mini-Drops Build Manual

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6-21-2017

rev 1.0

BEFORE PROCEEDING:

Building this instrument requires a litany of skills (and ancillary equipment) such as: soldering (both through-hole and surface-mount components, stripping and cutting electrical wires, soldering to connection sockets, familiarity with a multi-meter, using shrink wrap and heat gun, cutting plastic with hobby knives, using and applying epoxy, in addition to a good deal of patience and care. If you are unsure about your abilities in these areas or if you do not think you can perform these tasks safely, do not attempt to build this instrument. Please contact someone who can perform these tasks or teach you how to perform these tasks safely.

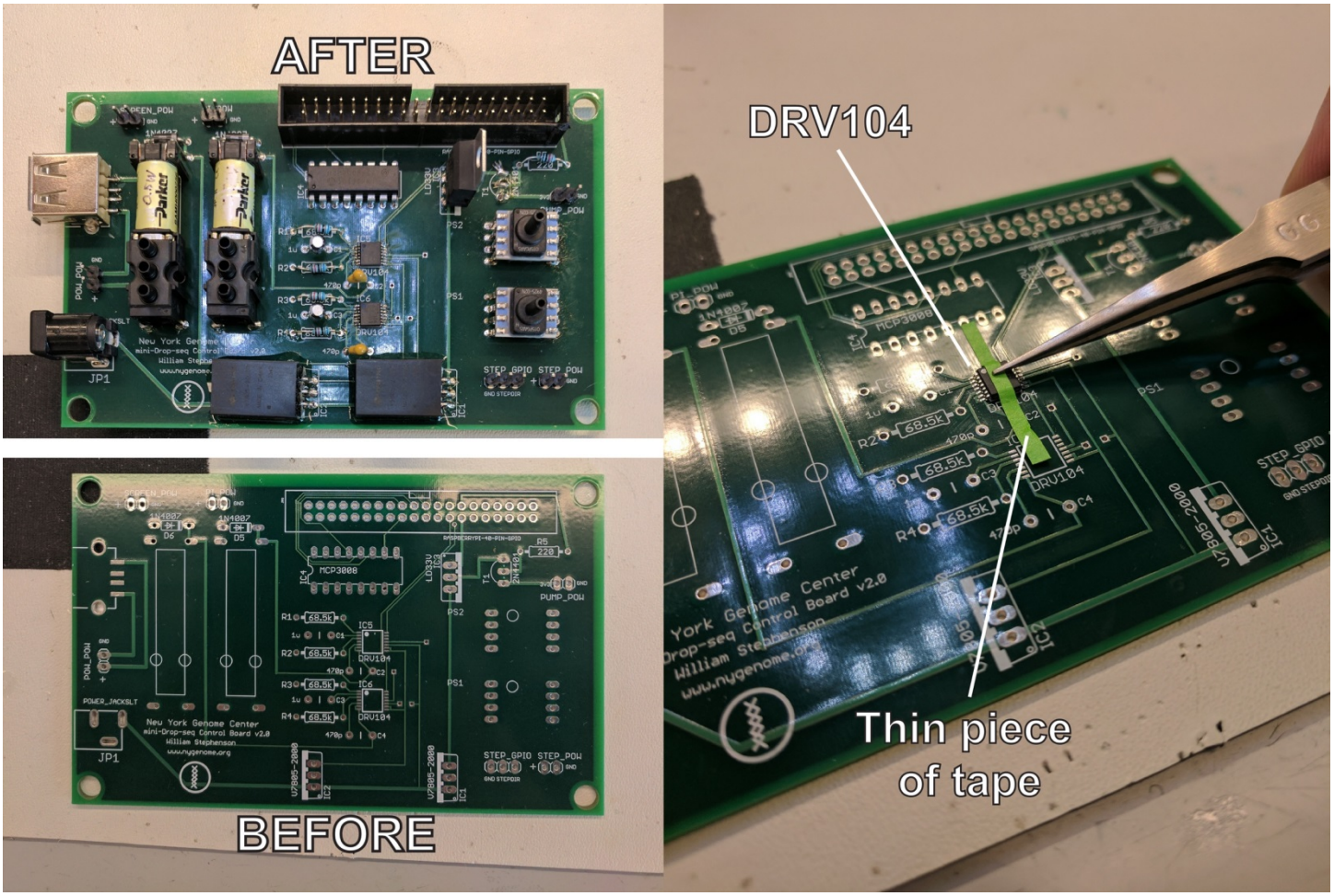
This build manual is a living document and any changes to the instrument will be reflected in this document to the best of my ability in a timely manner. That being said, this build manual may not perfectly be up to date with regards any updates/changes to the instrument. Please check any updates on the webpage that this document is found for any changes/modifications.

What you will need:

1. Tweezers
2. Screwdriver set
3. Soldering iron
4. Solder
5. Chem-wik (copper dewicker)
6. 3D printer – PLA plastic
7. Hobby knife
8. Tape
9. Scissors
10. Epoxy
11. Toothpicks
12. Electronic wires
13. Cable stripper (multi-size)
14. Wire clippers
15. Heat gun
16. Shrink wrap tubing
17. Break away male headers (Having both straight and 90 deg. is nice)
18. Connection housings (2, 3, 4-pin housings)
19. Connection sockets for connection housings (Mouser or Digikey, search TE connectivity, you may want a crimp tool as well, however I typically just use the needle nose pliers to crimp, but it takes some practice. Remember to solder the wire to the connection socket after crimping)
20. Multi-meter for verifying electrical connections
21. Needle nose pliers
22. Calipers or metric ruler
23. Hobby vise (Panavise)
24. Dremel with drill bit attachment or other small drill
25. All items from Bill of Materials

(Step 1) PCB soldering

Soldering the PCB is straightforward as all the components are labeled directly on the board. (Figure left) Start with soldering the DRV104 solenoid driver surface mount chip. This component is the only surface mount component on the PCB and thus requires a bit of extra skill and patience to solder. Begin by cutting a small piece of tape less than the width of the DRV104 chip but long enough to place over the top of the chip and keep it firmly attached to the board. (see figure right)



Ensure that the DRV104 is oriented correctly (Small dot in the upper left hand corner for IC5, IC6) and in line with the pins on both sides. With the tape still attached, carefully solder only one pin at one of the corners of the chip. Once one corner is soldered the chip can be gently rotated to align with the rest of the pins. Carefully solder the remaining pins, working from the corners inward. Ensure that the chip is in line and that you do not use excessive solder as this can bridge the pins and cause the board to malfunction.

HINT: If at any point too much solder is used and bridges multiple pins continue with soldering the other pins. After all pins have been soldered, use the Chem-wik to remove solder from any bridges that formed between pins. Gently lay the wik across the top of the pins and heat with the soldering iron to remove excess solder.

Verify that the pins are connected to the board using a multimeter with sound functionality. With the two leads of the multimeter place one on the soldered pin of the DRV104 and verify that each pin connects with the requisite component through hole on the circuit board. This is easily done while looking through an inspection microscope and listening for the “connection sound” from the multimeter.

Repeat this process for the other DRV104 chip (either at location IC5 or IC6) and verify connections using the multimeter.

