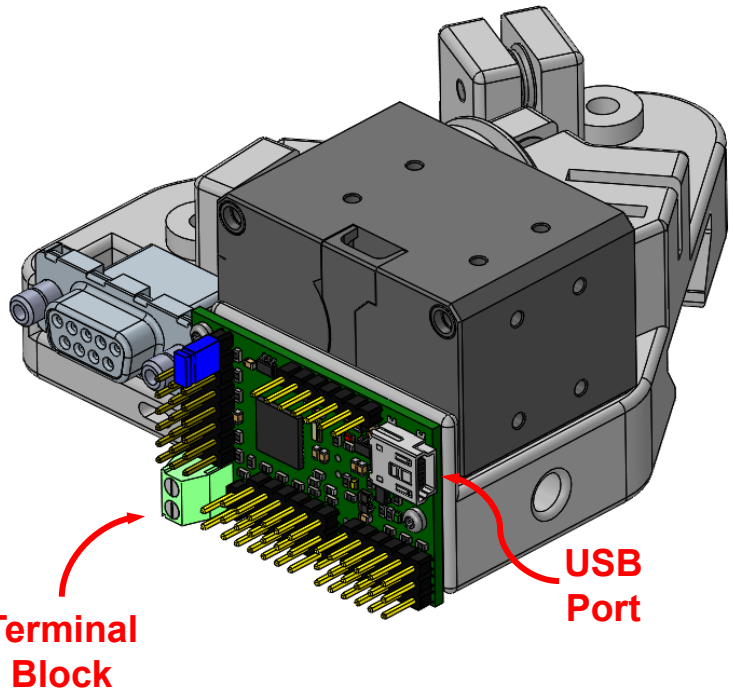


Install the Pololu MiniMaestro servo control board to `p8` with the self-tapping screws and/or double-stick foam tape.

Plug the mini-USB cable into the board.

Attach the pair of power wires installed on page 21 to the terminal block on the board, ensuring proper polarity.

