

# Build Instructions

**Developed at the University of Pittsburgh Vascular Medicine Institute**

*Full bill of materials can be found in our [Github](#)*

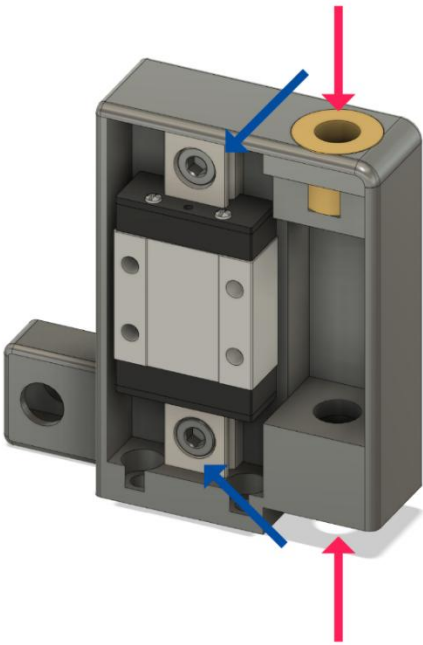
The majority of HemoLens' components are 3D printed from PLA filament. Part infill is discretionary; however, we printed the insert and main cradle at 25% infill, and all other components at 15%. The bath insert was printed out of PETG for better water retention. All parts were printed from the Bambulab X1 Carbon and sliced in Bambu Studio.

## Step 1: Manipulator Assembly

Begin assembly of HemoLens by building both 3-Axis manipulators. Required parts:

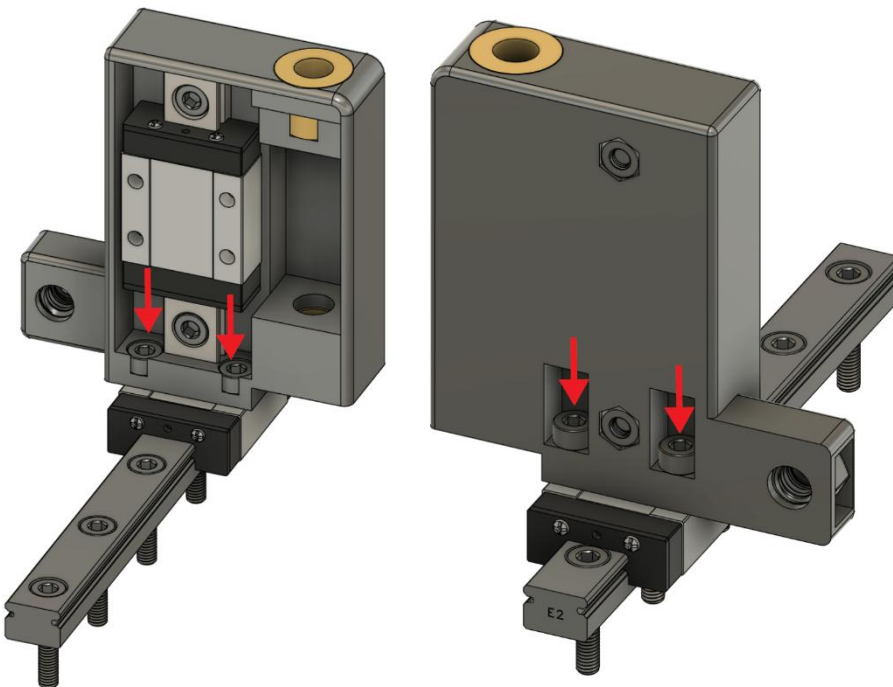
- (4x) M6\_Knurl\_Thumb
- (2x) Manipulator\_Main\_Bracket
- (2x) Manipulator\_Y\_Axis
- (2x) Cannula\_Main
- (2x) Cannula\_Sub
- (2x) Z\_Axis\_Accessory
- (4x) M6 x 1 mm bolt, 60mm long, Fully Threaded Hex Cap
- (8x) Oil-Embedded Bronze Flanged Sleeve Bearing
- (4x) 50mm MGN9 Rail and Carriage
- (2x) 150mm MG09C Rail and Carriage
- (4x) M6 Hex Socket Set Screw Collar
- (6x) M6 x 1 mm, Medium-Strength Steel Hex Nut
- (6x) M3 x 0.5 mm, Low-Strength Steel Hex Nut
- (2x) M3 x 0.5 mm, Medium-Strength Steel Thin Hex Nut
- (6x) M3 x 0.5 mm, 8mm long, Fully Threaded Socket Cap
- (10x) M3 x 0.5 mm, 6mm long, Fully Threaded Socket Cap
- (12x) M3 x 0.5 mm, 4mm long, Fully Threaded Socket Cap

## Step 1A: Assembling the Main Bracket



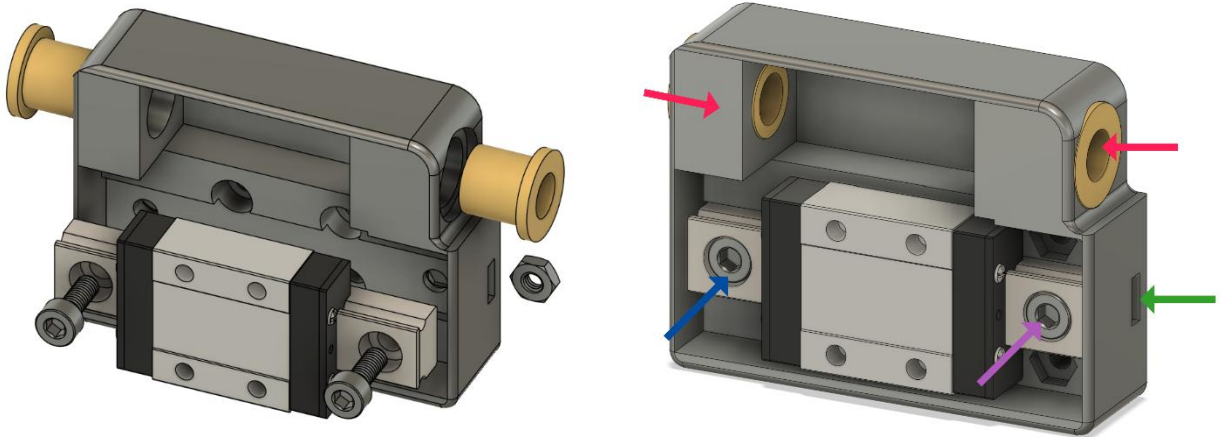
Place the 50mm MGN9 rail and carriage in the Manipulator\_Main\_Bracket housing, and screw two 8mm long M3 x 0.5 mm bolts into the housing (blue arrows). Place two M3 x 0.5 mm nuts on the opposite side of the housing, and screw through until the carriage is snug. Press two bronze sleeve bearings into the top and bottom side of the housing (red arrows).

## Step 1B: Mounting the X Axis Carriage and Rail



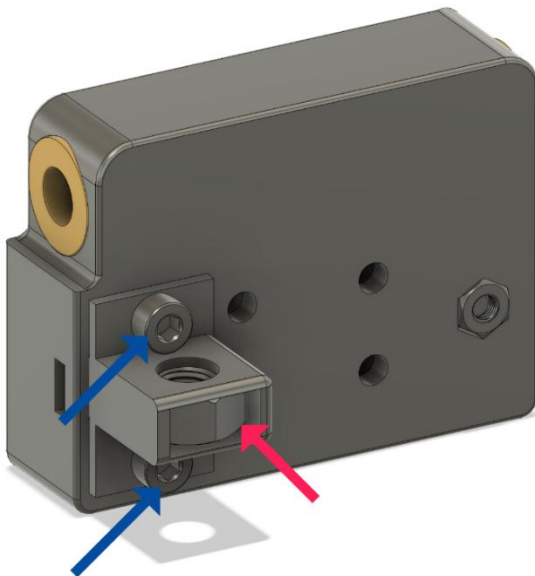
Place the main bracket on top of the 150mm MGN09C carriage and rail. Secure with four 6mm long M3 x 0.5 mm bolts (red arrows) using a ball hex head screwdriver.

## Step 1C: Assembling the Y Axis



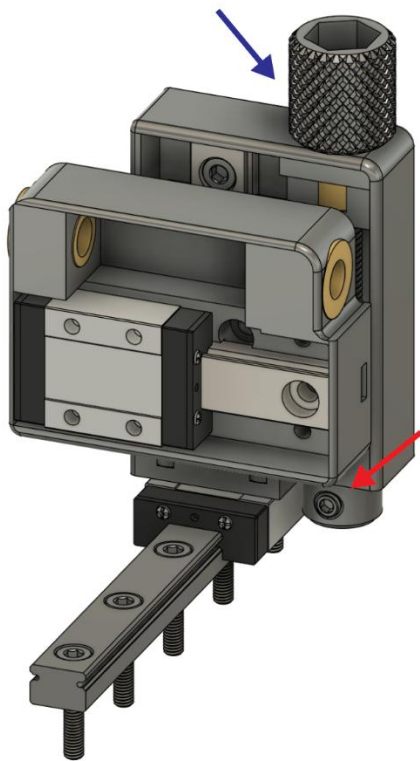
Place another 50mm MGN9 rail and carriage into the Manipulator\_Y\_Axis housing, and screw one 8mm long M3 x 0.5 mm bolt through the left rail hole (blue arrow) and through the plastic housing. Press one M3 x 0.5 mm nut onto the opposite side of the housing and tighten the bolt to secure. Then, after placing one M3 x 0.5 mm thin nut in the housing (green arrow), screw one 6mm long M3 x 0.5 mm bolt through the right rail hole (purple arrow). Press two more bronze sleeve bearings (red arrows) into the housing.

## Step 1D: Mounting the Z Axis Accessory



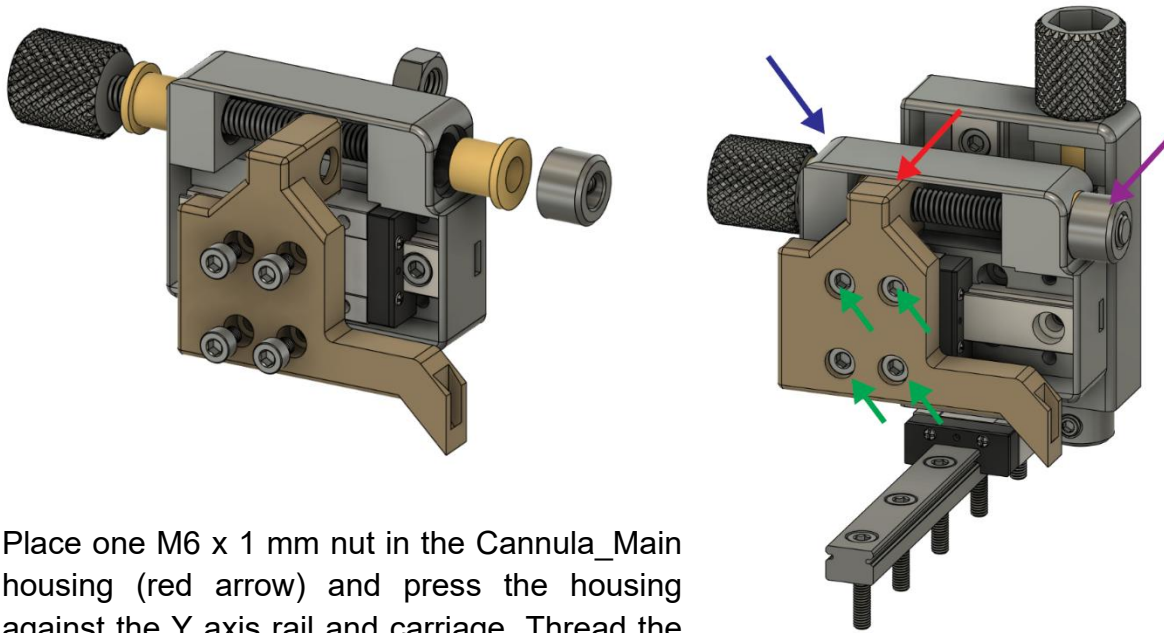
Flip the housing over and press the Z\_Axis\_Accessory into the housing. Screw it into the housing with two 4mm long M3 x 0.5 mm bolts (blue arrow). Insert one M6 x 1 mm nut (red arrow) into the accessory.

## Step 1E: Installing the Vertical Bolt



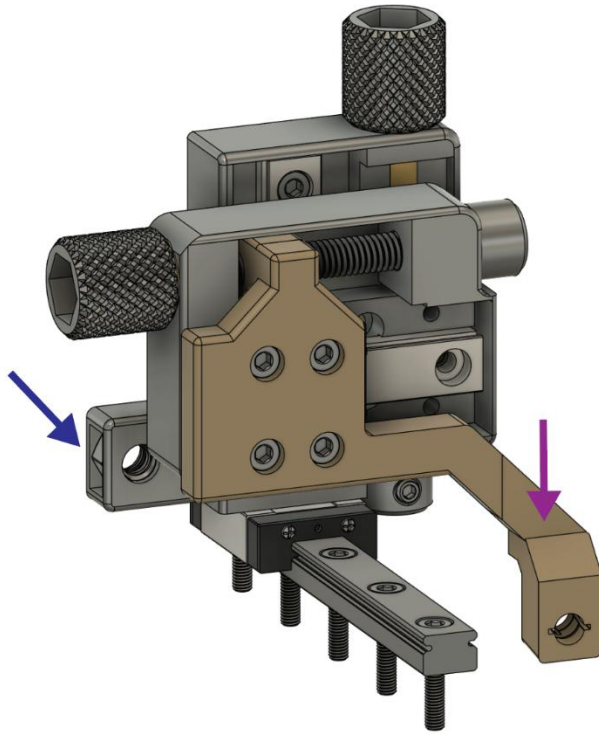
Press one 60mm long M6 x 1 mm bolt through one M6\_Knurl (blue arrow). Place the assembled Y axis into the main housing, allowing the Z\_Axis\_Accessory to fit into the vertical slot in the Manipulator\_Main\_Bracket housing, and thread the M6 bolt through the Z\_Axis\_Accessory. Secure the M6 bolt with one M6 set screw collar (red arrow).

## Step 1F: Mounting the Cannula Holder



Place one M6 x 1 mm nut in the Cannula\_Main housing (red arrow) and press the housing against the Y axis rail and carriage. Thread the 66mm long M6 x 1 mm bolt through the second M6\_Knurl (blue arrow), and through the Cannula\_Main housing. Secure the Cannula\_Main bracket to the Y axis carriage with four 4mm long M3 x 0.5 mm bolts (green arrows). Continue threading the M6 bolt through the Y axis housing and secure it with an M6 set screw collar (purple arrow).

## Step 1G: Finishing Assembly



Place an M6 x 1 mm nut in the Manipulator\_Main\_Bracket housing (blue arrow). Now, or when ready to perform an experiment, slot the Cannula\_Sub piece into the Cannula\_Main housing (purple arrow). The 3-Axis Manipulator is now complete. Repeat steps A through F for the second manipulator.