Solder the remainder of the components in the orientations seen in the above figure (AFTER). Be careful with the following components:

1) JP2: RASPBERRYPI-40-PIN-GPIO:
    a. Make sure the notch is facing outwards from the board
2) IC4: MCP3008
    a. Make sure the notch face left
3) PS1 and PS2: Honeywell Pressure sensors
    a. Align the “nub” on the pressure sensor with the circle on the circuit board
4) D5 and D6: 1N4007:
    a. Align the stripe of the diode with the stripe as seen on the circuit board
5) IC1 and IC2:
    a. These components have right angle pins
    b. The “body” of the component should be to the left of the pins as seen in the figure (AFTER)
6) Solenoids:
    a. The solenoids have screw attachments that should be aligned with the circles seen on the board but will not be used.

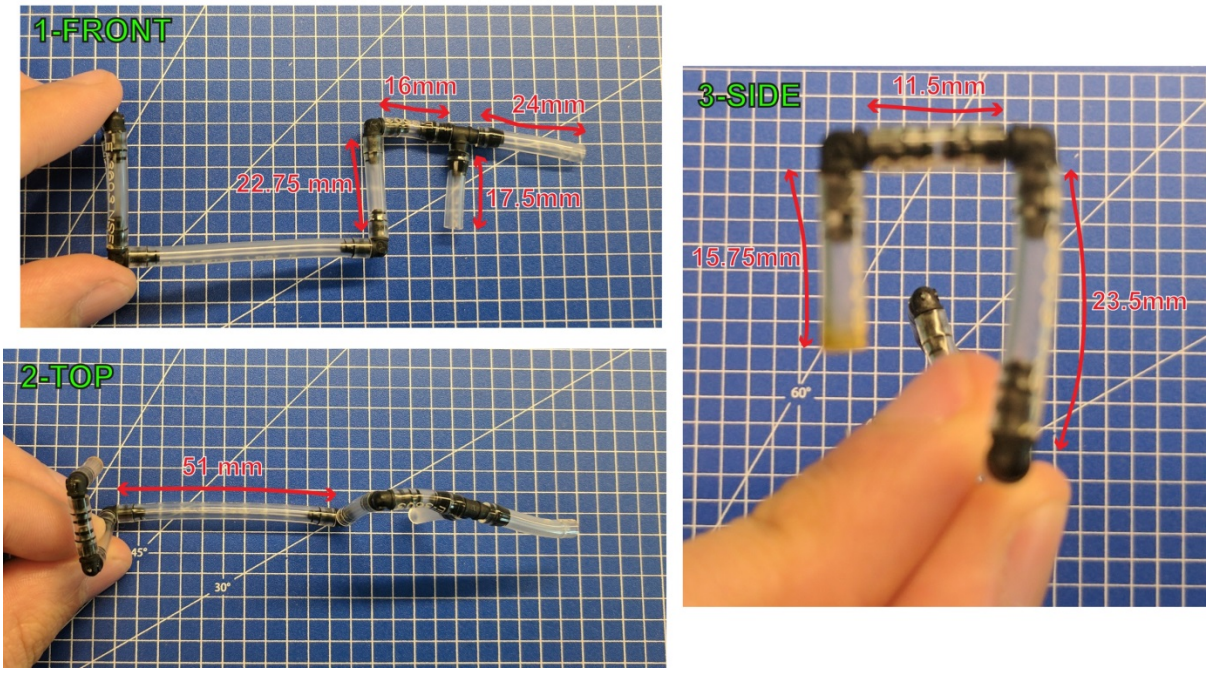
SCREEN_POW, PI_POW, PUMP_POW, STEP_GPIO, and STEP_POW provide connections to the touchscreen, raspberry pi, the micro air pump, the stepper motor controller, and the stepper motor power respectively. These can either be directly soldered to the component or header pins can be used. If using header pins you will need plastic connection housings (with 2 and 3 slots), connection sockets for 20-24 AWG wire and a crimper tool or pliers to crimp manually.

After soldering the PCB, connect up the board to the table top power supply (part no. 27 BOM). Using the multi-meter make sure you read ~5V across the + and GND pins for both PI_POW and SCREEN_POW.

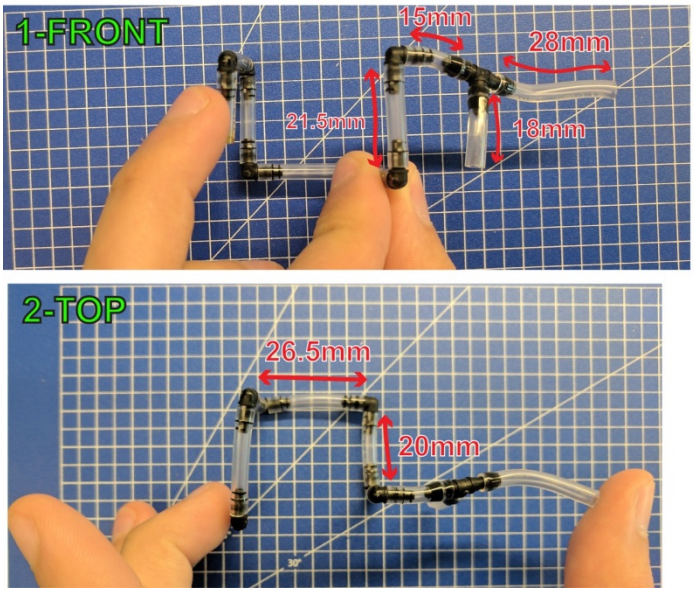
(Step 2) Pressure lines and attachment to PCB

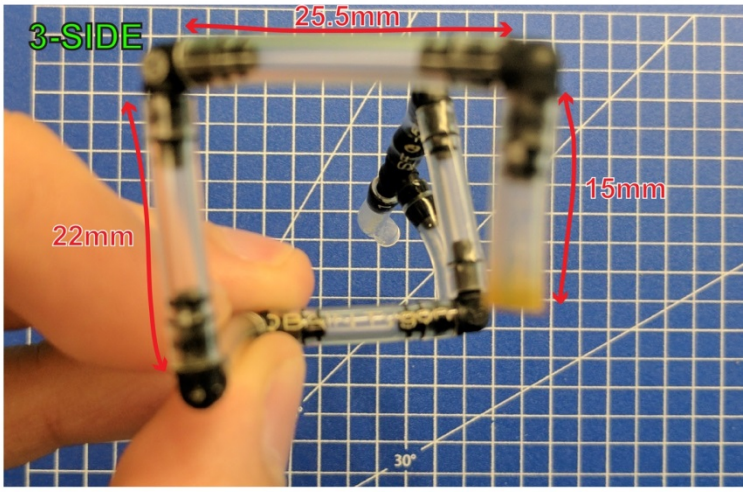
For this step you will need part No.’s 43 (Tee tube fitting), 44 (elbow tube fitting), and 46 (Tygon tubing) along with a hobby knife or razor blade to cut the tubing. First construct the two pressure lines to the specifications displayed in the following figures:

Pneumatic Line 1 (connection from PS1 / left solenoid)



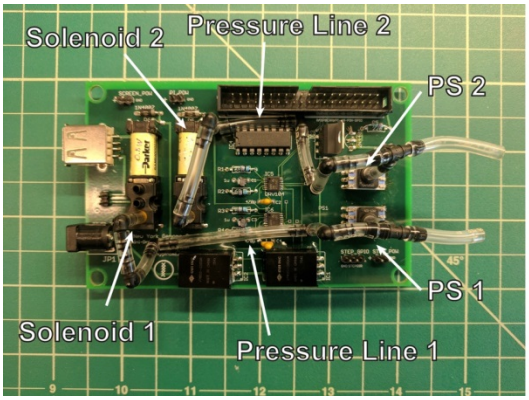
Pneumatic Line 2 (connection from PS2 / right solenoid)