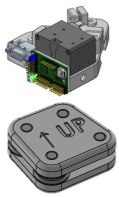




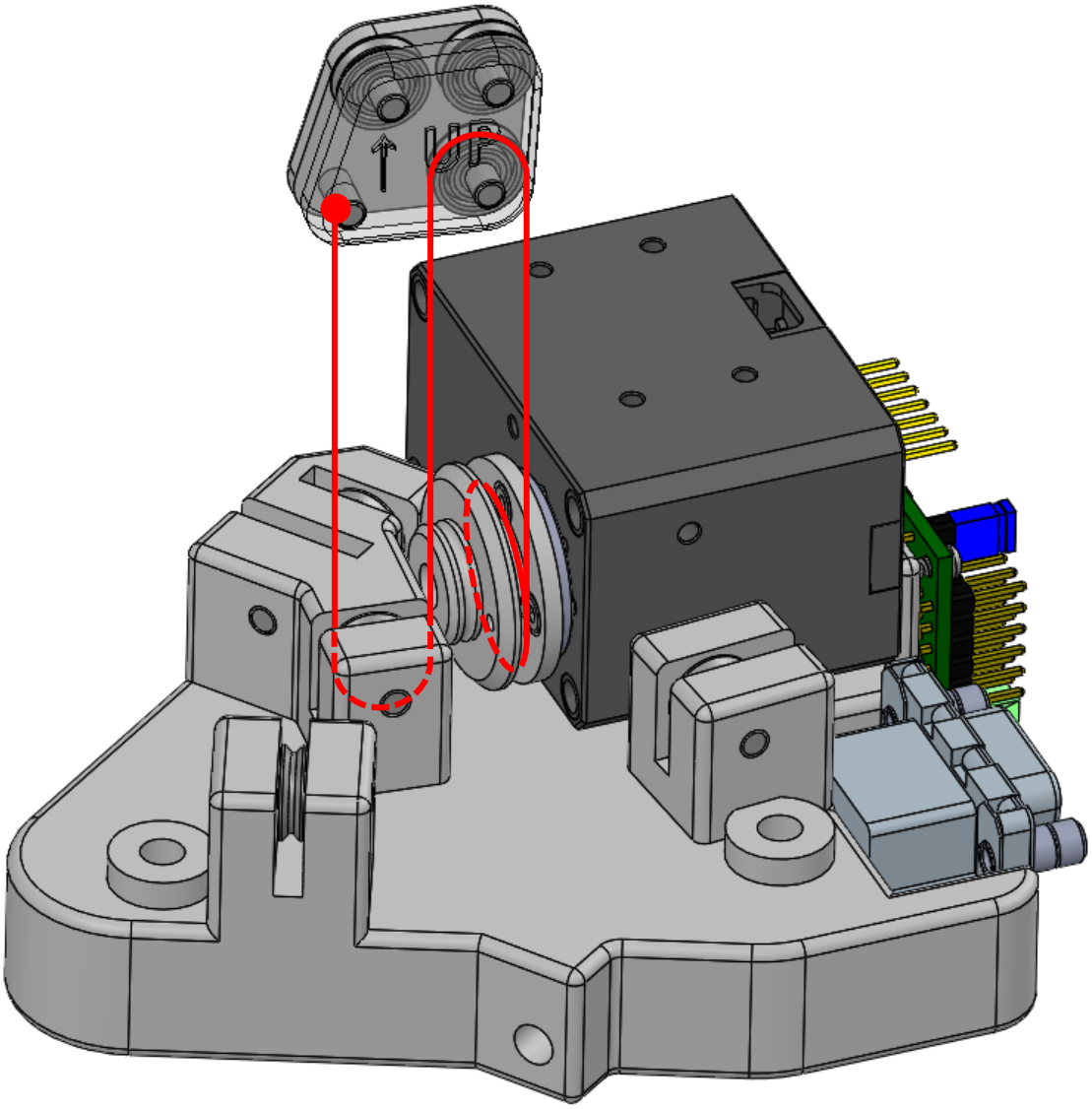
Final Assembly

Actuator Tendon Routing

Parts
Assembly from previous page (x1)
`p11a`/`p11b` assembly from page 18 (x1)
Super glue

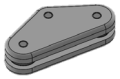
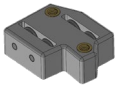


Route the tendon previously anchored on `p13` through the `p11a/p11b` assembly as pictured. Secure it to the dowel pin on the floating pulley block with a knot. To lock the knot in place, apply a small amount of super glue.

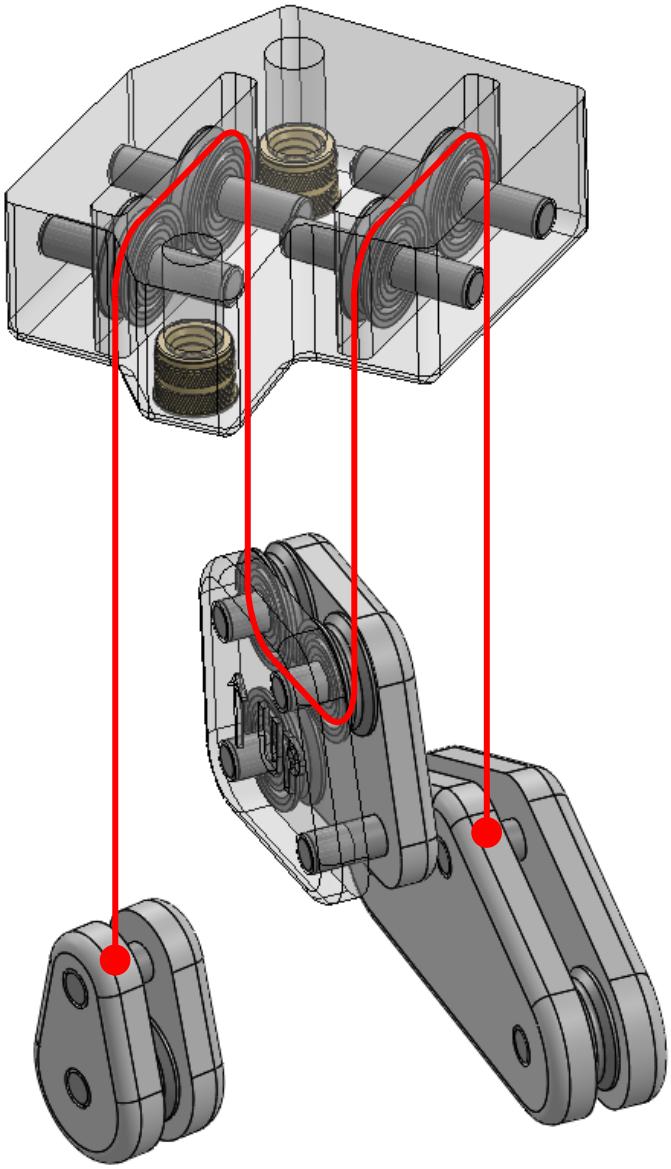


Final Assembly

Differential Tendon Routing

Parts	
Assembly from previous page (x1)	
`p9` assembly from page 18 (x1)	
`p10` assembly from page 18 (x1)	
`p12` assembly from page 19 (x1)	
Spectra Line	
Super glue	