## **Step 2: Manual Pressure Crank (iPRS)**

Continue assembly by building the manual pressure crank. Required parts:

(1x) iPRS\_Main

(1x) iPRS\_Syringe\_Holder

(1x) iPRS

(1x) Syringe\_Cover

(1x) M8 x 1.25 mm, Medium-Strength Steel Hex Nut

(1x) M8 Clamping Two-Piece Shaft Collar

(1x) M8 x 1.25 mm, 130mm long, Fully Threaded Hex Cap

(1x) M3 x 0.5 mm, 3.8mm long Heat-Set Insert

(6x) Small Circular Neodymium Magnets

(4x) M3 x 0.5 mm, 4mm long, Fully Threaded Socket Cap

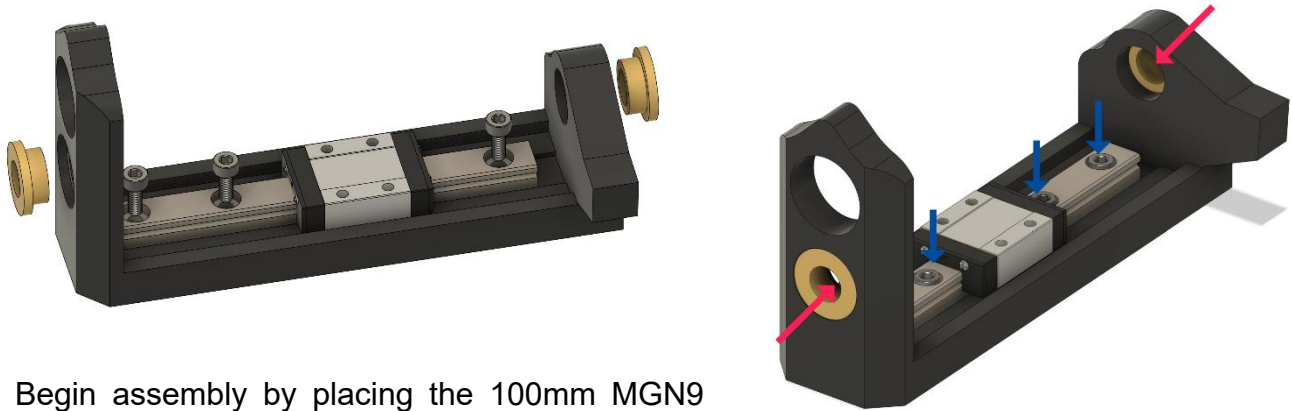
(1x) M3 x 0.5 mm, 6mm long, Fully Threaded Socket Cap

(6x) M3 x 0.5 mm, 8mm long, Fully Threaded Socket Cap

(1x) 100mm MG9N Carriage and Rail

(2x) Oil-Embedded Bronze Flanged Sleeve Bearing

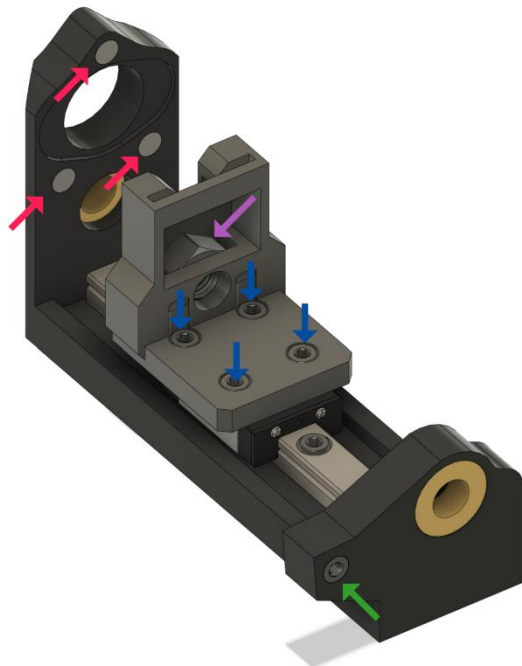
## Step 2A: Installing the Carriage and Rail



Begin assembly by placing the 100mm MGN9 carriage and rail into the iRPS\_Main housing.

Secure with five 8mm long M3 x 0.5mm bolts (blue arrows). Place five M3 x 0.5mm nuts on the opposite side of the housing and tighten the bolts to secure the rail. Press two bronze sleeve bearings into both sides of the housing (red arrows).

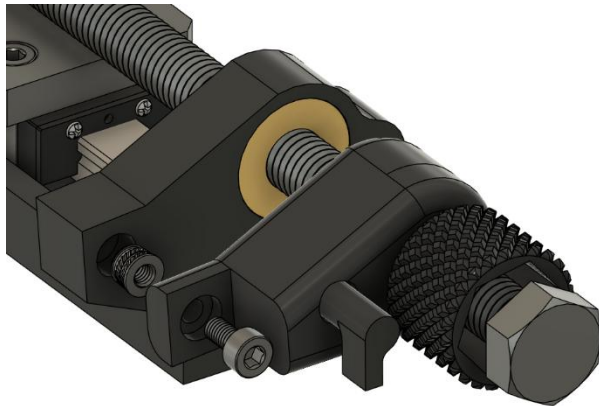
## Step 2B: Installing the Syringe Holder



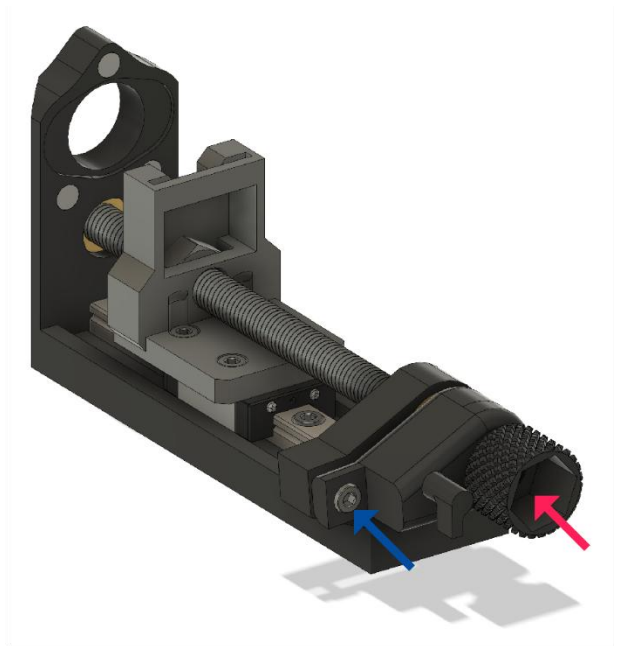
Adhere three of the small neodymium magnets to their respective sockets (red arrows). Place an M8 x 1.25mm nut inside the housing of the Ratchet\_Syringe\_Holder (purple arrow). Place the iRPS\_Syringe\_Holder on the carriage, and secure with four 4mm long M3 x 0.5mm bolts (blue arrows). Heat-set an M3 x 0.5mm insert to the Ratchet\_Main housing (green arrow).



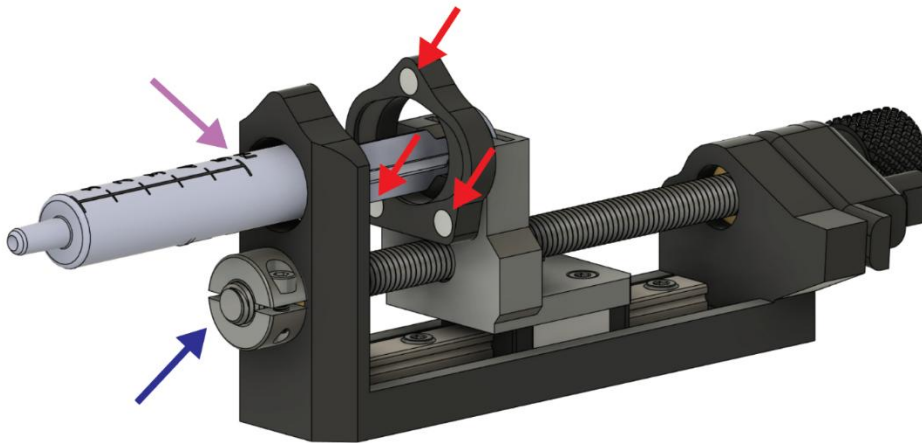
## Step 2C: Installing the iRPS



Place the iRPS on the Ratchet\_Main housing, and secure with an M3 x 6 mm screw (blue arrow). Thread the 130mm M8 x 1.25 mm bolt through the entire assembly (red arrow).



## Step 2D: Installing the Syringe Cover



Secure the M8 bolt with an M8 clamping collar (blue arrow). Adhere 3 circular Neodymium magnets (red arrows) to the Syringe\_Cover. Attach the cover when ready to perform an experiment. Insert a 3mL or 5mL syringe (purple arrow) when ready to perform an experiment. Assembly is now complete.

## Step 3: Regular Adjustment of Modulated Pressure (RAMP)

Continue assembly by building the RAMP system. Required parts:

(1x) RAMP\_Main

(1x) RAMP\_Gate

(1x) Nema 17 Stepper Motor

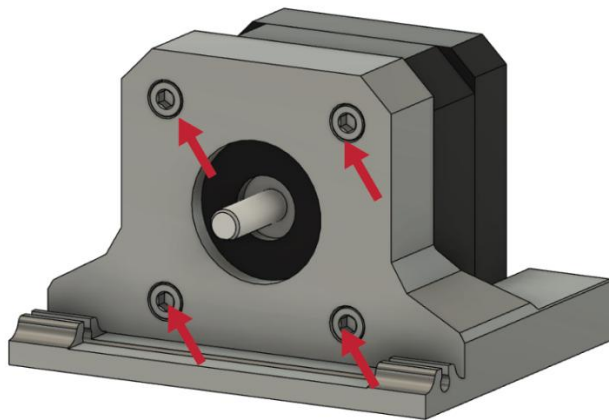
(5x) M3 x 0.5 mm, 6mm long, Fully Threaded Socket Cap

(1x) M3 x 0.5 mm, 12mm long, Fully Threaded Socket Cap

(1x) M3 x 0.5 mm, Medium-Strength Steel Thin Hex Nut

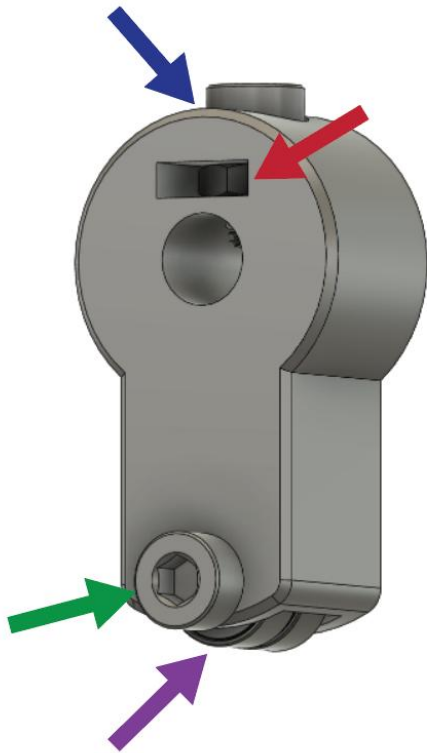
(2x) M3 Stainless Steel Ball Bearing

### Step 3A: Mounting the Stepper Motor



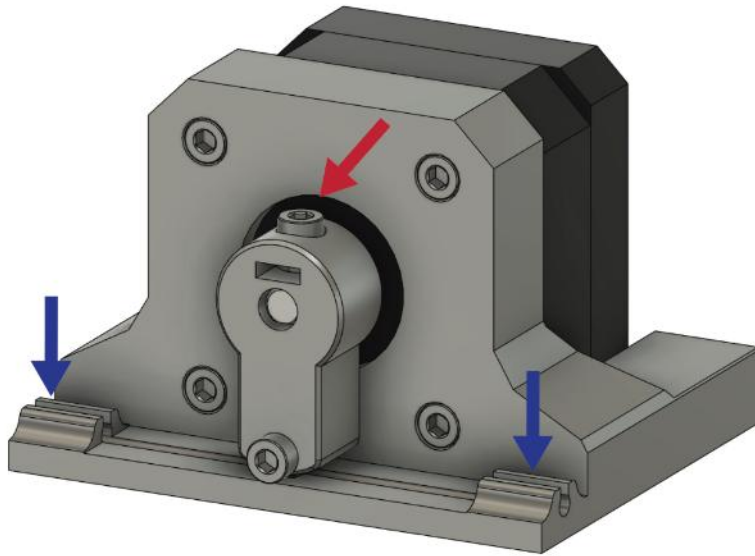
Press the Nema 17 stepper motor into the RAMP\_Main housing, and secure with four 6mm long M3 x 0.5 mm bolts (red arrows).

### Step 3B: Preparing the RAMP Gate



Slot an M3 x 0.5 mm thin nut into the RAMP\_Gate housing (red arrow) and secure it by partially threading a 6mm long M3 x 0.5 mm bolt (blue arrow) through the housing. Press both M3 bearings into the RAMP\_Gate housing (purple arrow), and secure by threading one 12mm long M3 x 0.5 mm bolt (green arrow) through the housing.

### Step 3C: Mounting the RAMP Gate



Press the RAMP\_Gate onto the stepper motor shaft, and secure by tightening the 6mm long M3 bolt (red arrow). Ensure the RAMP\_Gate is positioned such that the tightened screw contacts the flat part of the motor shaft. Place the perfusion line in the tubing holders (blue arrows) when ready to perform an experiment. Assembly is now complete.

## Step 4: Camera Module

Continue assembly by building the camera module. Required parts:

(1x) Arducam USB camera

(1x) Camera\_Main

(1x) Camera\_Z\_Stage

(1x) Camera\_Bracket

(1x) M6\_Knurl\_Large

(1x) 50mm MGN90 Rail and Carriage

(2x) Oil-Embedded Bronze Flanged Sleeve Bearing

(2x) M3 x 0.5 mm, 6mm long, Fully Threaded Socket Cap

(4x) M3 x 0.5 mm, 4mm long, Fully Threaded Socket Cap

(2x) M3 x 0.5 mm, Low-Strength Steel Hex Nut

(4x) Rectangular Neodymium Magnet

(4x) Circular Neodymium Magnet

(4x) M2 x 0.4 mm, Medium-Strength Steel Hex Nut

(4x) M2 x 0.4 mm, 8mm long, Fully Threaded Socket Cap

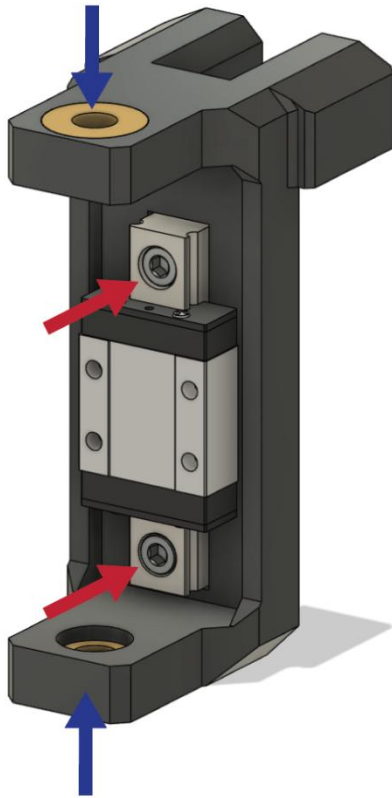
(1x) M12 Lens of Choice

(1x) M6 Two-Piece Shaft Collar

(1x) M6 x 1 mm, 90mm long, Fully Threaded Hex Cap

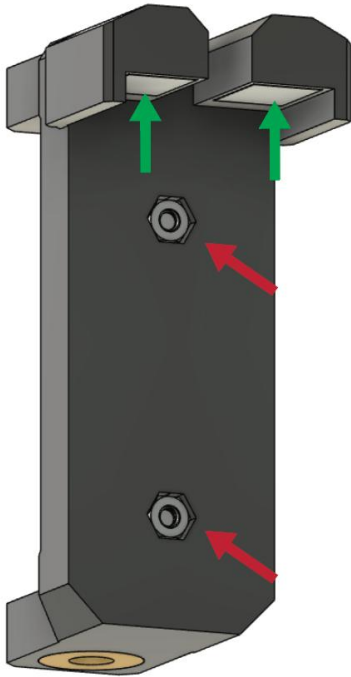
(1x) M6 x 1 mm, Medium-Strength Steel Hex Nut