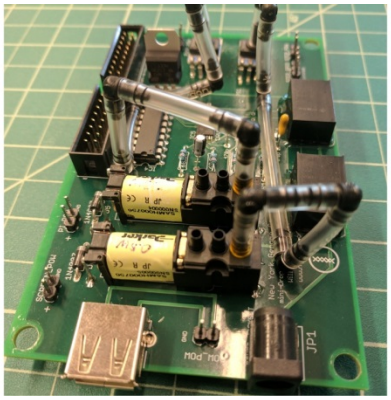


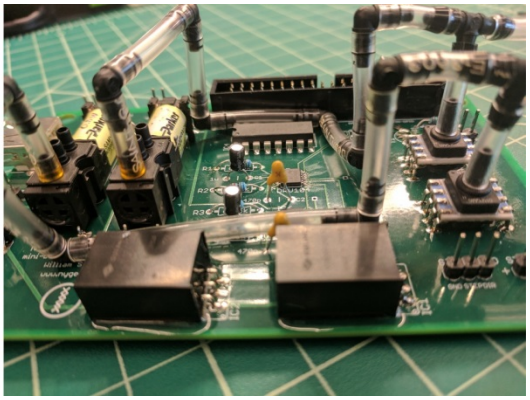


The distance measured if the actual length of tubing that needs to be cut, and the tubing should fit snugly and entirely over the barbs of the elbow and tee fittings as seen in the figures. If they are not fully over the barb the tubing can come loose and you will have loss of pressure, leading to instrument/experiment malfunction. These two pneumatic/pressure lines connect the regulators to the pressure sensors and eventually to the solenoid valves. Pneumatic line 1 connects pressure sensor 1 to solenoid 1. Pneumatic line 2 connects pressure sensor 2 to solenoid 2. Ensure that the constructed pressure lines are free of any punctures or holes in the Tygon tubing.

Next take the constructed pressure lines and attach them to the completed circuit board as seen in the figure below:



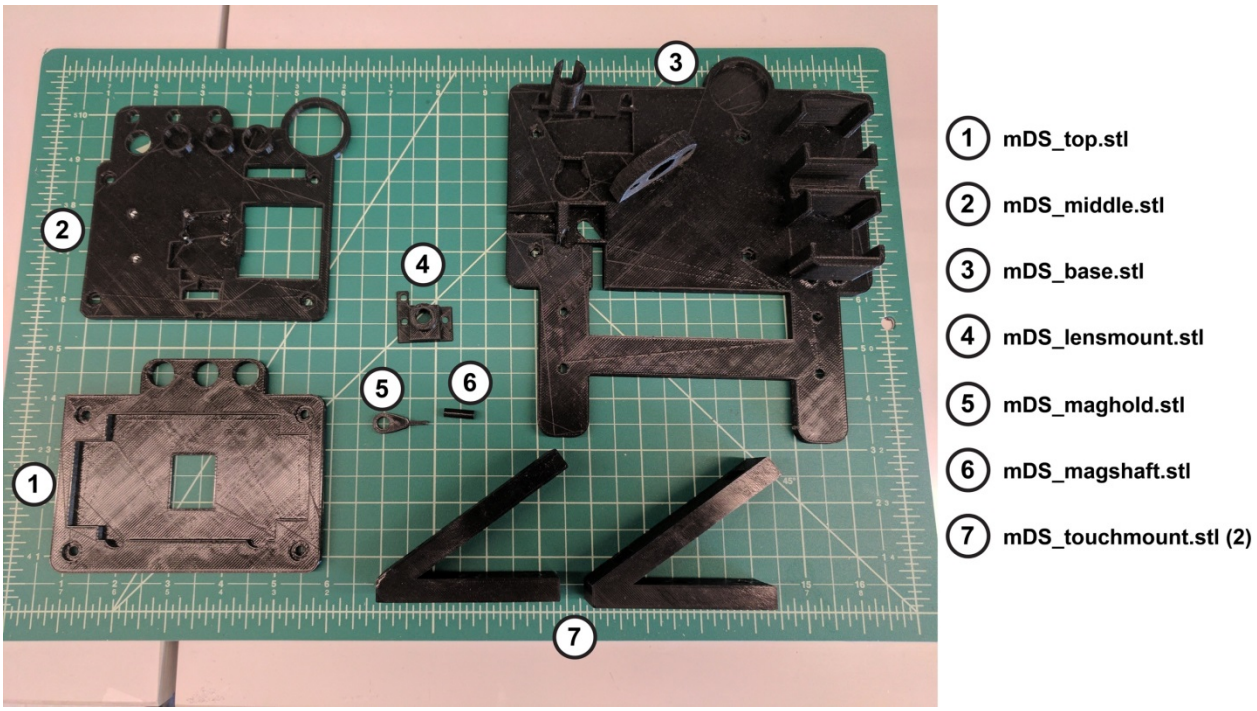




Both pneumatic/pressure lines have a tee junction which sits directly over the pressure sensors. The tubing should fit snugly over both the pressure sensor ports and the solenoid ports (most “southern” ports when viewing the PCB as in the figure).

(Step 3) 3D printing

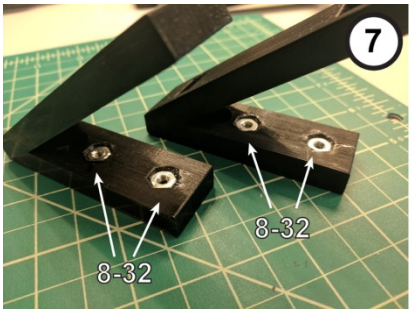
The following parts should be 3D printed:

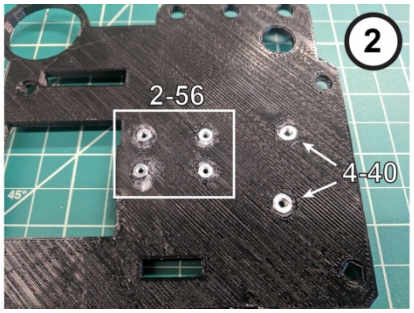


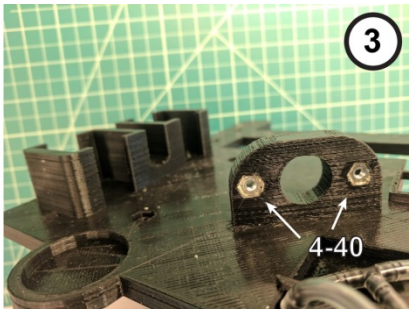
After printing, make sure to remove any support material or irregularities in the part due to the printing process. For example, use a hobby knife to remove plastic from holes (which later will have screws/standoffs inserted in/through them).

(Step 4) Insetting nuts

Next, perform “insetting” of nuts into the following 3D printed parts. Nuts should be epoxied into the cleaned (free of excess plastic) slots so as to immobilize the nut after curing. Use caution and ensure that no epoxy is accidentally placed inside the threading of the nut.