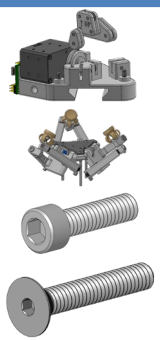
Route an 11-inch piece of Spectra line from the `p9` assembly through the `p12` and `p11a/p11b` assemblies as pictured, terminating on the `p10` assembly. Secure both ends to the dowel pins on the floating pulley blocks with knots and super glue.



Final Assembly

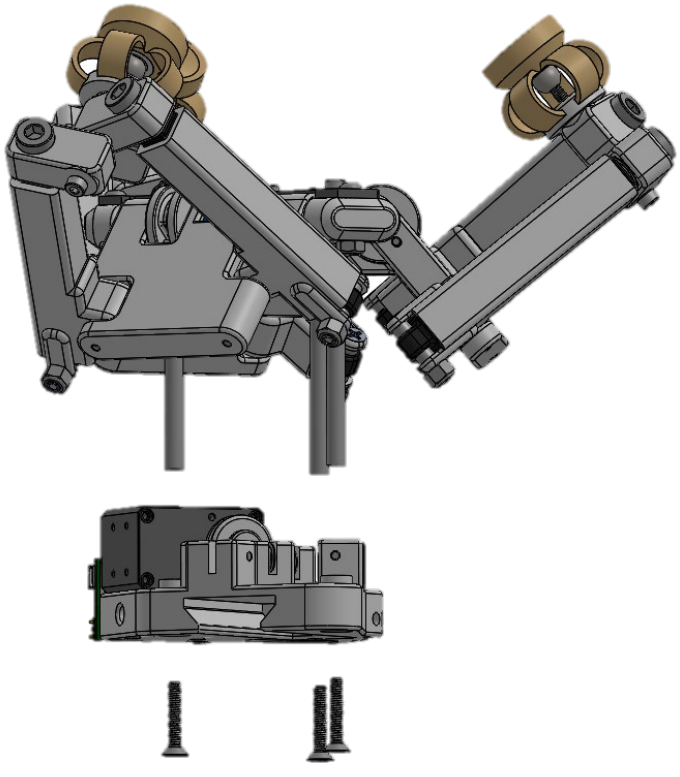
Base Installation

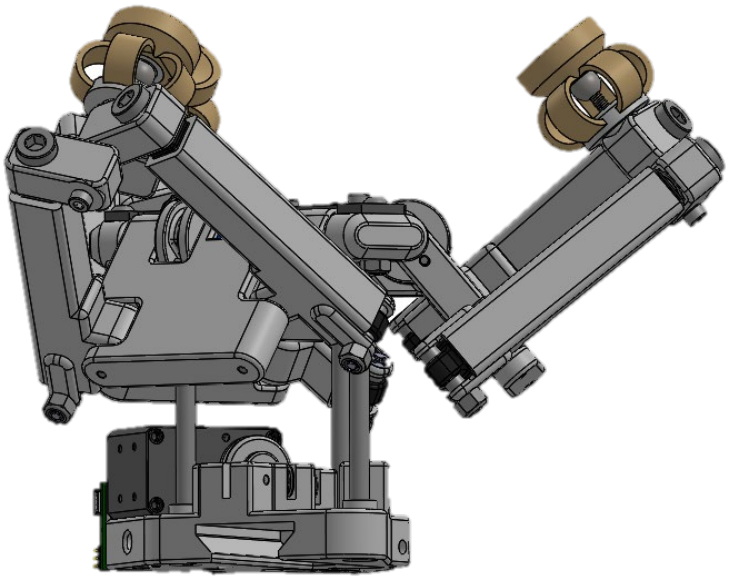
Parts
Assembly from previous page (x1)
Assembly from page 17 (x1)
8-32 L5/8” socket bolt (x2)
8-32 L1” countersunk screw (x3)



Secure the `p12` assembly to `w1` with the socket bolts (note, the fingers are excluded in the figure for clarity).