## Step 4A: Mounting the Carriage and Rail



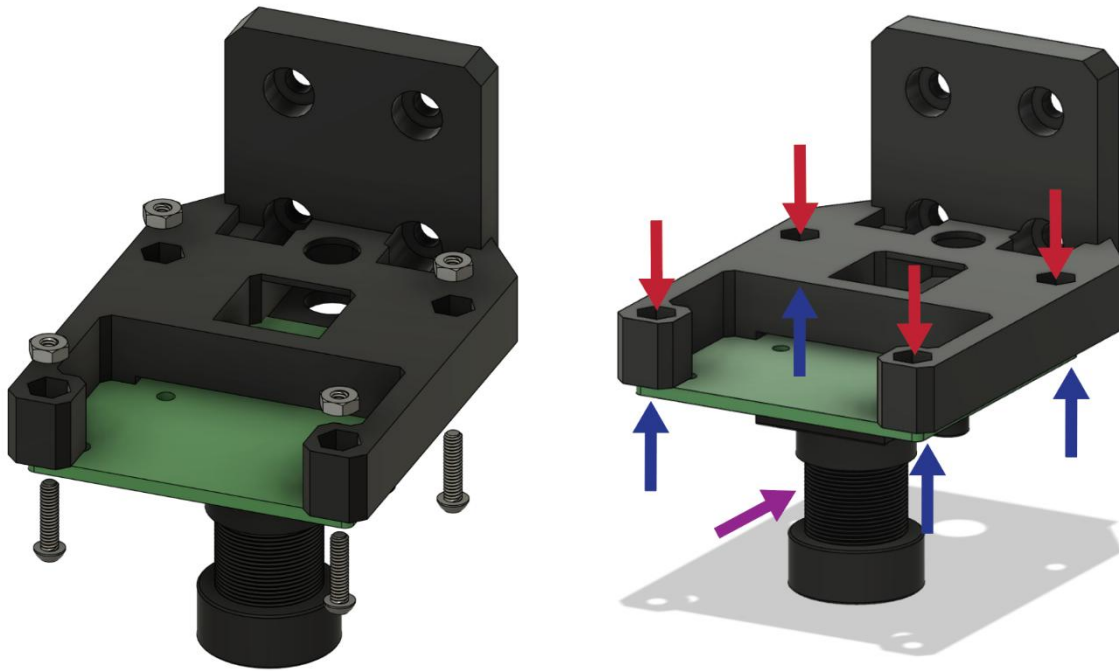
Press the 50mm MG9N0 rail into the Camera\_Main housing, and secure with two 6mm long M3 x 0.5 mm bolts (red arrows). Press two bronze flanged bearings into the housing (blue arrows).

## Step 4B: Preparing the Housing



Place two M3 x 0.5 mm nuts (red arrows) on the opposite side of the housing and tighten the bolts to secure the carriage and rail. Adhere two rectangular neodymium magnets (green arrows) into their respective sockets.

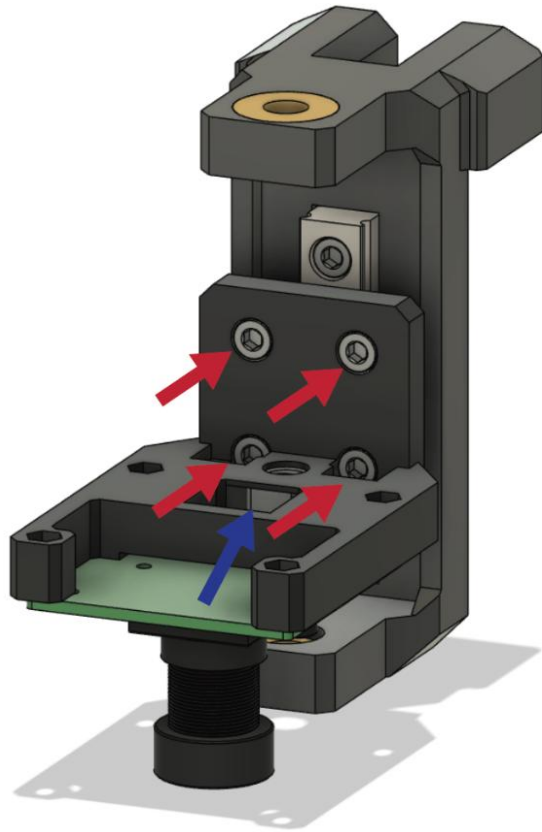
## Step 4C: Preparing the Camera Z Stage



Press four M2 x 0.4 mm nuts into the Z\_Stage housing (red arrows). Place the Arducam against the housing, and secure by threading four 8mm long M2 x 0.4 mm bolts (blue arrow) through the camera holes and into the nuts. Thread the M12 lens of choice (purple arrow) onto the Arducam.

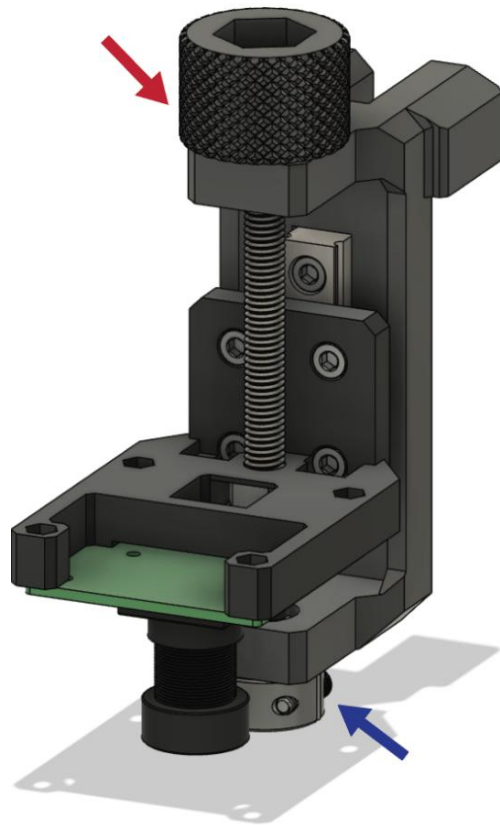


## Step 4D: Mounting the Camera Z Stage



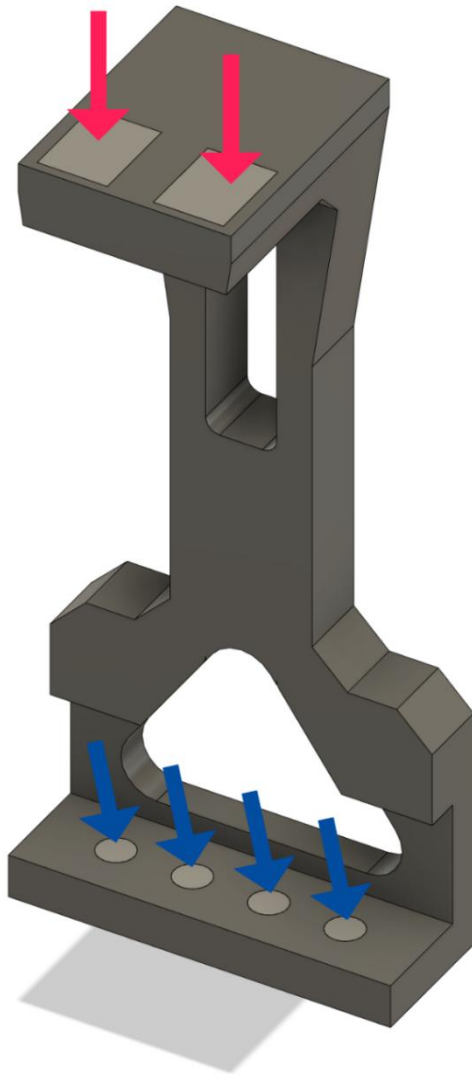
Place an M6 x 1 mm nut in the Camera\_Z\_Stage housing (blue arrow). Place the camera mount on the carriage, and secure with four 4mm long M3 x 0.5 mm bolts (red arrows).

## Step 4E: Installing the Vertical Bolt



Thread the 100mm long M6 x 1 mm bolt through the M6\_Knurl\_Thumb, and through the Camera\_Z\_Stage (red arrow). Secure with a M6 clamping collar (blue arrow).

## Step 4F: Preparing the Camera Bracket



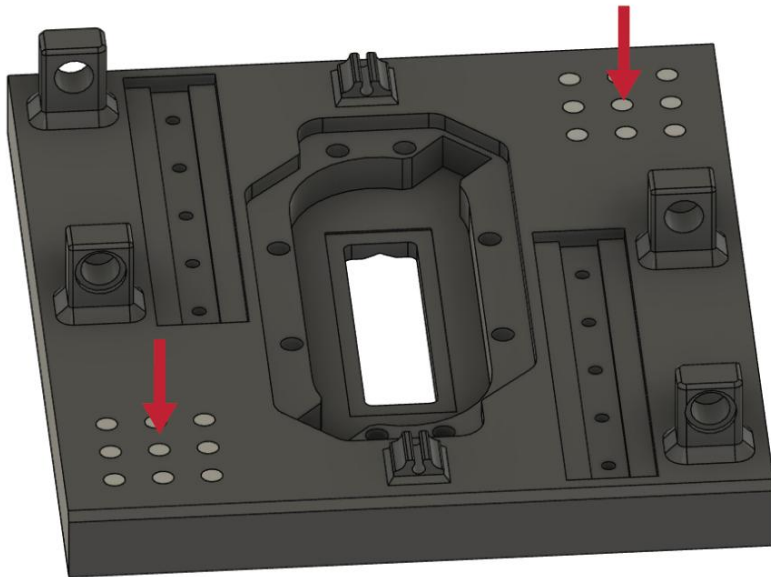
Adhere two rectangular neodymium magnets (red arrows) to their respective sockets on the top of the Camera\_Bracket. Adhere four circular neodymium magnets (blue arrows) in the same way to the base of the Camera\_Bracket. Assembly is now complete.

## Step 5: Main Platform

Continue assembly by building the HemoLens' main platform. Required parts:

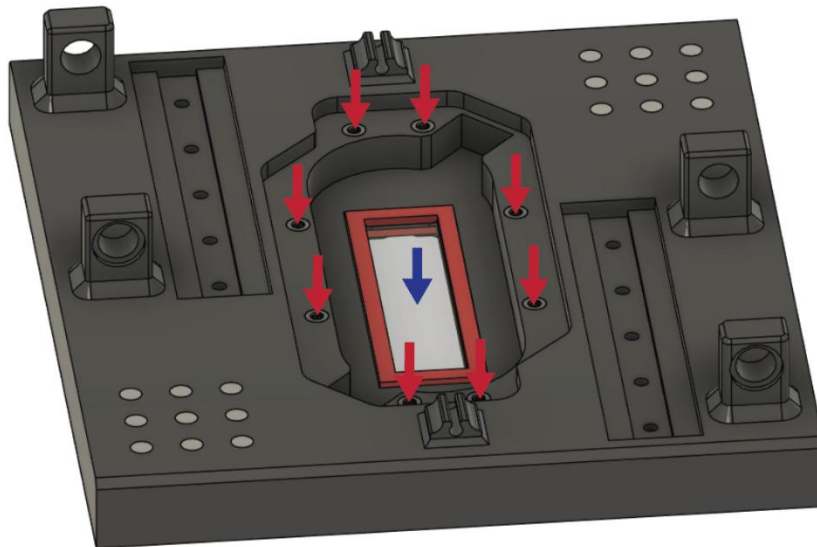
- (1x) Cradle
- (2x) M6\_Knurl
- (1x) Cradle\_Insert
- (2x) Tubing\_Holder
- (4x) Cradle\_Feet
- (46x) Circular Neodymium Magnet
- (2x) 75 x 25 mm Glass Microscope Slide
- (1x) 75 x 25 mm Rubber Gasket (Optional Cricut Maker 3)
- (4x) Oil-Embedded Bronze Flanged Sleeve Bearing
- (12x) M3 x 0.5 mm, 3.8mm long Heat-Set Insert
- (8x) M3 x 0.5 mm, 6mm long, Fully Threaded Socket Cap
- (8x) M3 Stainless Steel Washer
- (2x) M6 x 1 mm, 100mm long, Fully Threaded Hex Cap
- (2x) M6 x 1 mm, Medium-Strength Steel Hex Nut
- (2x) Plastic Barbed Tube Fitting
- (10x) M3 x 0.5 mm, Low-Strength Steel Hex Nut
- (4x) 16mm Outer-Diameter Rubber Grommet

## Step 5A: Installing the Magnets



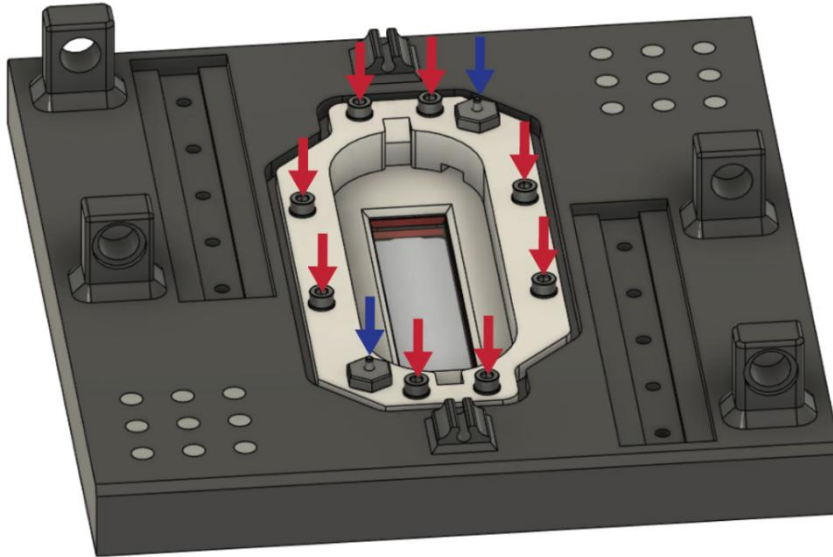
Adhere eighteen circular neodymium magnets to their respective sockets in the cradle (red arrows).

## Step 5B: Installing the Heat-Set Inserts



Heat-set eight M3 x 0.5 mm inserts into their respective sockets in the Cradle (red arrows). Place a 75 x 25mm rubber gasket, 75 x 25 mm microscope slide, and a second rubber gasket of the same size in the rectangular cutout (blue arrow). We cut these gaskets using the Cricut Maker 3 and accompanying software.

Using this machine is optional, however, as these gaskets can be manually cut with an X-ACTO knife or similar tool.