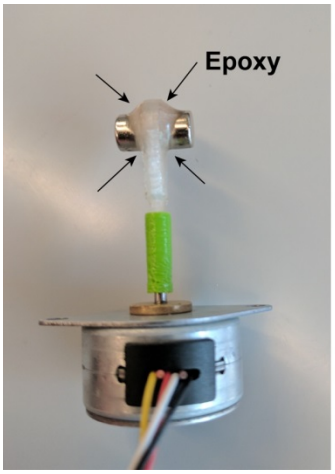


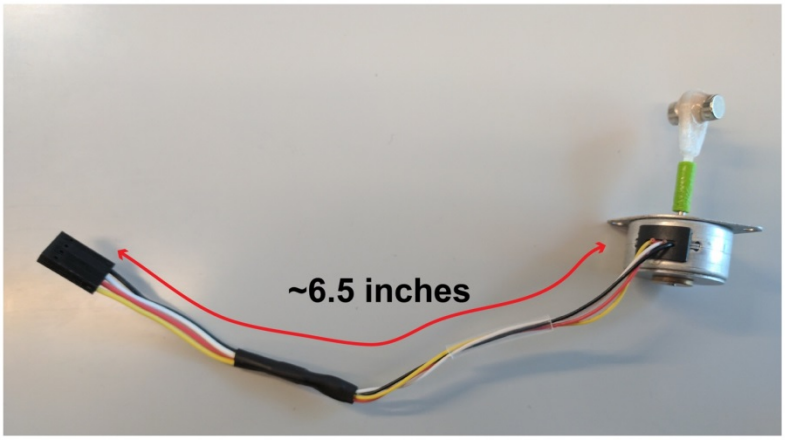


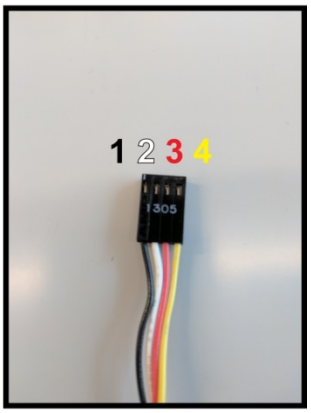
(Step 5) Assemble the stepper motor shaft

For this step you will need part no. 9 (stepper motor see BOM) and the 3D printed parts (5) and (6) along with the cylinder magnet part no. 29 (see BOM). First, using a hobby knife shave the inside hole of part (5) so as to accommodate the cylinder magnet without it being too loose. Next Shave the shaft of part (5) for easy insertion

into part (6). Additionally, use the hobby knife to shave the other hole of part (6) so that the part fits easily onto the shaft of the stepper motor. Once everything is fitted, you can start to epoxy the parts together (one at a time!) Start by applying epoxy to the magnet within the holder. Add epoxy all around the edges It is helpful to use a vice to hold the holder while applying the epoxy. Be careful around metals as the magnet may become unseated from the holder before the epoxy has had a chance to set. After this part has fully set (typically a few hours), epoxy the magnet in the holder to the 3d printed shaft (6). Let fully set. Next score the shaft of the stepper motor with a file to roughen the surface and promote adhesion of the epoxy to the metal. Apply epoxy to the stepper motor shaft and insert the completed magnet holder assembly (magnet, 3d printed part (5), 3d printed part (6) to the stepper motor) as seen below:

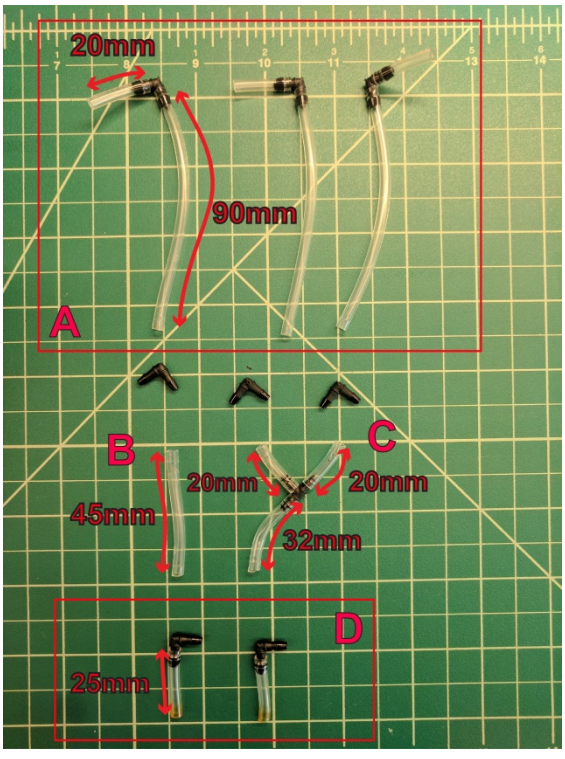






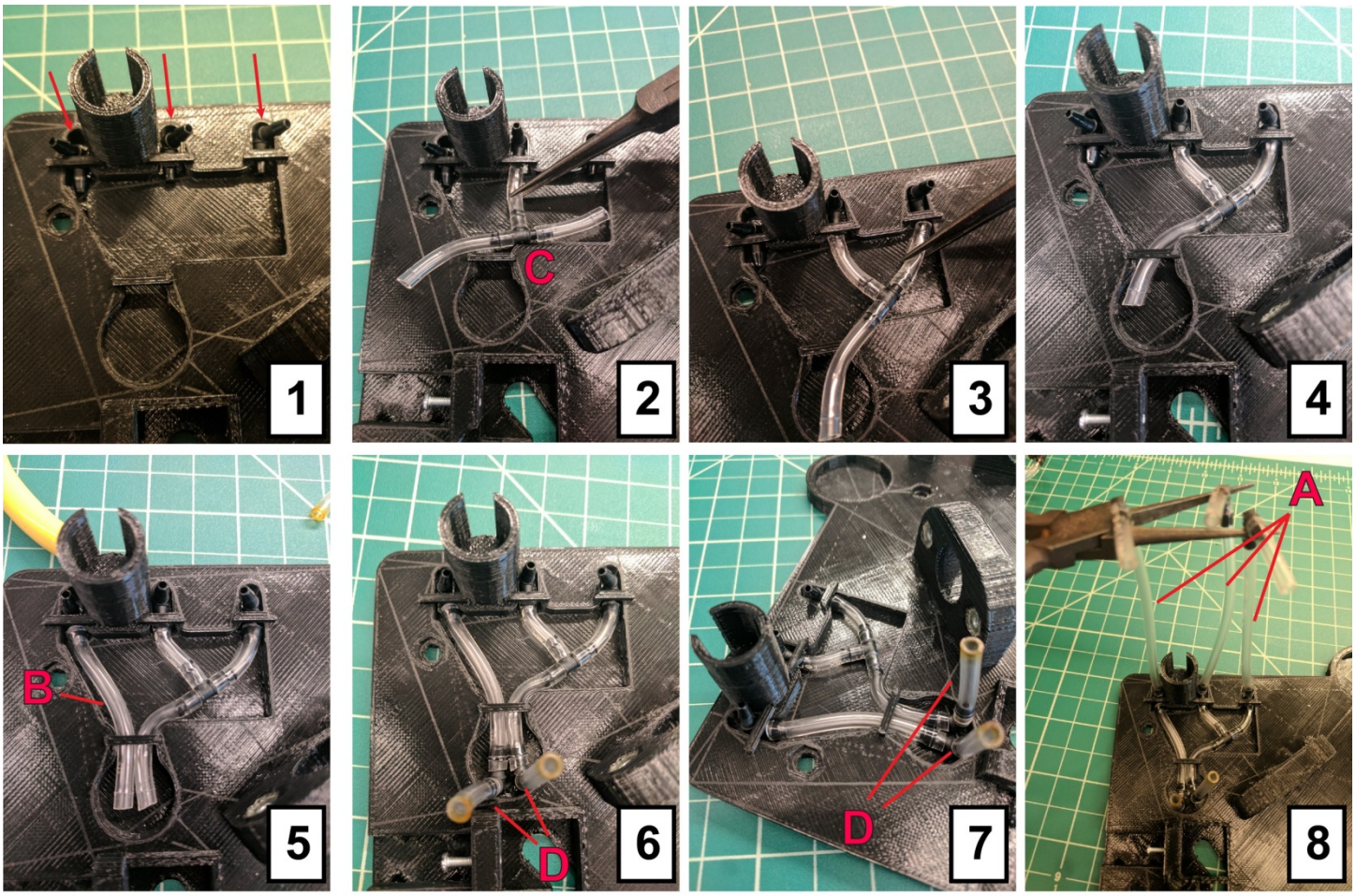
In addition, the stepper motor has 6 wires: Black, Brown, White, Red, Orange, and Yellow. Cut the Brown and orange wires while leaving the remaining wires intact. Extend the remaining wires using colored extension wire such that the overall length of the wires is ~ 6.5 inches. Crimp connection sockets to the wires and add them to a 4-pin housing with the following pin positions: 1- Black, 2- White, 3-Red, 4-Yellow.