Connect the top and bottom assemblies of the hand using the countersunk screws.

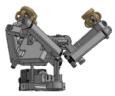




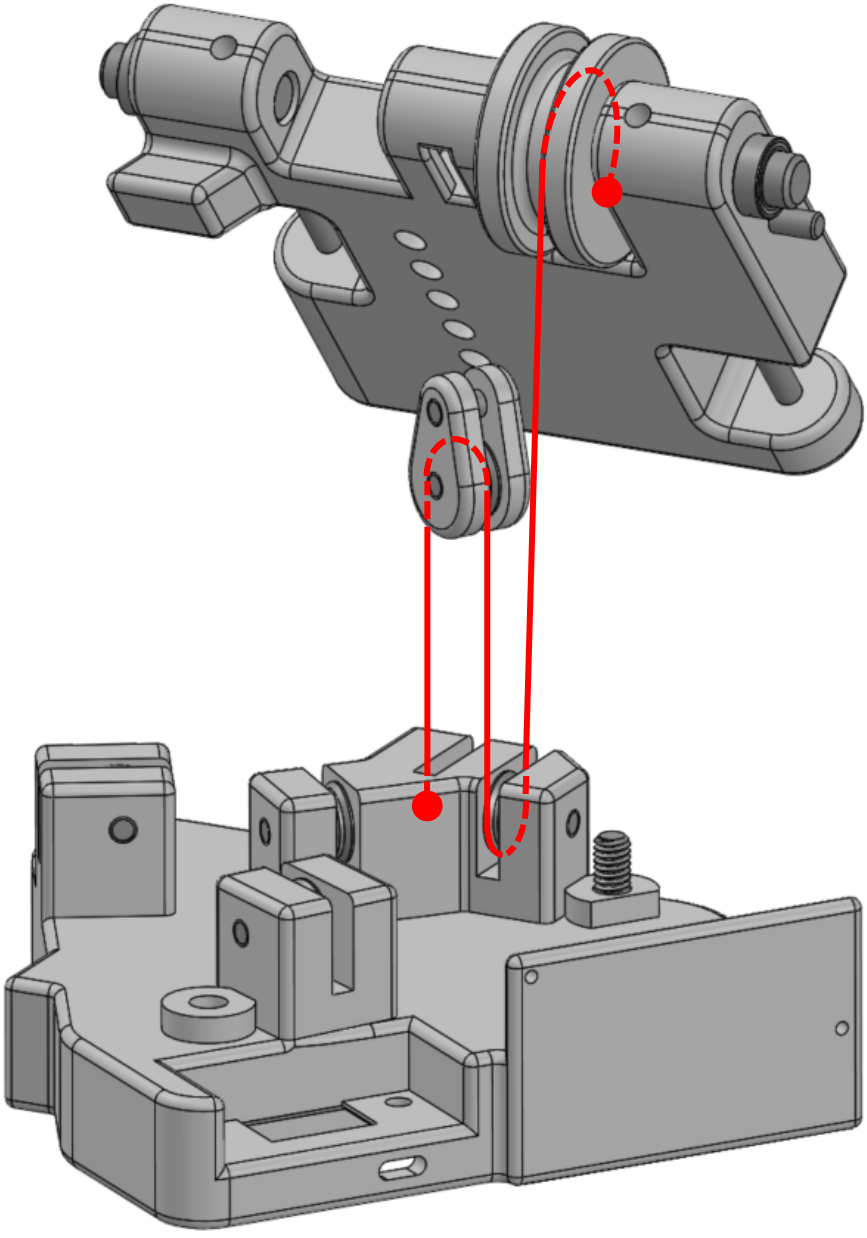
Final Assembly

Tendon Routing – Independent Finger

Parts
Assembly from previous page (x1)
Spectra Line



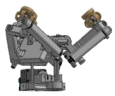
Route a 13-inch piece of Spectra line as shown in the figure, securing both ends to the corresponding dowel pins with knots and super glue. On the finger, attach the tendon to exposed section of the 1/8” dowel pin passing through `p6`.