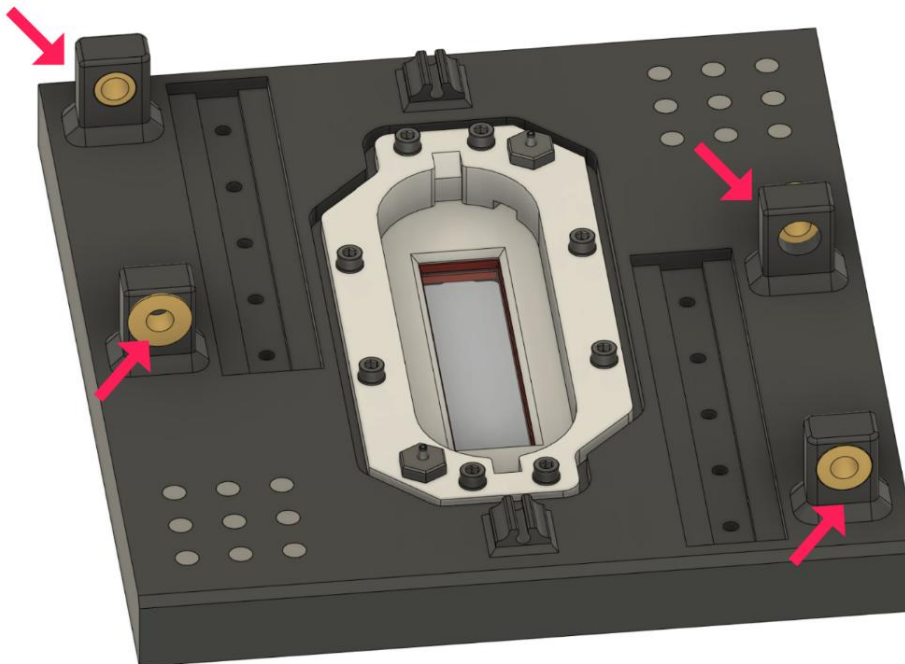


## Step 5C: Installing the Cradle Insert

Press the Cradle\_Insert on top of the rubber gasket and secure it into the Cradle housing by screwing eight 6mm long M3 x 0.5 mm bolts and M3 washers (red arrows) through their respective holes. Twist in two plastic barbed tubing

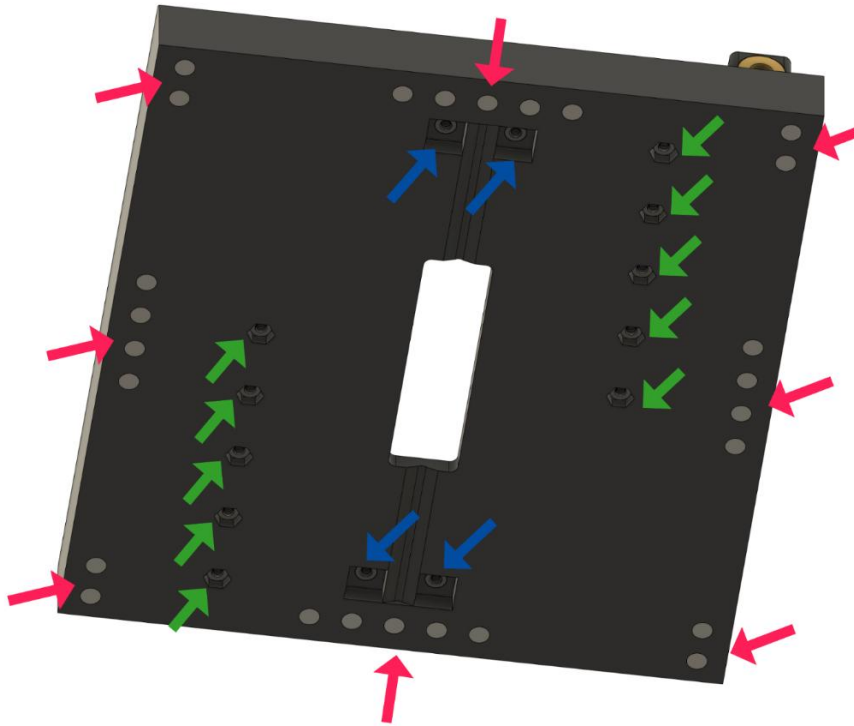
fittings (blue arrows) to the insert. It is recommended to use Teflon tape around barbed inserts to ensure no leaking during operation.

## Step 5D: Installing the Sleeve Bearings



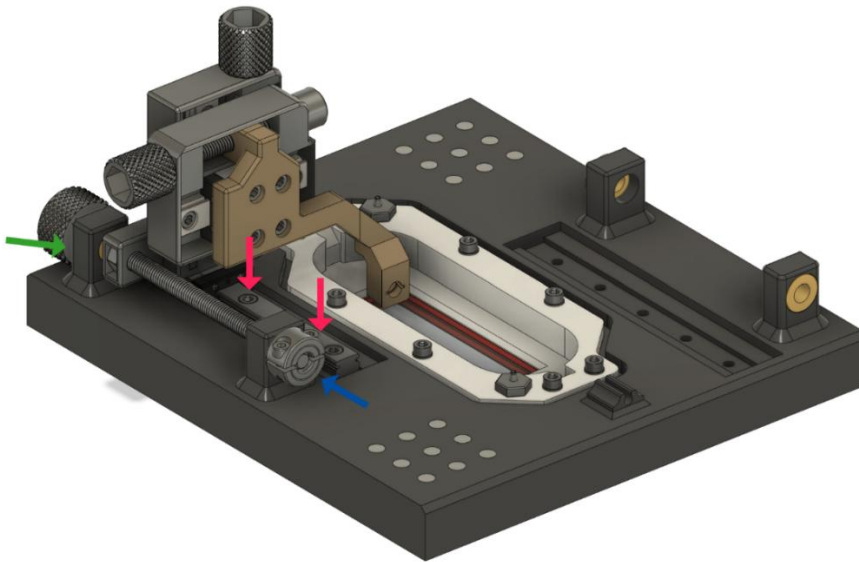
Press four bronze sleeve bearings (red arrows) into the Cradle housing.

## Step 5E: Finishing Magnet Installation



Adhere sixteen circular neodymium magnets to the underside of the Cradle (red arrows). Place ten M3 x 0.5 mm nuts for the micromanipulator rails in the Cradle housing (green arrows). Heat-set four M3 x 0.5 mm inserts (blue arrows) into the Cradle housing.

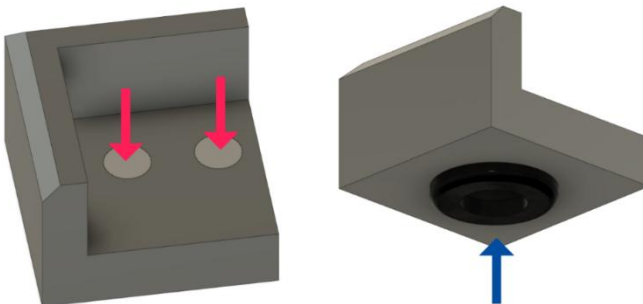
## Step 5F: Installing the Manipulators



Place a manipulator on the Cradle. Place five 12mm long M3 x 0.5 mm bolts (red arrows, three not shown) through the holes in the manipulator rail. Tighten these to secure the manipulator to the Cradle. Thread the 100mm long M6 x 1 mm bolt through the M6\_Knurl (green

arrow) and through the M6 nut in the Manipulator\_Main housing. Secure with an M6 x 1 mm clamping collar (blue arrow). Repeat for the other manipulator.

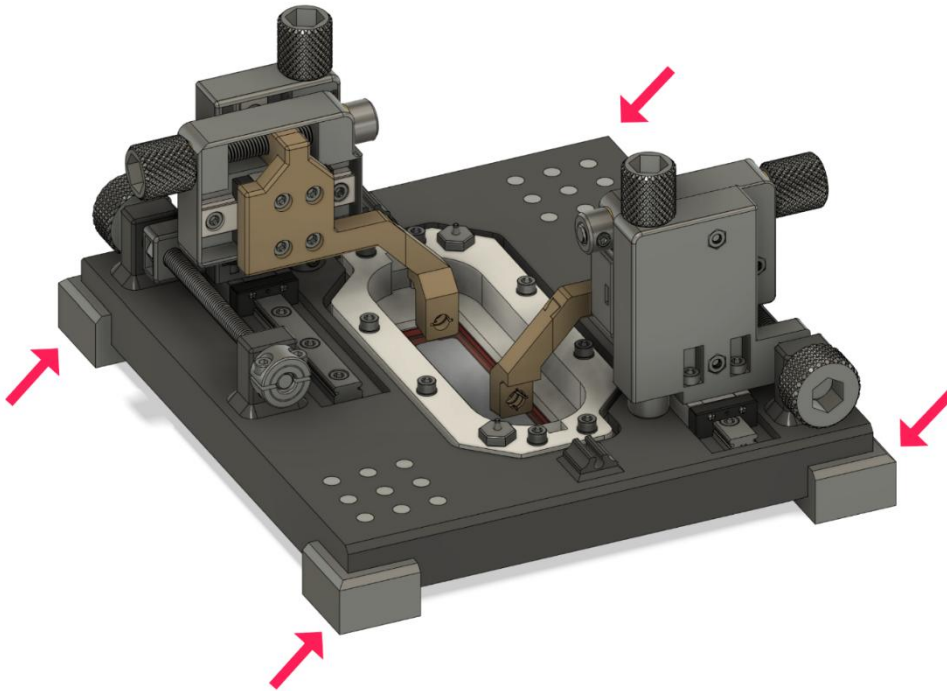
## Step 5H: Preparing the Cradle Feet



Prepare the four Cradle\_Feet by adhering two circular neodymium magnets (red arrows) in the indents, and press-fitting a 16mm OD rubber grommet (blue arrow) into the underside. Repeat for each foot.

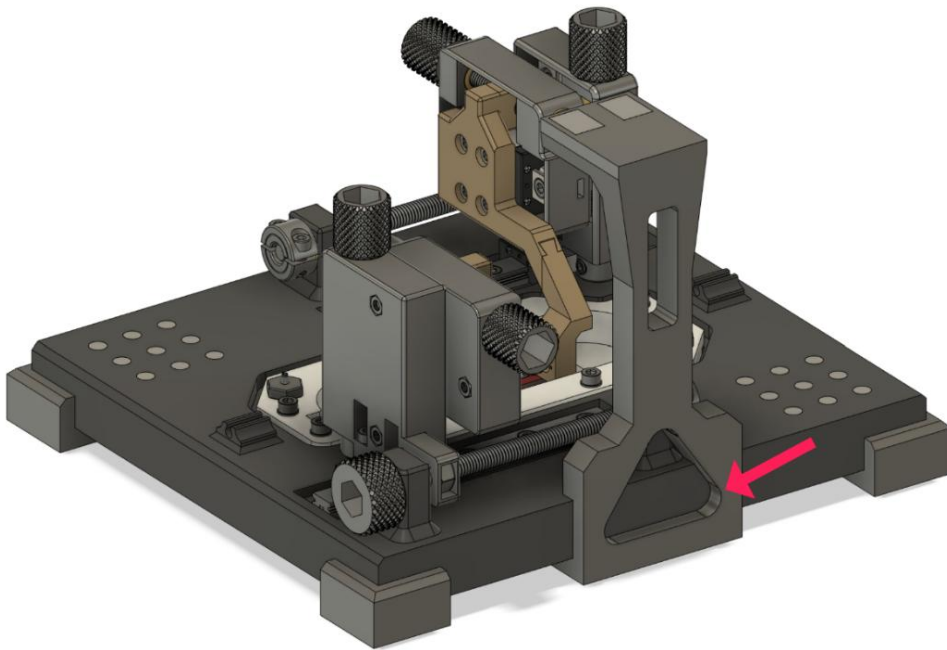


### Step 5I: Mounting the Cradle Feet



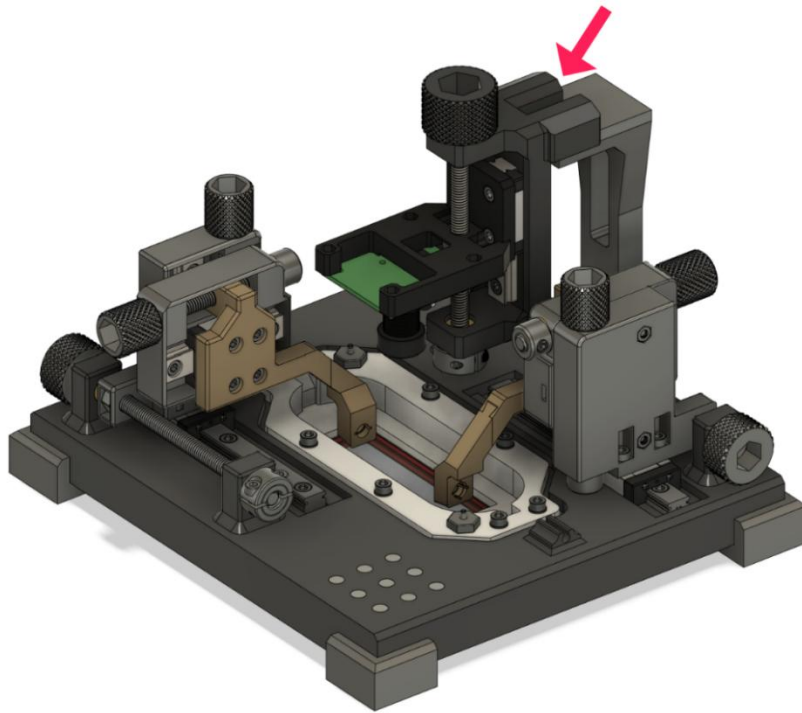
Magnetically attach the feet to the base of the cradle.

### Step 5J: Mounting the Camera Bracket



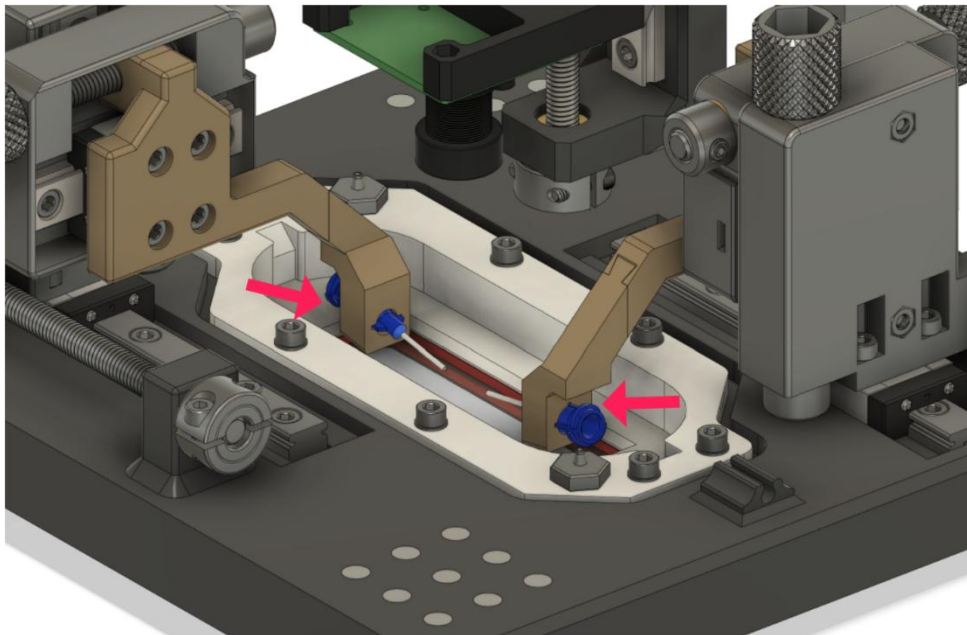
Magnetically attach the Camera\_Bracket to the side of the cradle (red arrow).