(Step 6) Make base pneumatic tubing and affix to base



Generate the tubing assemblies seen to the left by cutting tubing with a razor blade or a hobby knife. Again, insure that tubing is free of holes/damage as this may adversely affect instrument performance. Pieces in red boxes are identical (for part A, three are needed, for part D, two are needed)

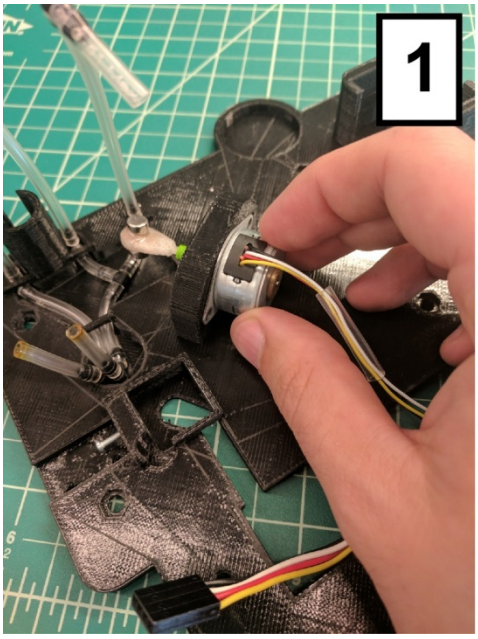
Now to add the tubing assemblies to the base of the instrument, start by placing three part no. 45's (elbow tube fitting - see BOM, and above figure) in the slots in the upper left portion of the base (panel 1 figure below). Next affix tubing assembly C to the elbow using needle nose pliers as seen in panel 2 and 3 below. Thread the free end of the tubing under the fixed spanner as seen in panel 4.

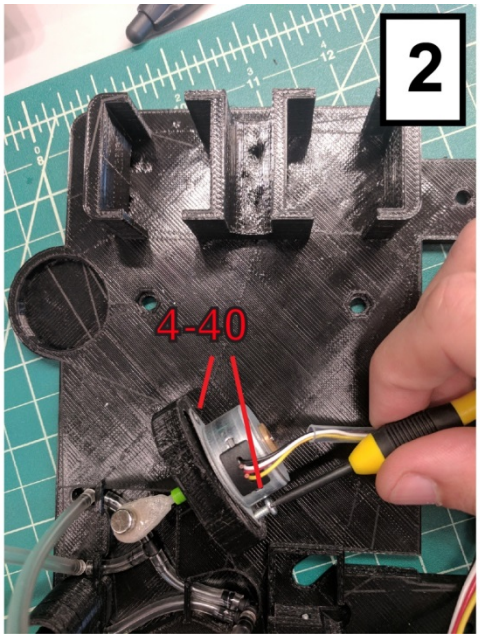


Next add tubing B to the left most elbow tube fitting as seen in panel 5. Ensure that the tubing is completely over the barbs on all fittings! Add the 2x of tubing D to the free ends of the tubing assemblies as seen in panel 6 and 7. Finally add tubing assemblies A (3x) to the free ports of the elbow fittings at the periphery of the instrument as seen in panel 8.

(Step 7) Affix the stepper motor stirrer to the base

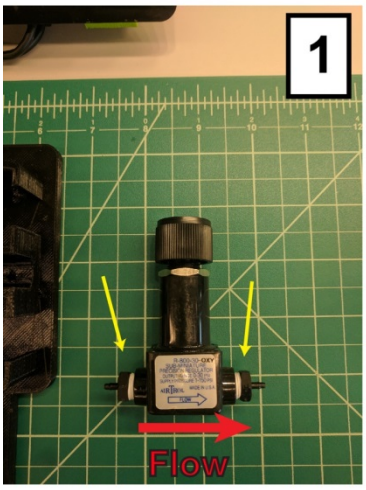
Place the stepper motor (with magnet shaft assembly) in the motor mount of the base as seen in panel 1 below. The wires should be facing UP. Next add two 4-40 screws and tighten to secure the stepper motor stirrer as see in panel 2 and 3.

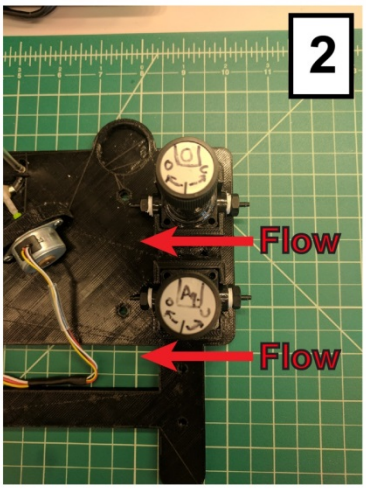


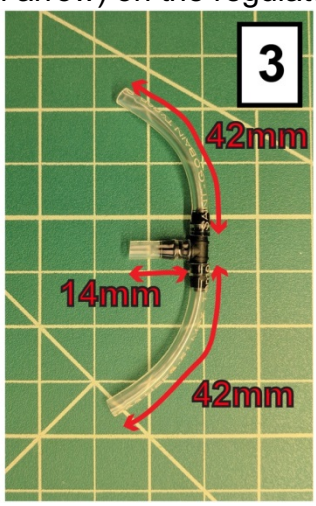


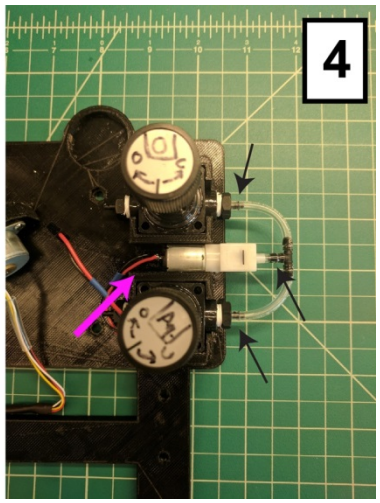
(Step 8) Add the pump and regulators to the base

First add the thread to barb adapters (part no. 43 BOM) to the regulators (part no. 7 BOM) using a bit of plumbers tape (nylon tape) to seal the thread (panel 1 below). Your part may be a different color than the one in the images below, as long as there is a tight seal between the tubing and the barbed adaptor there is no reason to worry) Do not overtighten the adapters as the regulator housing is plastic and can break with overtightening. Place the regulators in the base with the flow directions pointing inwards towards the stepper motor stirrer (panel 2 below). Mark the regulator knobs with an “O” (Oil) for one and “Aq” (Aqueous) for the other. I have also found it helpful to denote which way is open (“o” with arrow and which way is closed “c” with arrow) on the regulator knobs.