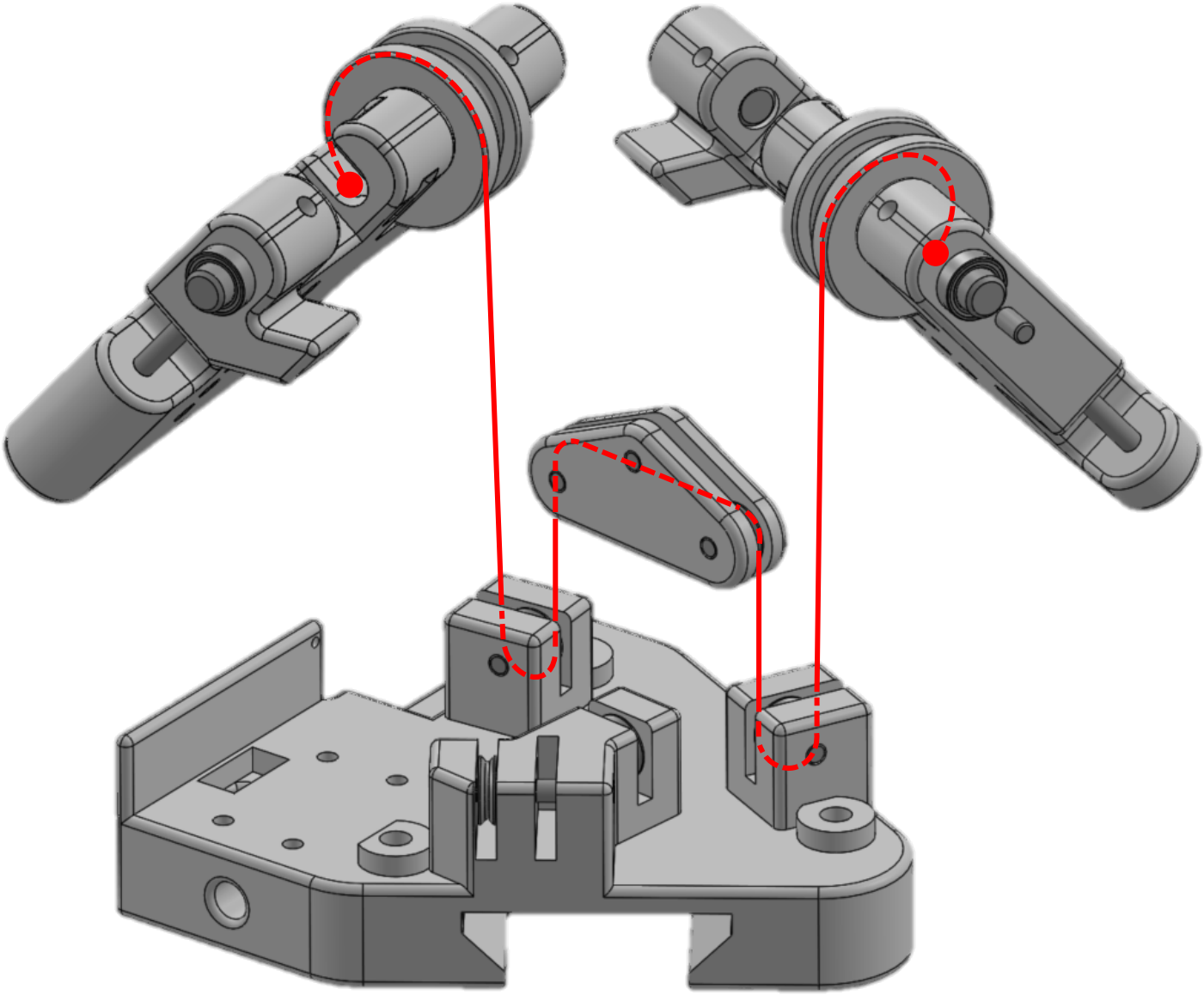
Final Assembly

Tendon Routing – Coupled Fingers

Parts
Assembly from previous page (x1)
Spectra Line



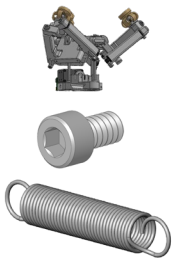
Route a 17-inch piece of Spectra line as shown in the figure, securing both ends to the corresponding dowel pins with knots and super glue. On each finger, attach the tendon to exposed section of the 1/8” dowel pin passing through `p6`.