## Step 5L: Mounting the Camera\_Gantry



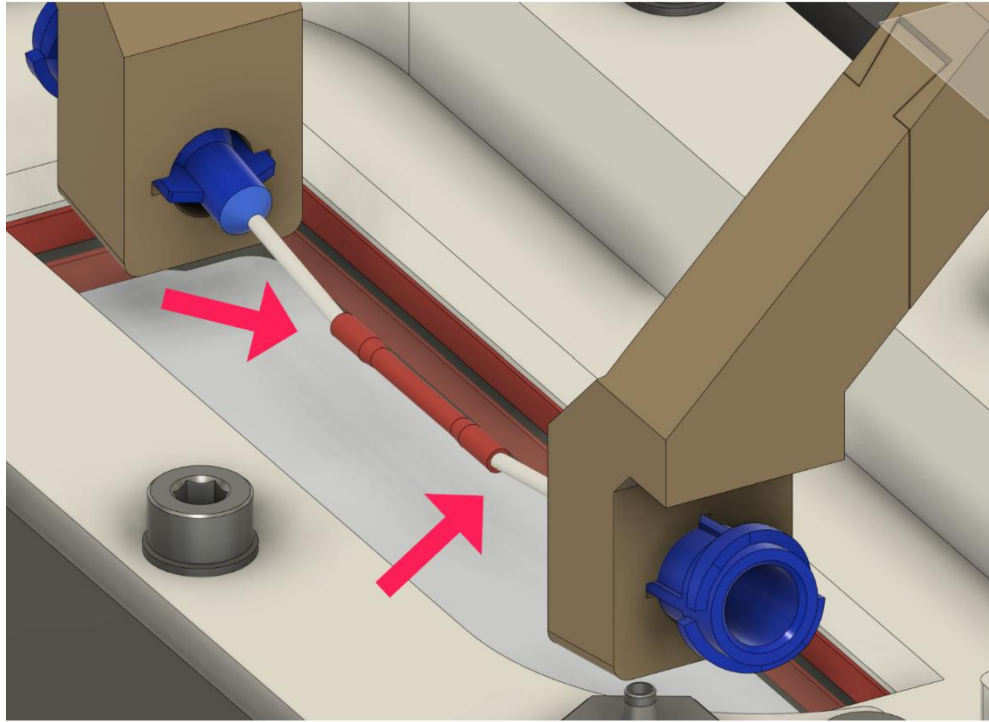
Magnetically  
attach the  
assembled  
camera gantry  
onto the  
Camera\_Bracket.

## Step 5M: Installing the Luer Needles



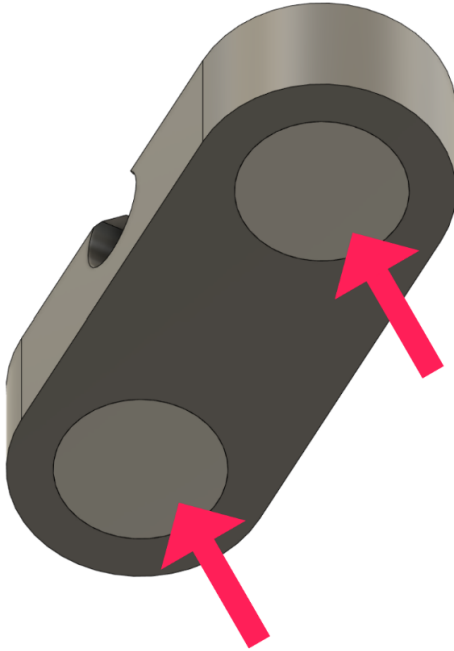
Place Luer  
needles (red  
arrows) of choice  
into the  
Cannula\_Sub  
housing.

## Step 5N: Mounting the Vessel



This step demonstrates the vessel mounting process as performed in our paper. Suture the vessel of choice (red arrows) onto the Luer needles and fill the chamber with solution. An instructional video is provided with this publication

## Step 50: Preparing the Tubing Holders



Optionally, adhere two circular neodymium magnets (red arrows) to the indents in the Tubing\_Holder. Repeat for the other Tubing\_Holder, or as many as are desired. Place these on HemoLens' magnet array and use to secure perfusion tubing.

## Step 6: Electronics Box

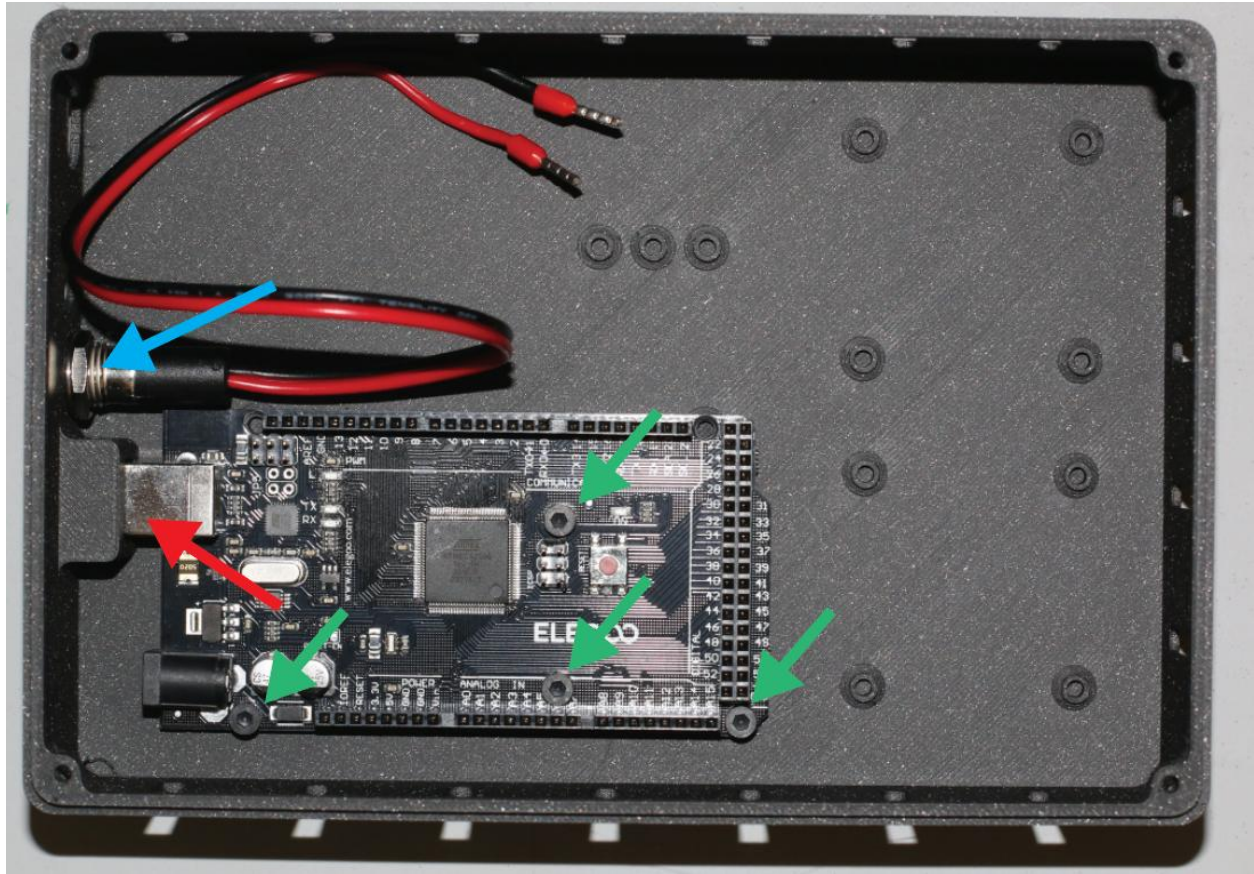
*For additional details on the wiring process, please see the wiring guide on pages 45-46.*

*Note: Unless otherwise stated, all wires in step 6 were crimped using a ferrule crimping tool and ferrule terminals*

Continue assembly by building the HemoLens electronics box. Required parts:

- (1x) Enclosure\_Base
- (1x) Enclosure\_Lid
- (1x) ELEGOO Mega
- (1x) 12V, 3 Amp DC Power Supply
- (1x) TMC2209 Stepper Motor Driver Board
- (1x) Wheatstone Amplifier Shield
- (1x) L298N Motor Driver Board
- (1x) TOPINCN Small Volume Aquarium Pump
- (2x) Gikfun Micro Small-Volume Peristaltic Pump
- (1x) Stepper Motor Cable
- (1x) Barrel Jack
- (1x) 20 AWG Wire Spool
- (14x) Ferrule Terminals
- (2x) 4-Pin Dupont Connectors
- (2x) Plastic Submersible Cord Grip
- (1x) Quick and Secure Connect Terminal Block
- (4x) M3 x 0.5 mm, 6mm long, Fully Threaded Socket Cap
- (16x) M3 x 0.5 mm, 4mm long, Fully Threaded Socket Cap
- (1x) HiLetgo Keypad LCD Shield

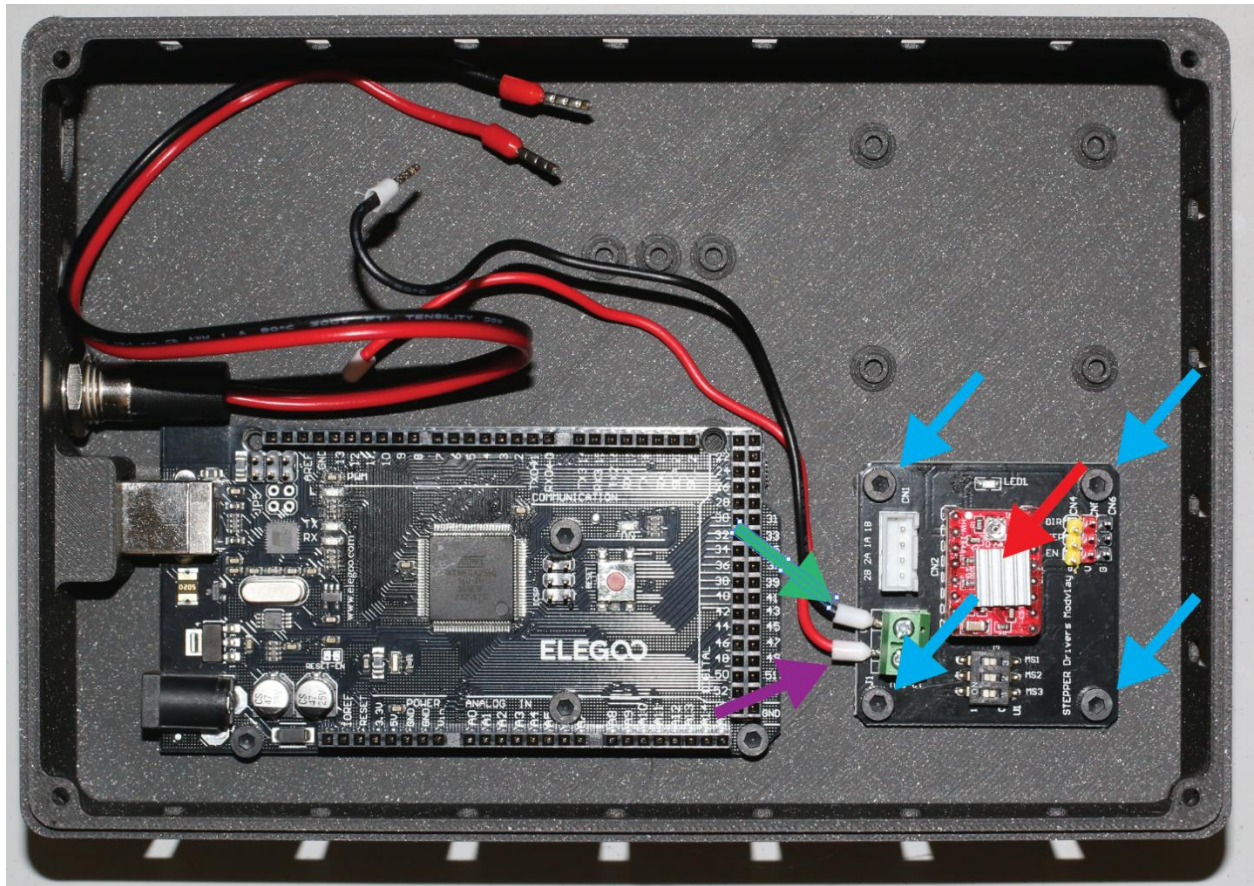
## Step 6A: Installing the ELEGOO Mega and Barrel Jack



Begin assembly of the electronics box by placing the ELEGOO Mega (red arrow) and barrel jack (blue arrow) inside the Enclosure\_Base. Secure the ELEGOO Mega with four 4mm long M3 x 0.5 mm bolts (green arrows). Secure the barrel jack by twisting its hexagonal ring counterclockwise until flush with the Enclosure\_Base.

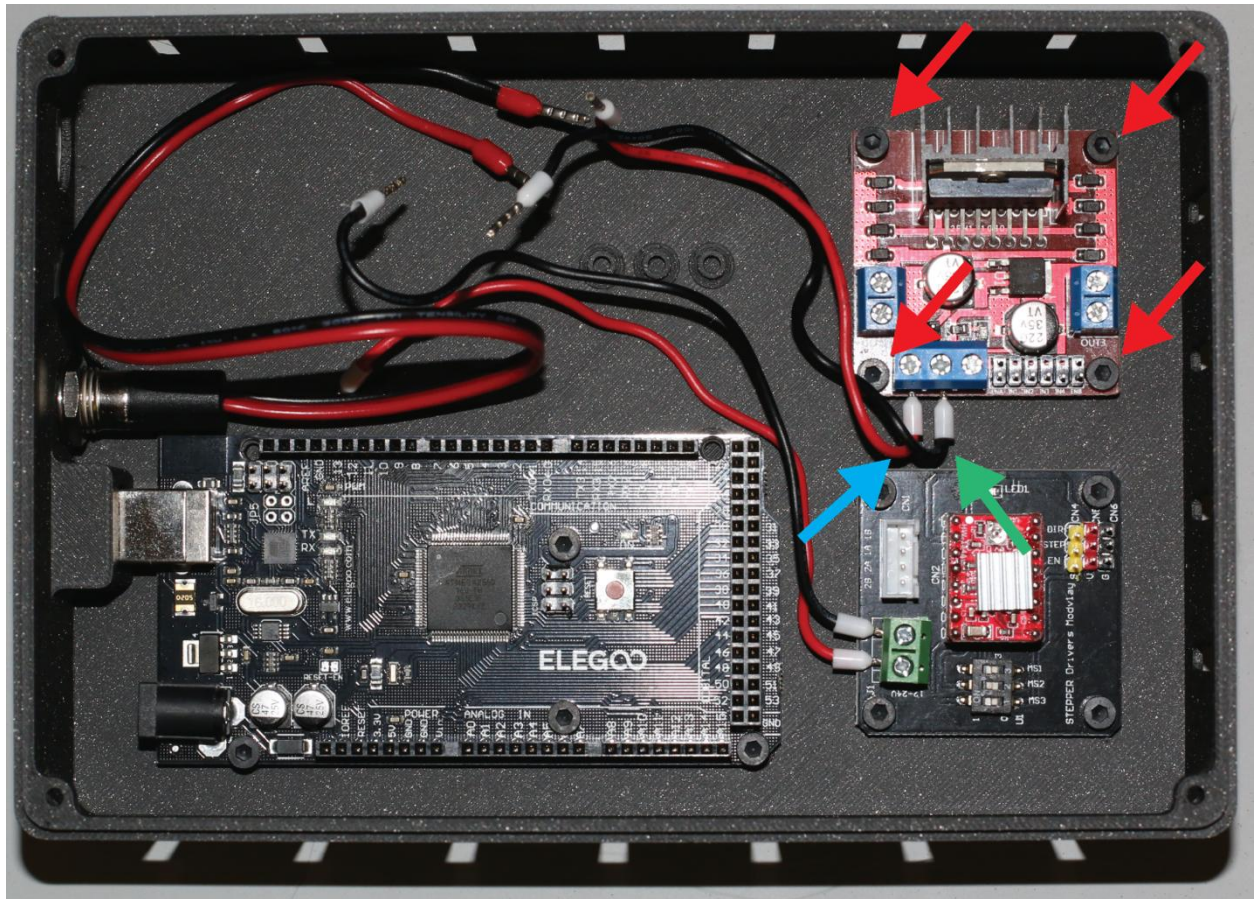


## Step 6B: Installing the Stepper Driver and Breakout Board



Place the TMC2209 stepper motor driver (red arrow) in the stepper breakout board and place the breakout board in the housing. Secure by screwing four 4mm long M3 x 0.5 mm bolts (blue arrows) into the housing. Place a crimped lead in both the negative terminal (green arrow) and positive terminal (purple arrow) of the board.