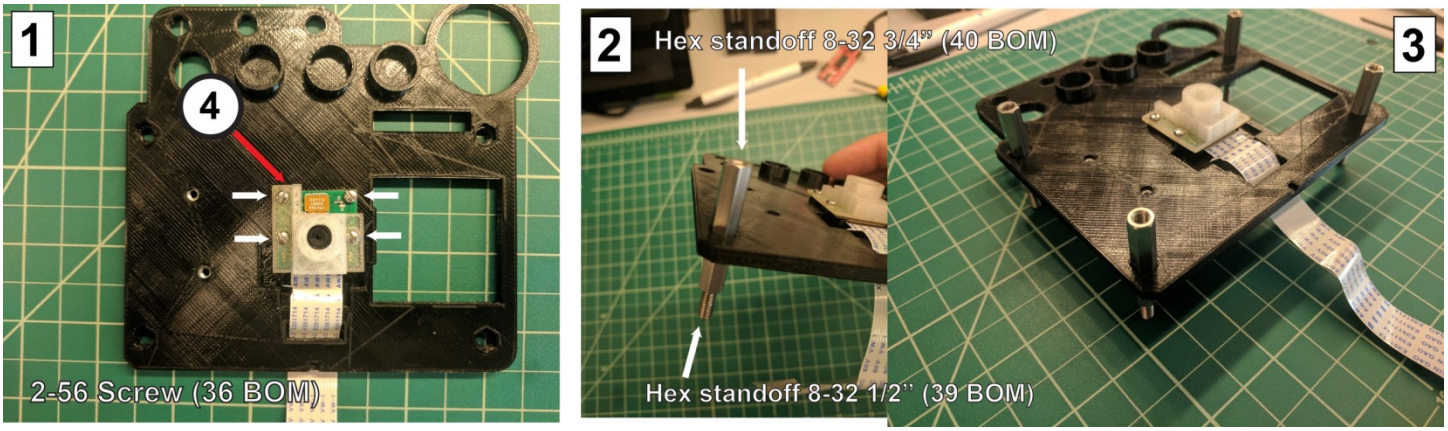




Next generate the tubing assembly seen in panel 3 using a tee tube fitting (part no. 44 BOM) and the Tygon tubing. Finally, solder positive and negative connections to the micro air pump (part no. 8 BOM) (pink arrow panel 4) and place the end leads into a 2-pin housing with connection socket. The wires should be at least 100mm long but less than 125mm (alternatively the end leads could be directly soldered into the PCB) Place the pump in the base and connect the tubing assembly from panel 3 to the pump and regulators as seen in panel 4 above.

(Step 9) Attach camera and standoffs to middle level

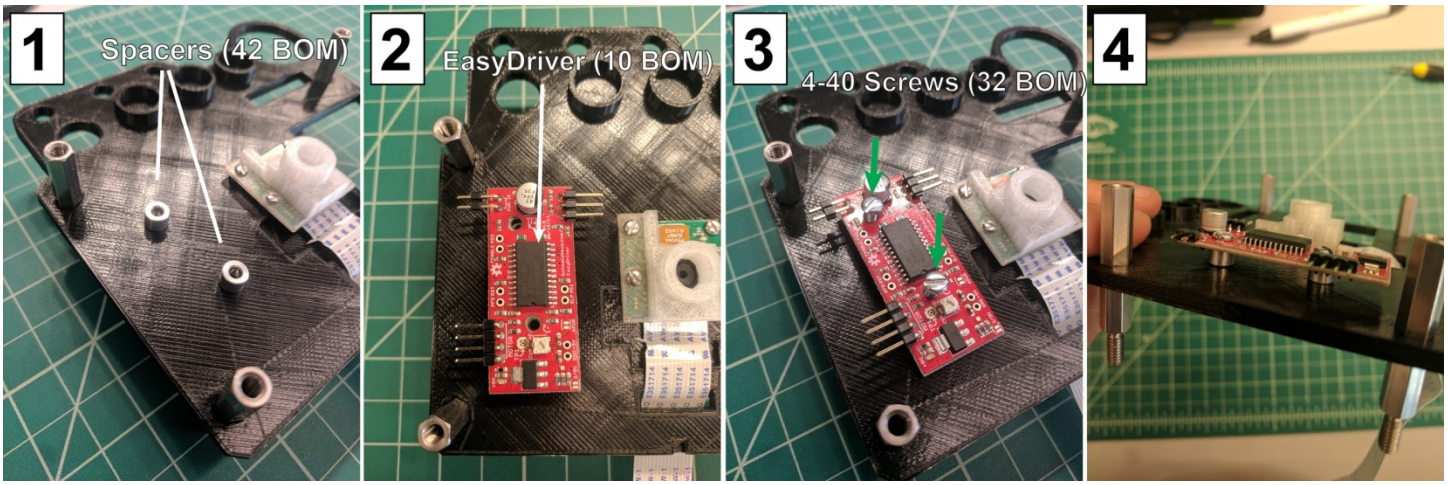
Place 3D printed part (4) over the top of the camera and attach to the platform (3D printed part (2)) using 4 2-56 screws. Thread the camera ribbon cable through the small slot as seen in panel 1 of figure below:



Attach hex standoffs (40 BOM and 39 BOM) to both sides of the platform as seen in panel 2. The top standoff is part 40 from the BOM (longer) and the lower standoff is part 39 BOM (shorter). It is imperative to get the correct standoffs placed on this platform as the distance of this platform from the top platform dictates the fixed focal point of the instrument (i.e. if you flip the hex standoffs the microfluidic chip will be out of focus). Place standoffs at all 4 corners of the middle platform as seen in panel 3. The top hex standoffs should fit within the recessed slots of the middle platform. When placed on a flat surface the assembly should be perfectly level.