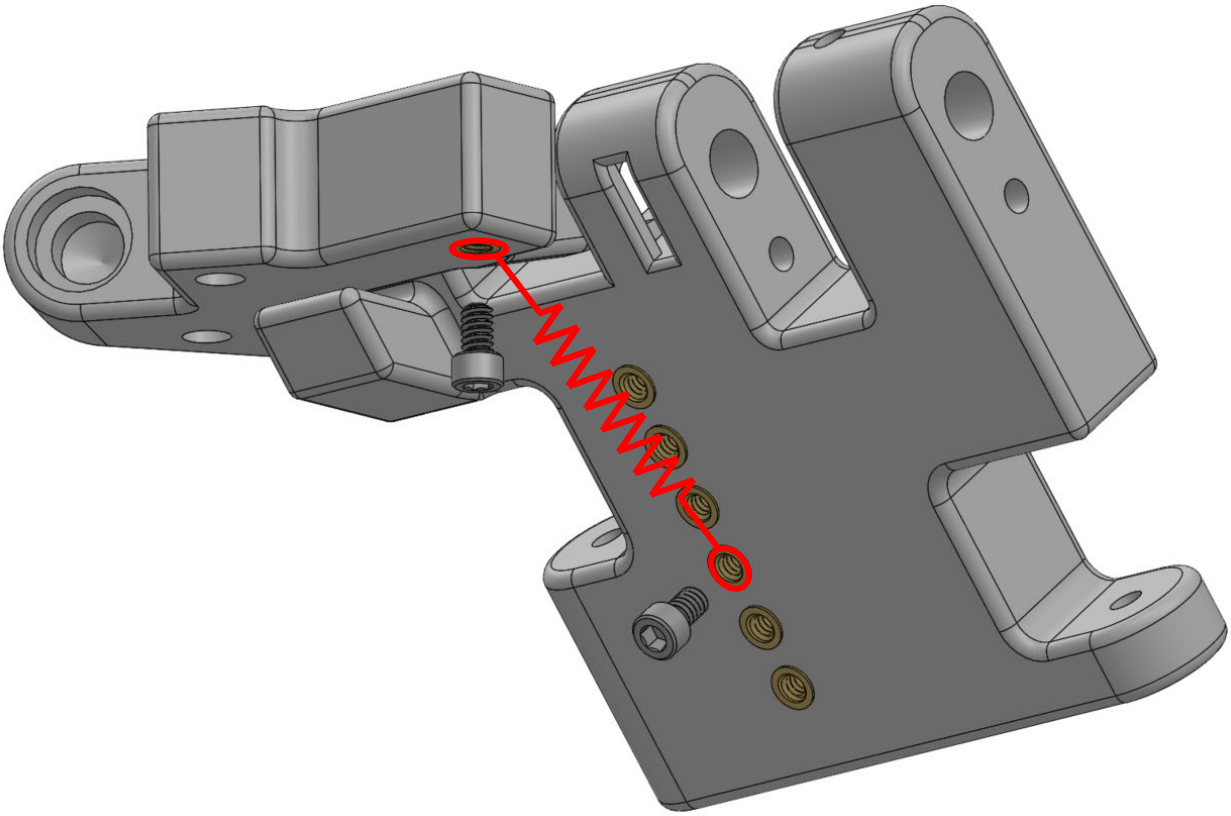
Final Assembly

Antagonist Springs

Parts
Assembly from previous page (x1)
4-40 L3/16” socket bolt (x6)
Extension spring (x3)

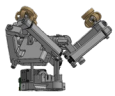


Use the bolts to anchor the extension springs between `p5` and `p7` on each finger. Choose the attachment hole on `p5` so that the finger just returns to it’s fully opened position when the hand is held upside down against gravity. Try to ensure equal spring tension between the three fingers to balance the differential.



Final Assembly

Cable Management

Parts
Assembly from previous page (x1) 

Wrap all actuator and potentiometer cables around the threaded standoffs, securing them in place with zip-ties. For longer cables, wrap them multiple times to secure them in place.

Plug each component into the channel indicated in the figure below on the control board.

If sensor noise is found to be a problem between the potentiometers, install jumper wires between the signal and ground pins on channels 7, 9, & 11 and set these channels as inputs, as well. This will help clear the onboard ADC between actual measurements on the adjacent channels.