## Step 6C: Installing the L298N Motor Driver and Leads

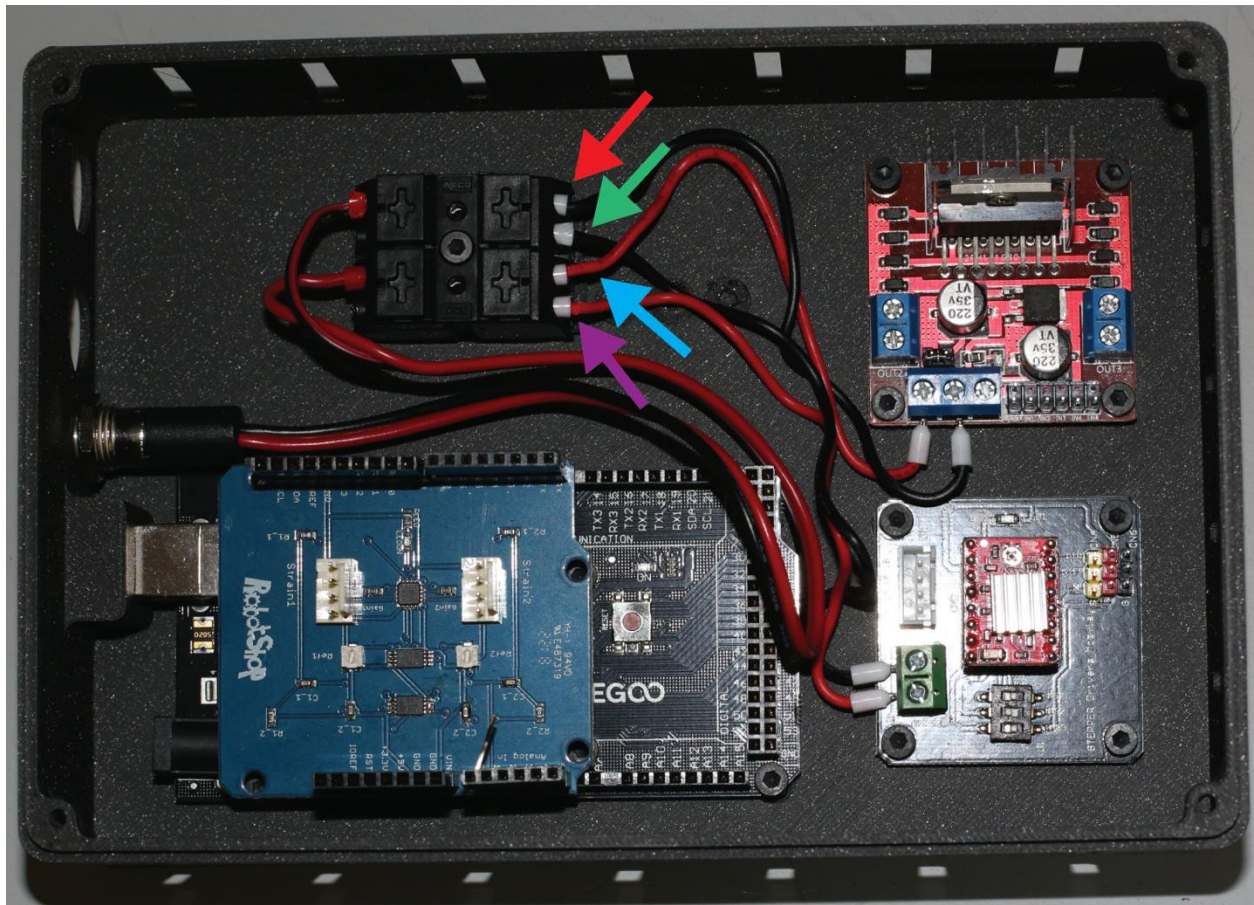


Place the L298N motor driver in the housing and secure with four 4mm long M3 x 0.5 mm bolts (red arrows). Place a crimped lead in both the negative terminal (green arrow) and positive terminal (blue arrow) of the driver.



Adhere the power splitter terminal block (red arrow) to the housing using an adhesive. Insert the negative terminal of the barrel jack (blue arrow) to the far side of the terminal block. Insert the positive terminal (green arrow) to the near side of the terminal block. Insert the Wheatstone shield (purple arrow) into the ELEGOO Mega so the pins align.

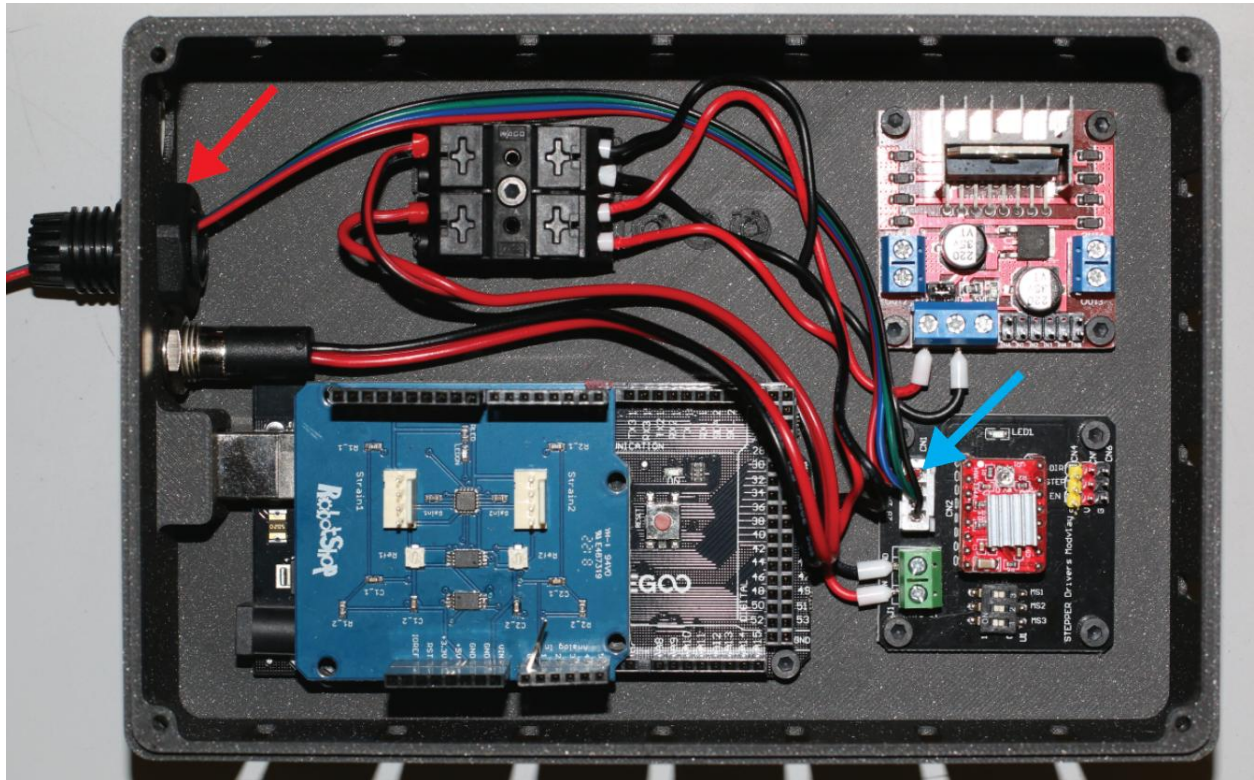
## Step 6E: Powering the Stepper and Motor Driver Boards



Insert the L298N motor driver's negative lead (red arrow) into the far side of the power splitter. Insert the motor driver's positive lead into the near side (blue arrow). Insert the stepper motor driver's negative lead (green arrow) into the remaining slot in the far side of the power splitter. Insert the stepper motor driver's positive lead (purple arrow) into the near side of splitter.

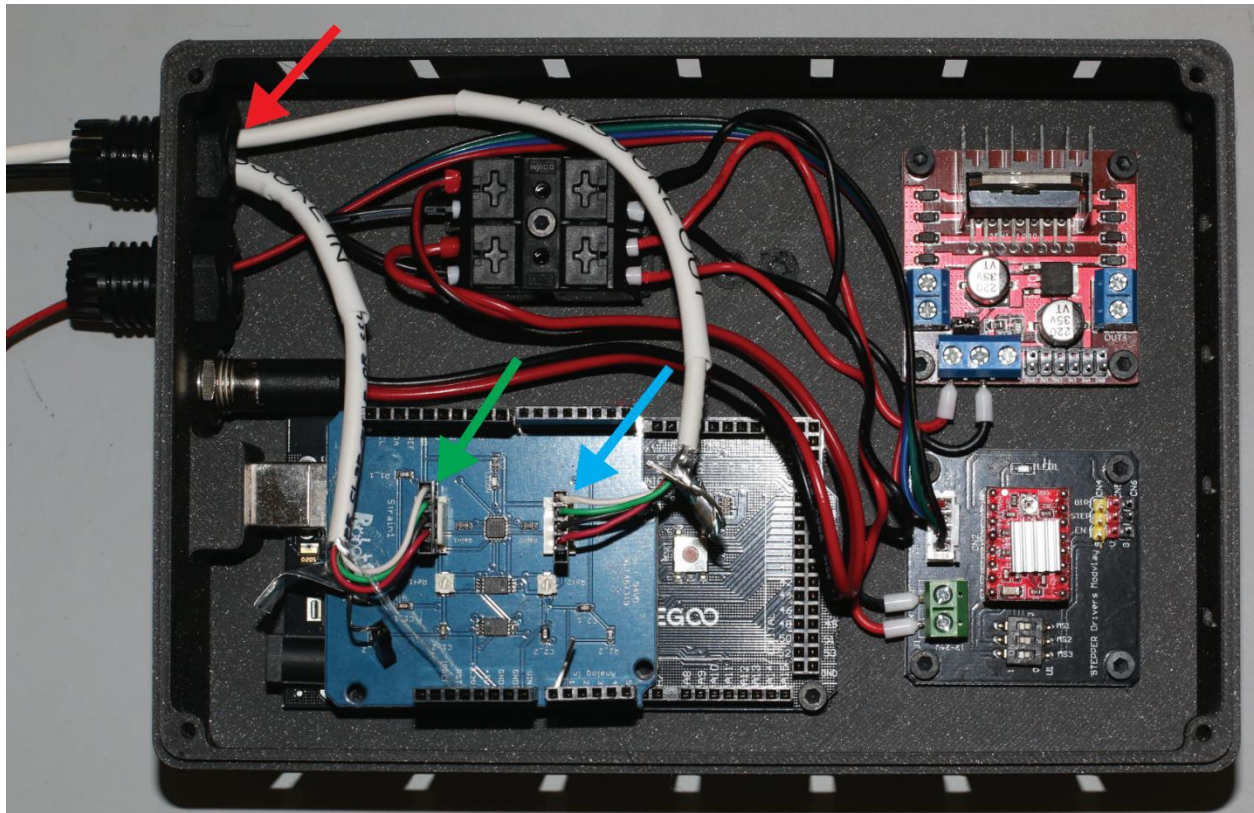


## Step 6F: Installing the Stepper Motor Cable



Secure a plastic submersible cord grip to the housing (red arrow). Insert the stepper motor cable into the stepper motor driver (blue arrow), and thread through the plastic cord grip and outside of the housing.

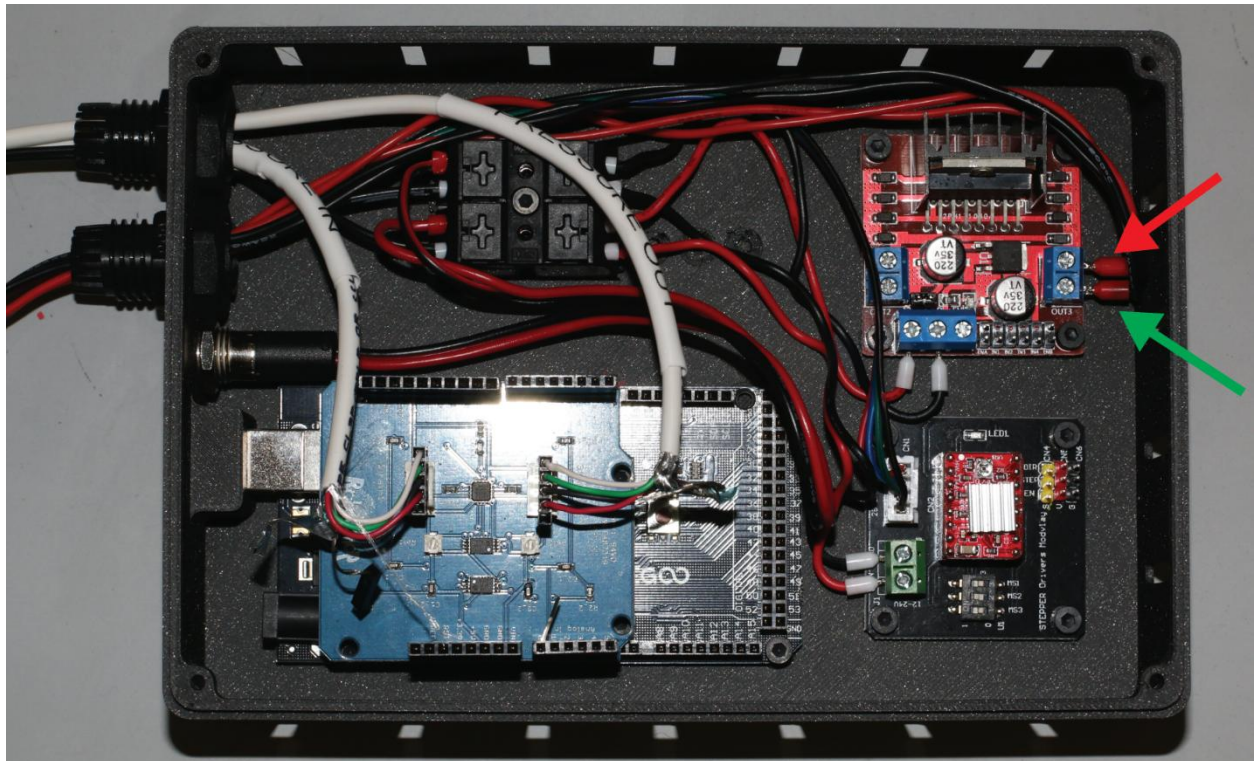
## Step 6G: Wiring the Wheatstone Shield



Insert the second plastic submersible cord grip into the housing. Thread both sets of 4-pin Dupont wires through the plastic cord grip and connect to the Wheatstone shield. We labeled these “PRESSURE IN” (green arrow) and “PRESSURE OUT” (blue arrow), though their placement on the shield is interchangeable. Connect each of these to its respective pressure sensor.