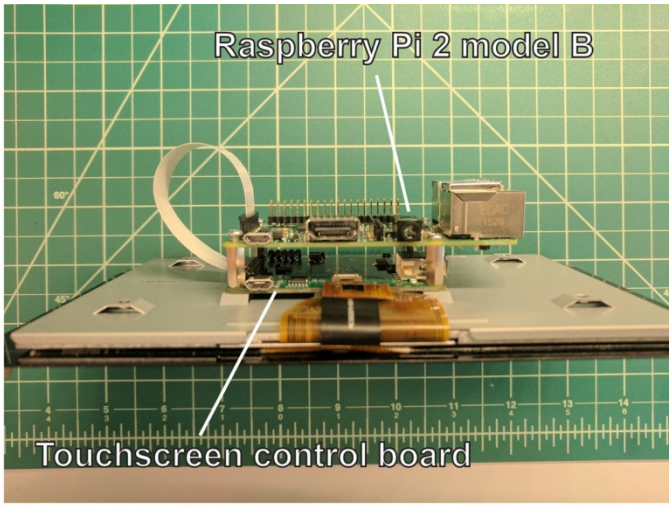
(Step 10) Attach the EasyDriver to the middle level

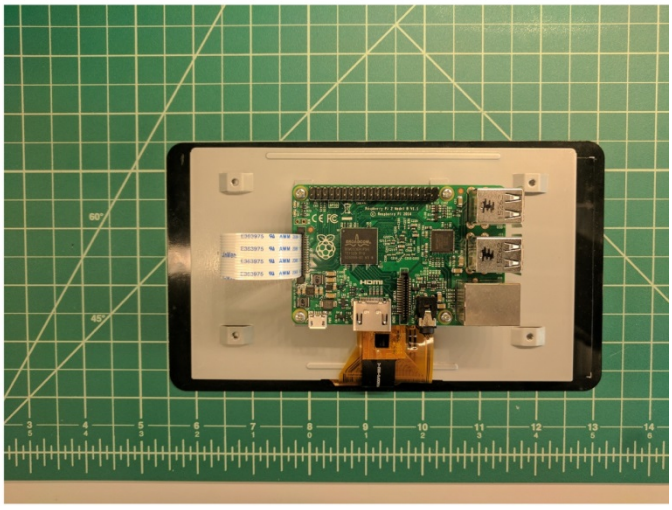
------First, ensure that the EasyDriver has been affixed with right angle male header pins as shown in panel 2 of the figure below. If directly soldering to the easy driver, please read the entire build manual to ensure correct lengths of wires needed.------ Place two spacers (part 42 BOM) above the holes adjacent to the camera that was just mounted as seen in panel 1 of the figure below. Next align and place the EasyDriver stepper motor controller over the spacers (panel 2). Using two 4-40 screws (32 BOM) attach the EasyDriver to the middle level platform. The assembly should look like panel 4 when you are finished.



(Step 11) Assemble the raspberry pi and touchscreen

Follow the instructions supplied with the touchscreen to assemble the touchscreen/raspberry pi combo. Do not use jumpers to power the pi from the control board, we will be generating power cables at a later point. Ensure that the pi is oriented as seen in the figure below. Ensure that the cable from the touchscreen control board to the raspberry pi is oriented correctly. (If nothing shows up on the touchscreen and the raspberry pi shows power, this can often mean an incorrect connection via the monitor cable).

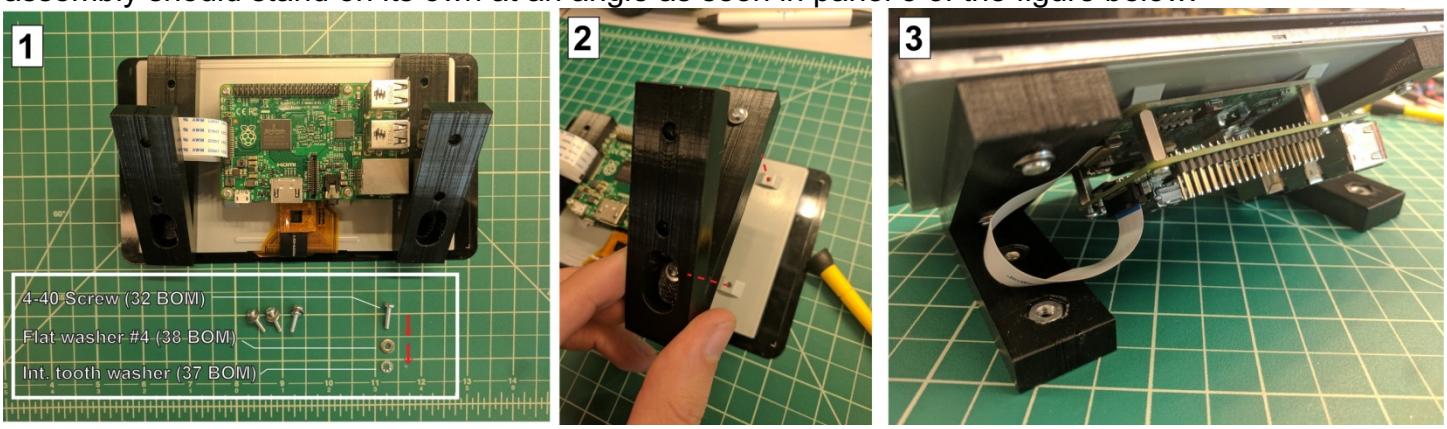




(Step 12) Attach the touchscreen mounts to the touchscreen/raspberry pi assembly

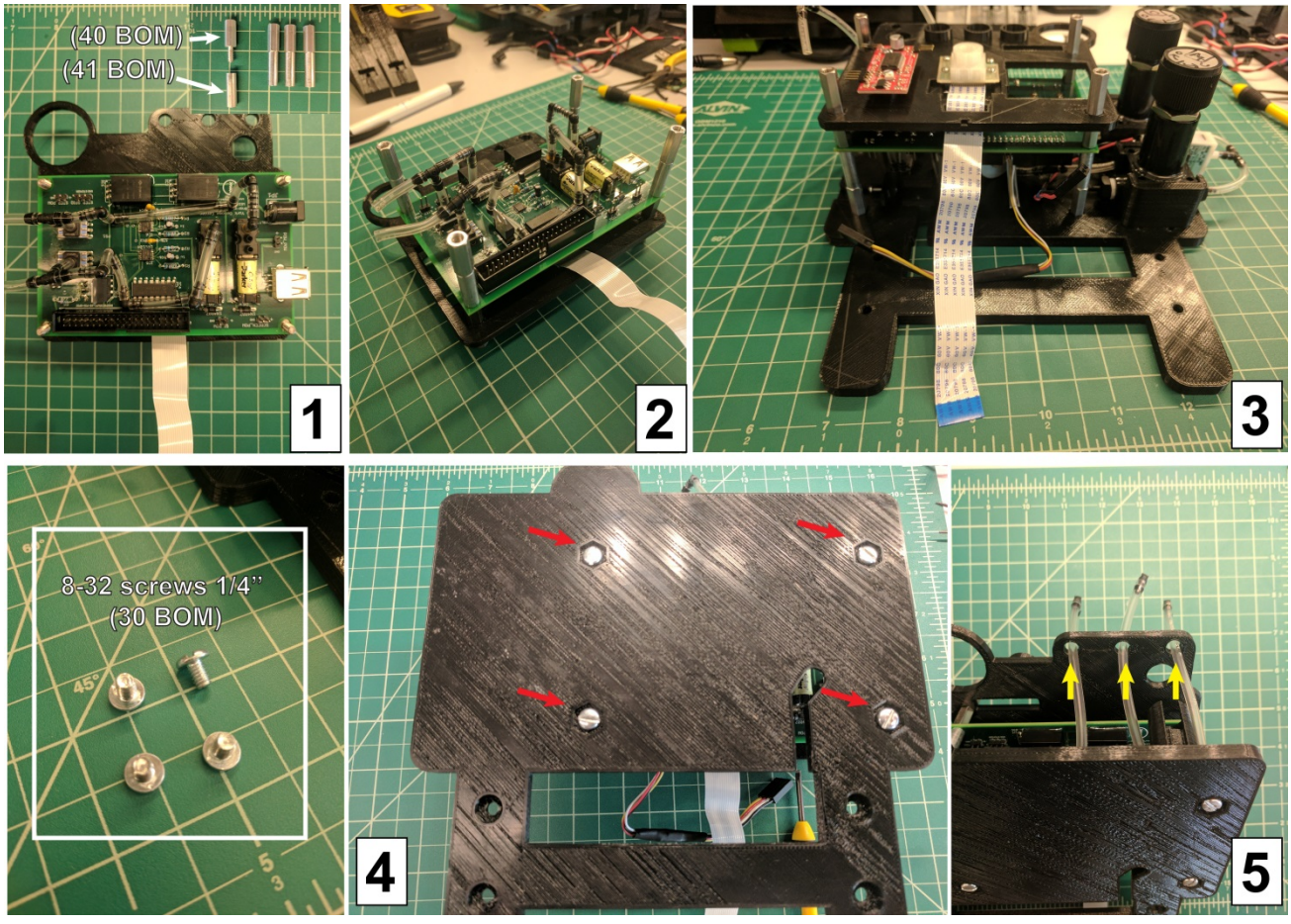
After assembling the touchscreen and raspberry pi, we will now add the mounting legs to facilitate attachment to the rest of the instrument. Using four 4-40 screws (32 BOM), flat washers (38 BOM) and teeth washers (37 BOM) screw the legs into the back of the touchscreen. Do not overtighten the screws. Screws should be inserted through the flat washer, then the teeth washer then screwed through the mounting legs into the back of the touchscreen (panel 2). Make sure to orient the legs such that the protruding portion is on the side of the touchscreen also containing the ribbon cable