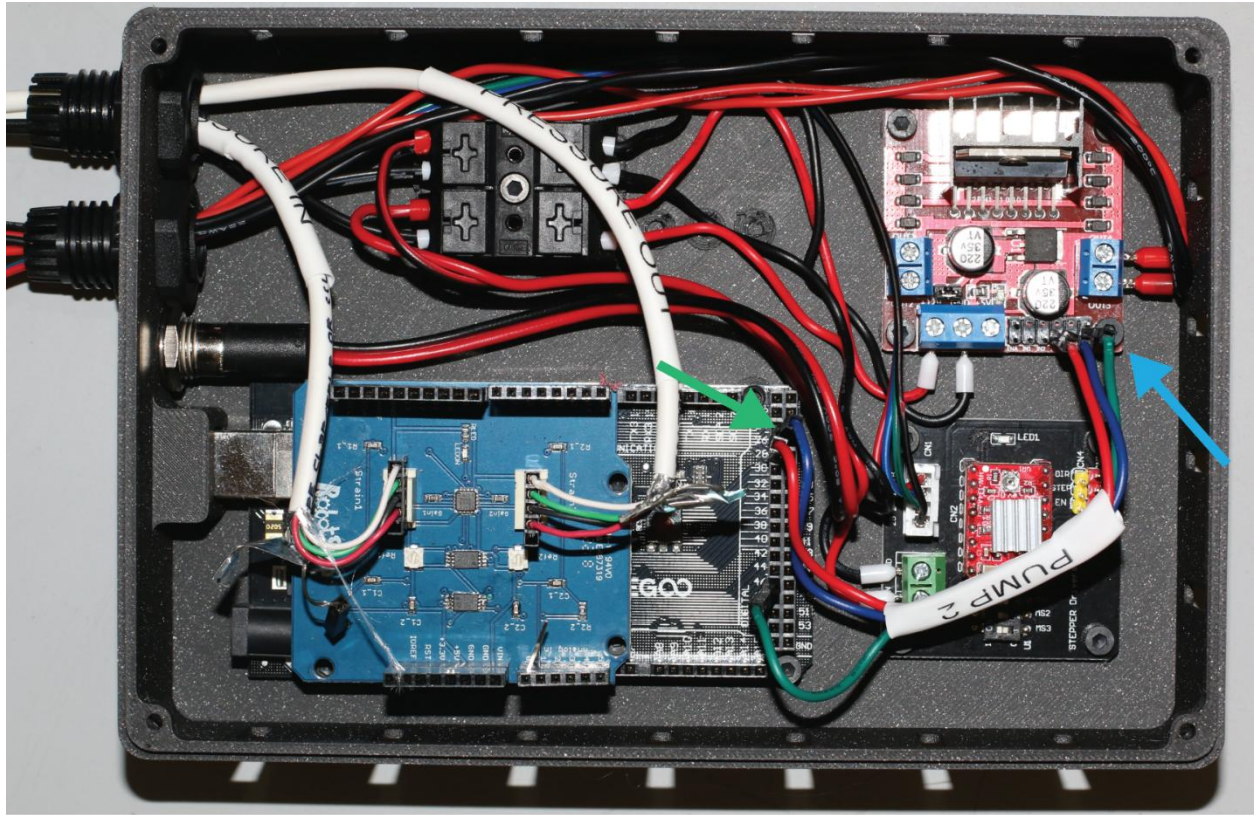


## Step 6H: Powering the Peristaltic Pumps



Each peristaltic pump has two metal terminals: one for a positive lead, one for a negative lead. To power the pumps at a reasonable distance from the electronics box, soldering leads with a relatively long length of wire is required. Prepare four leads by isolating four segments of 20 AWG wire, stripping a segment on one side of each wire, and twisting the loose copper ends of each wire into a rigid form. Wrap the end of one lead around a terminal of the first peristaltic pump and secure using tin solder. Repeat for the other terminal and the second pump. Wire spade connectors can be used for this step as opposed to soldering, depending on personal preference. Optionally, cover the solder-prong connection at each terminal with heat shrink tubing or hot glue for additional tension relief and waterproofing. Grab the positive leads from both pumps, stripping additional plastic casing as necessary. Twist the loose copper ends of each lead together to form a singular rigid end. Feed this end into a 20 AWG ferrule terminal. Using a ferrule crimping tool, crimp the wire into the terminal to secure. Grab the negative leads from both pumps and repeat this process. Thread the positive crimped leads (red arrow) and negative crimped leads (green arrow) through the lower plastic cord grip and into the L298N motor driver.

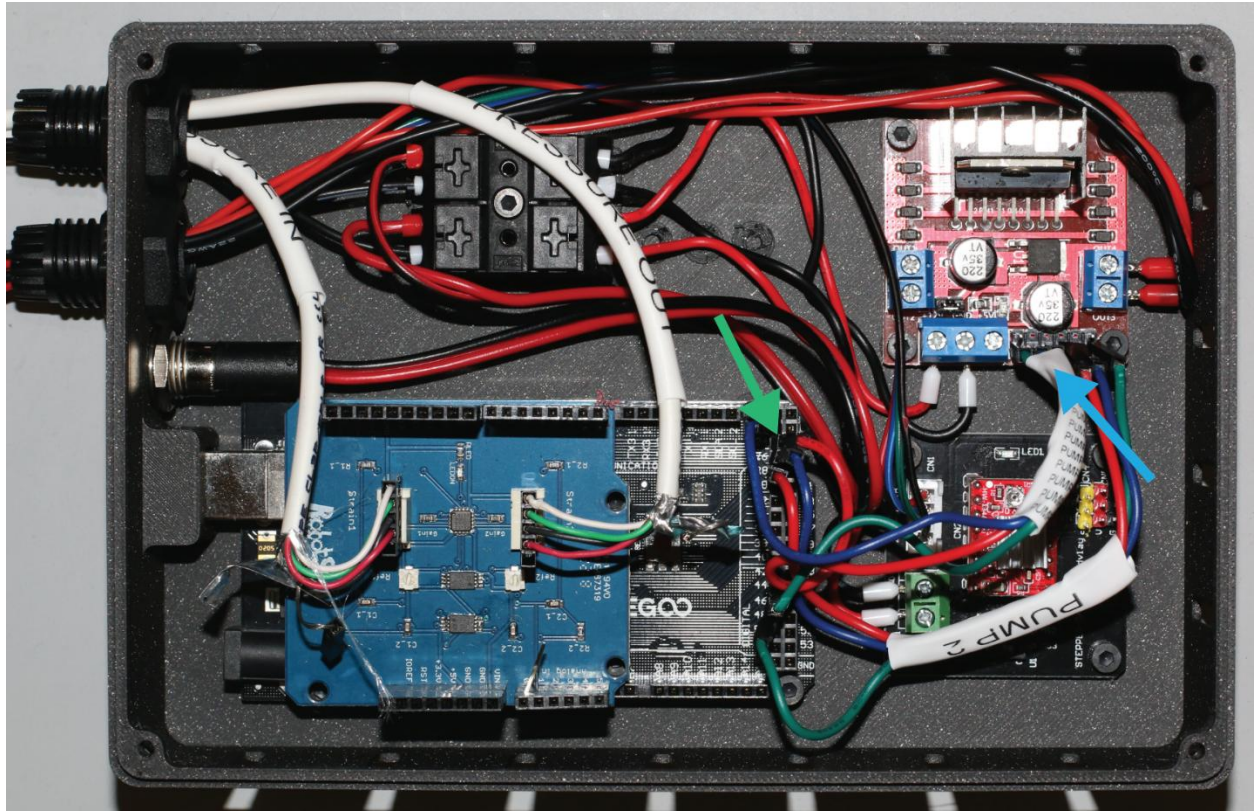
## Step 6I: Wiring the First Pump



Wire the first pump from the L298N motor driver (blue arrow) to the ELEGOO Mega (green arrow) per the wiring guide. Wire the L298N's ENB pin to the ELEGOO's pin 46. Wire the L298N's IN4 pin to the ELEGOO's pin 26. Wire the L298N's IN3 pin to the ELEGOO's pin 28.

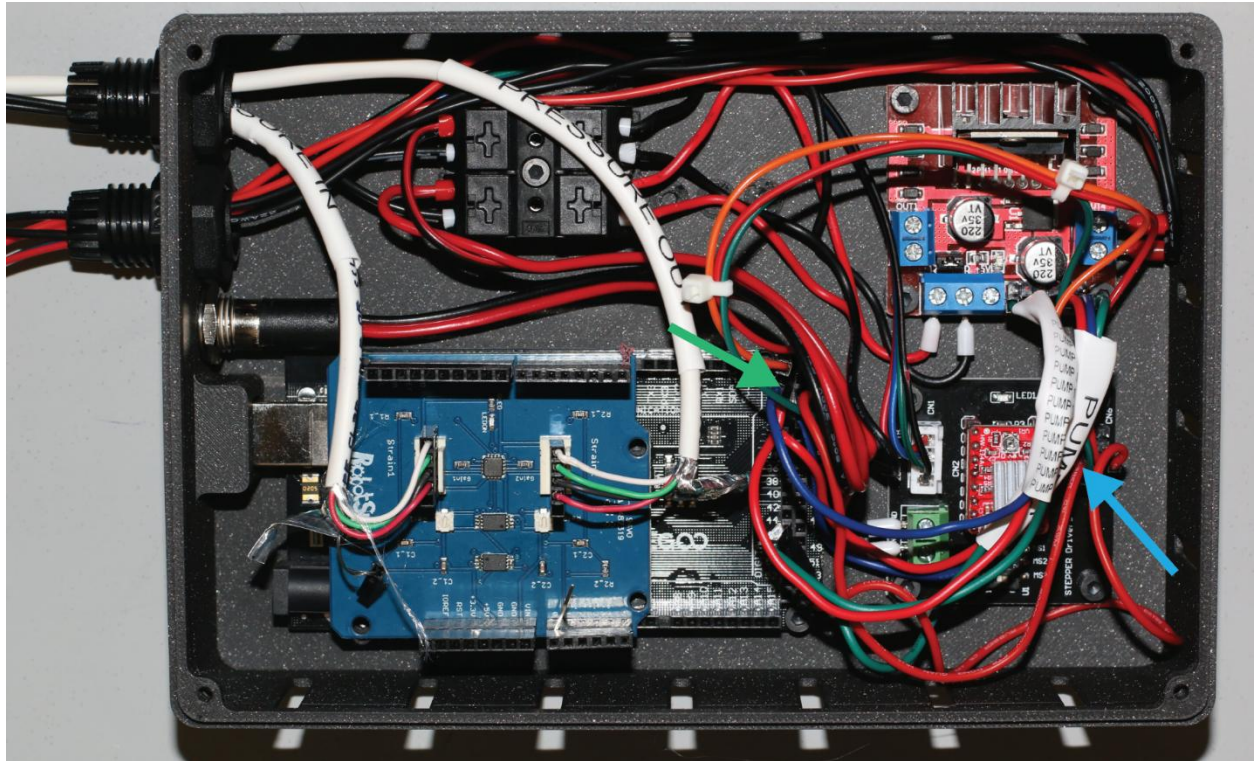


## Step 6J: Wiring the Second Pump



Wire the second pump from the L298N motor driver (blue arrow) to the ELEGOO Mega (green arrow) per the wiring guide. Wire the L298N's ENA pin to the ELEGOO's pin 44. Wire the L298N's IN1 pin to the ELEGOO's pin 22. Wire the L298N's IN2 pin to the ELEGOO's pin 24.

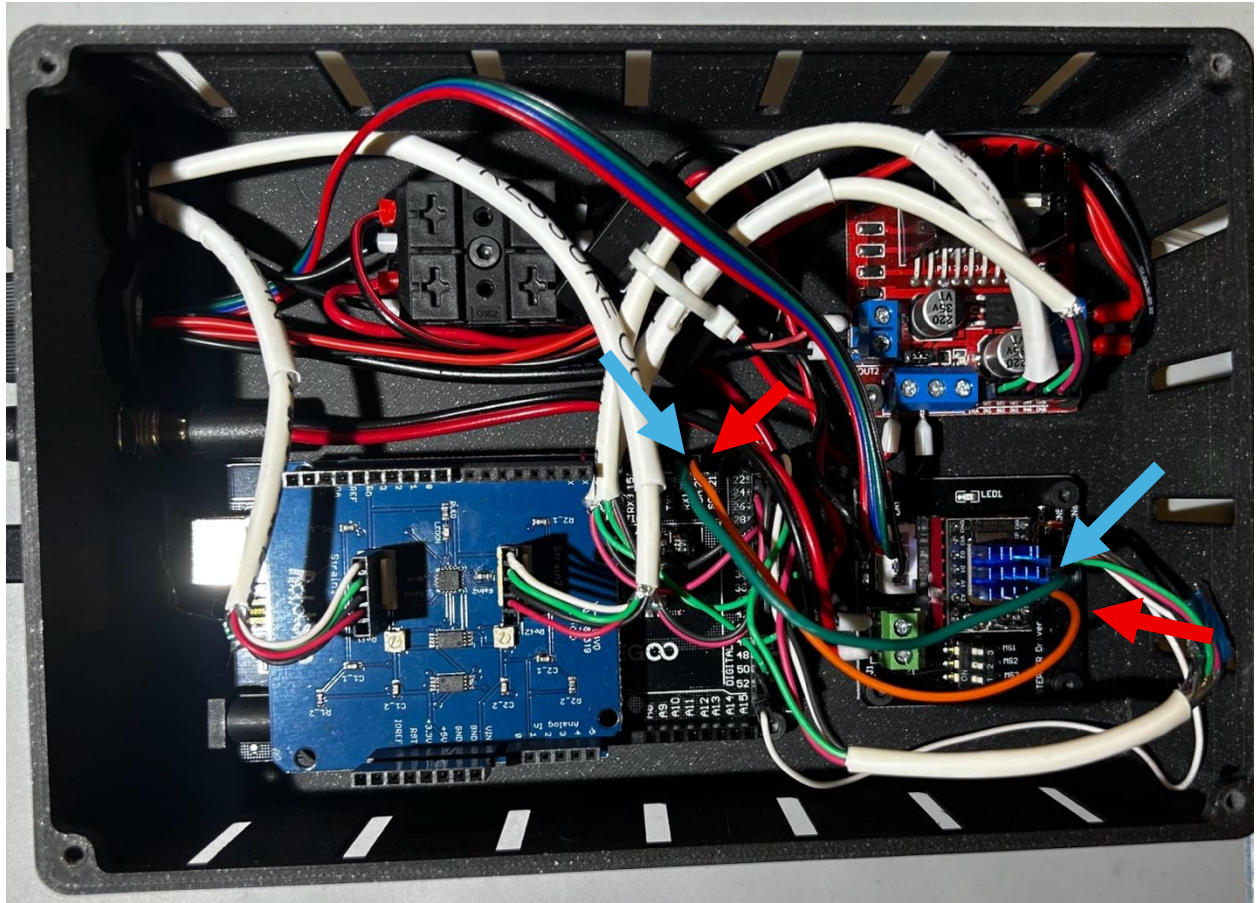
## Step 6K: Wiring the Second Pump



Wire the stepper motor driver (blue arrow) to the ELEGOO Mega per the wiring guide. Wire the motor driver's direction pin to the ELEGOO's pin 23. Wire the motor driver's step pin to the ELEGOO's pin 25. Wire the motor driver's en pin to the ELEGOO's pin 27.

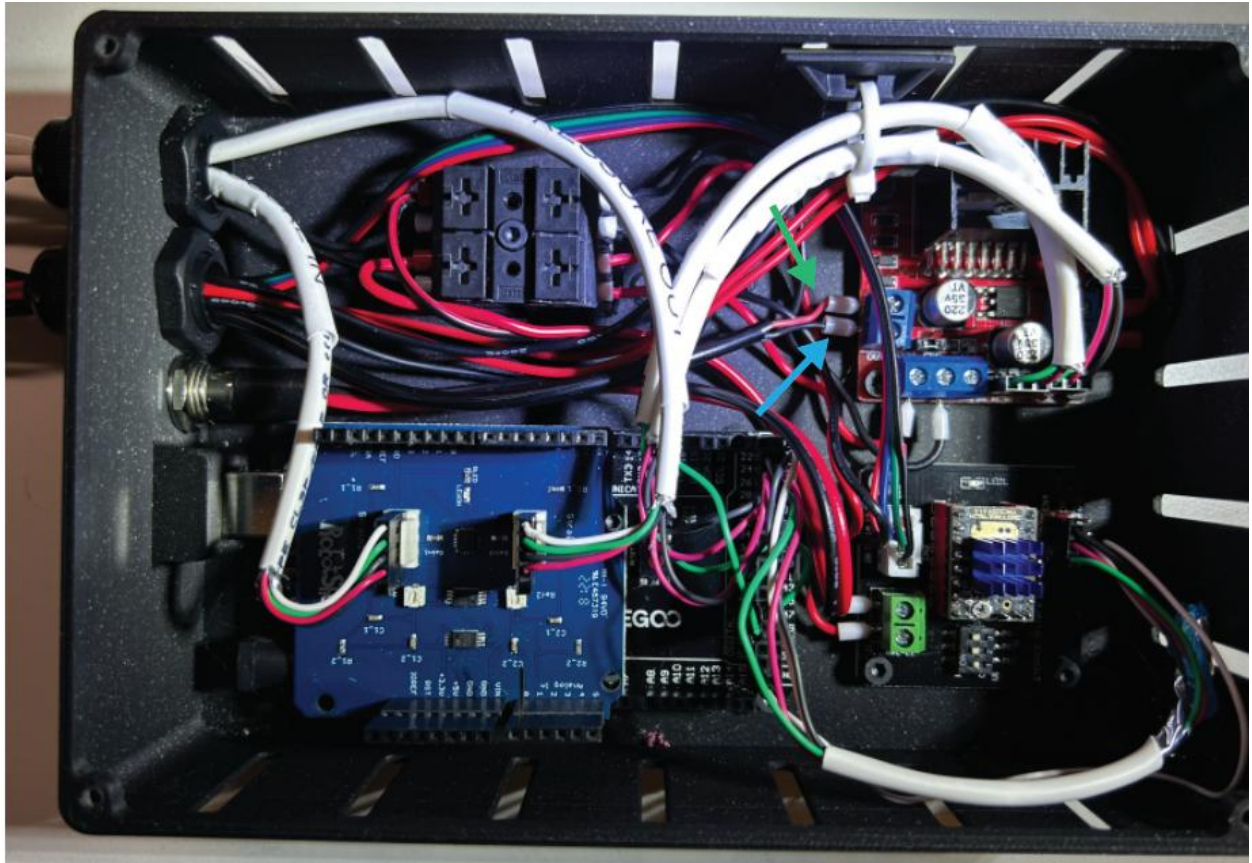


## Step 6L: Wiring TMC RX and TX pins



Wire the TMC RX (red arrow) and TX (blue arrow) pins to pins RX1pin19 and TX1pin18 on the ELGOO Mega Board

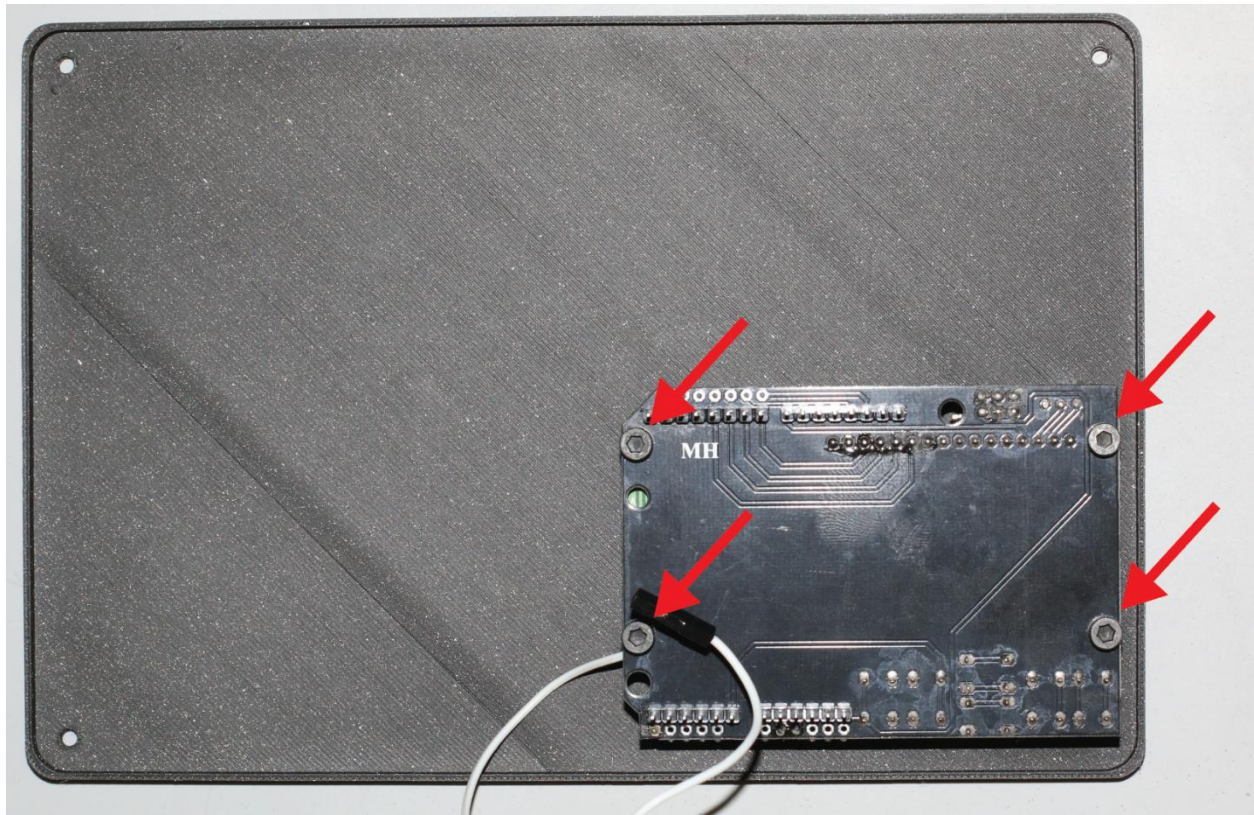
## Step 6M: Wiring the Aquarium Pump



Cut the AC adapter away from the aquarium pump. Peel the positive and negative lead away from one another and crimp them using the same technique as used for the peristaltic pumps. Place the positive lead in the OUT1 terminal of the L298N board (green arrow). Place the negative lead in the OUT2 terminal of the L298N board (blue arrow).

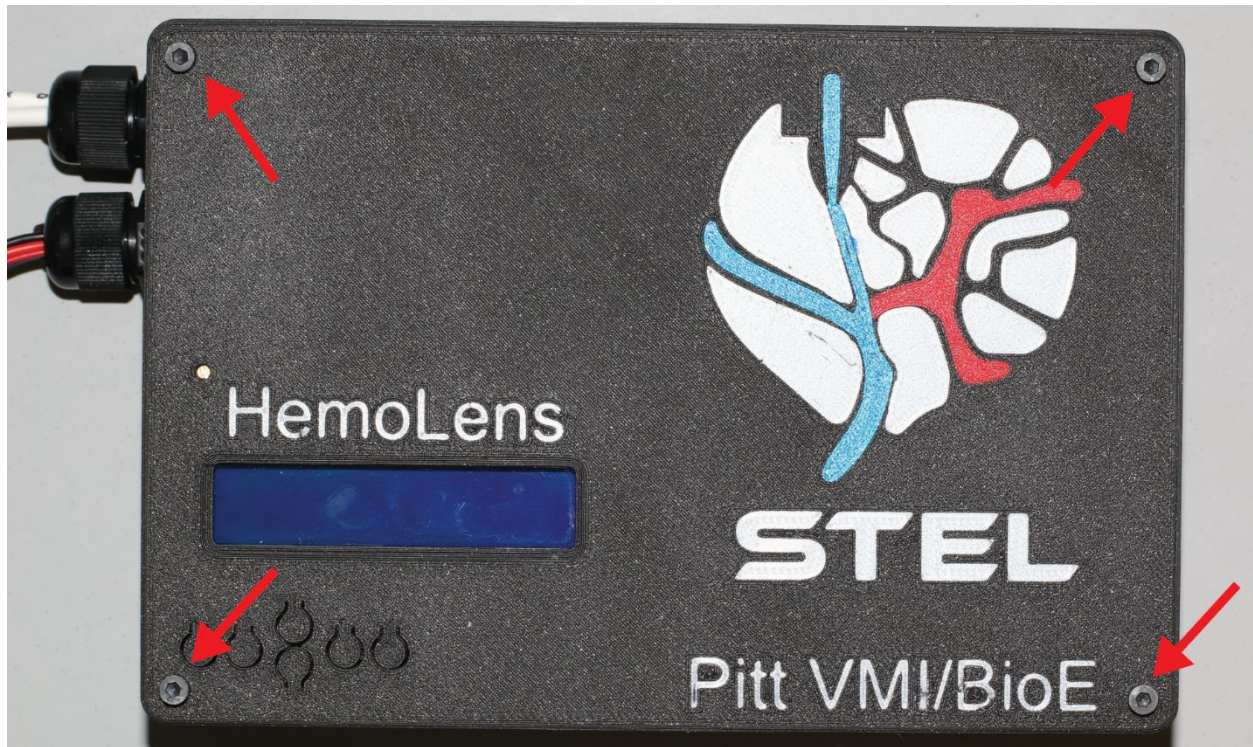


## Step 6N: Installing the LCD Shield



Press the LCD shield onto the Enclosure\_Lid. Secure by screwing four 4mm long M3 x 0.5 mm bolts (red arrows) through the shield and into the lid.

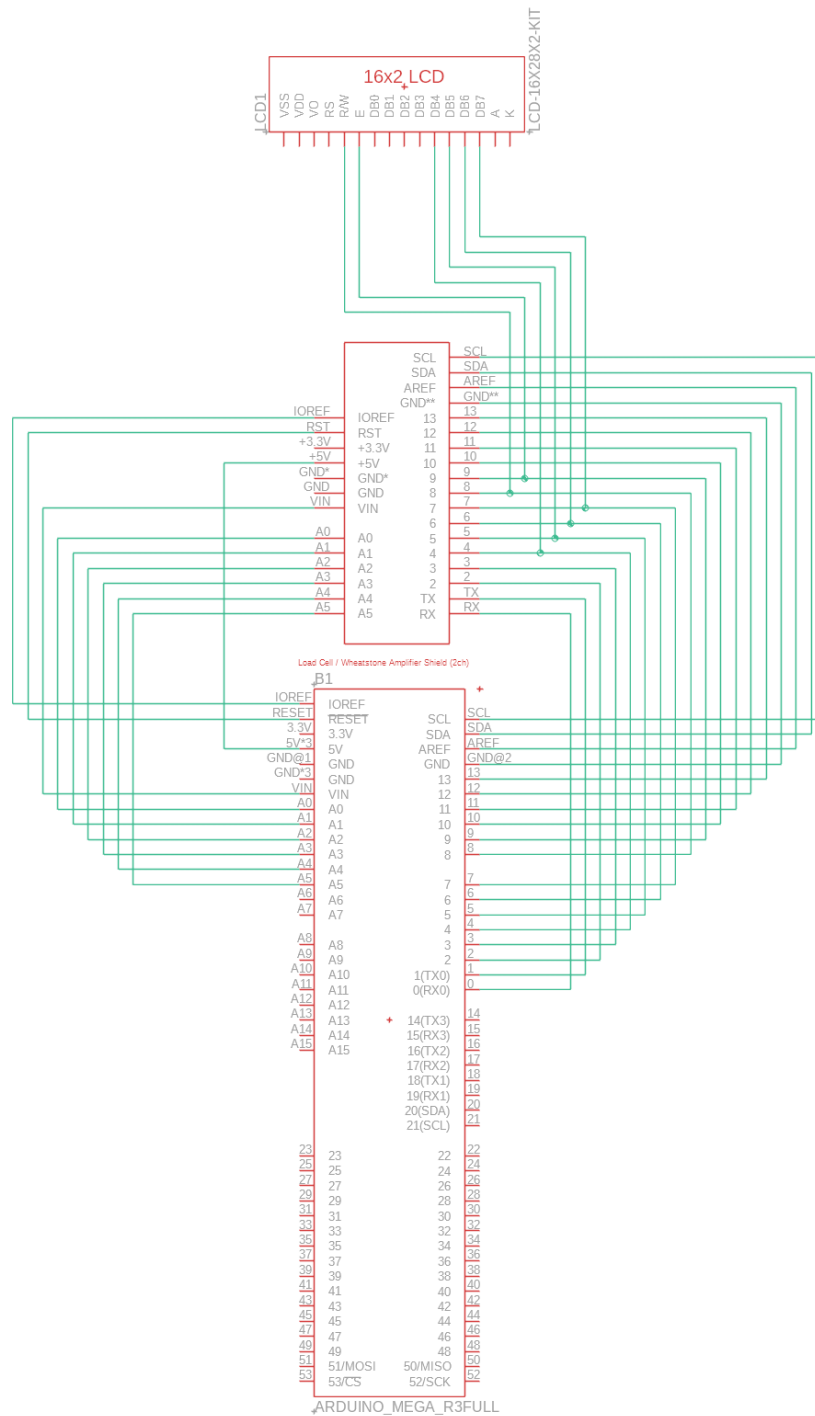
## Step 60: Mounting the Lid



Connect the LCD shield wire to the ELEGOO Mega as per the wiring diagram. Press the Enclosure\_Lid onto the base enclosure, ensuring the LCD pins connect with the Wheatstone shield. Connection between the Lid and Wheatstone bridge can be confirmed by viewing the terminals through the side of the enclosure box. Secure the enclosure lid by screwing four 6mm long M3 x 0.5 mm bolts (red arrows) through the enclosure lid and into the base. Connect the 12V DC power supply to the barrel jack when ready to power the electronics box. Assembly of HemoLens' electronics box is now complete. Assembly of HemoLens is now complete.

## Wiring Guide

The Wheatstone bridge and LCD screen are stacked on top of the ELG00 Mega board. Using passthrough breakout pins, attached the load cell to analog IOREF to A5 and Digital Pins: SCL- 0(RX0). The LCD screen is stacked on top of the Wheatstone bridge on pins 4-8. Image below is provided as a simple guide



# TMC2209 Stepper Motor Wiring Guide