attachment to the touchscreen control board. (see panel 1 and 2) After securing the legs, the assembly should stand on its own at an angle as seen in panel 3 of the figure below.



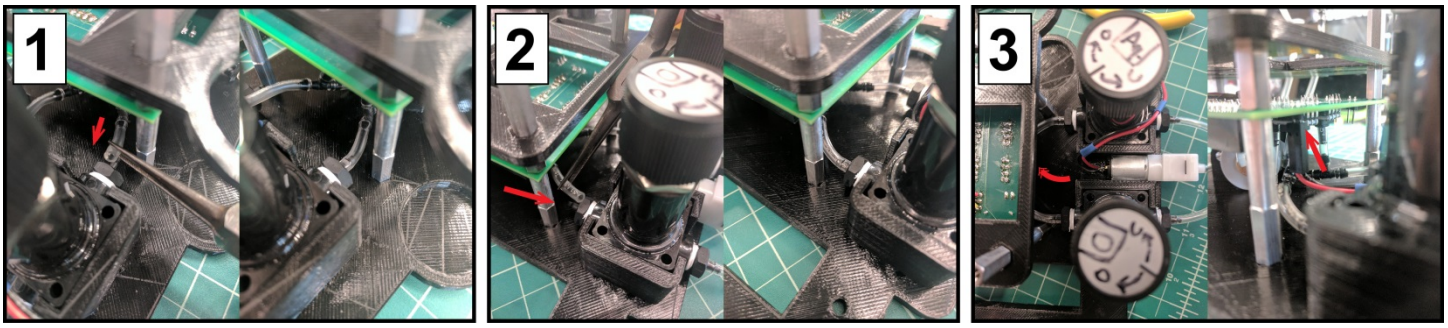
(Step 13) Attach the base to the middle level assembly

Start by assembling 4 “legs” using parts no. 40 and 41 from the BOM. Place the PCB in the orientation see in panel 1 of the figure below. Next, screw on the 4 legs to the assembly as seen in panel 2. After attachment, flip the assembly over and place onto the base as seen in panel 3. The legs may need slight adjustment at the bottom to ensure that they fit within the recessed ports of the base. If this is so, gently loosen the hex leg until it slides into the recessed slot. This typically only requires one quarter turn or less. With all 4 legs seated in the base, flip the instrument over and using 8-32 ¼” screws (part no. 30 BOM) attach the base and middle level assembly together at the 4 holes (red arrows) seen in panel 4. Finally thread the rear tubing lines through the small holes at the rear of the instrument as seen in panel 5. These keep the tubing upright and facilitate attachment to sample vials.

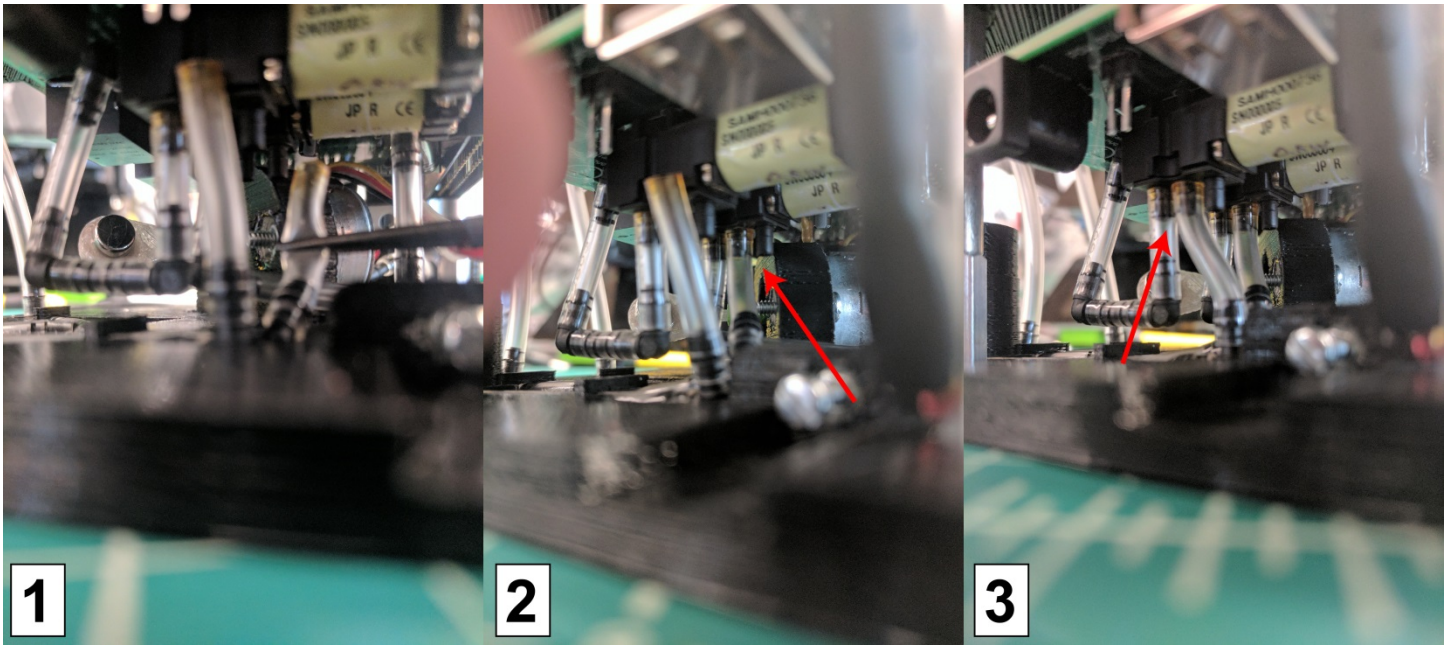


(Step 14) Attach the pressure lines/air pump to the instrument

First using needle nose pliers, attach the pressure lines to their respective regulators. The pressure lines should attach to the regulator that is closest and they should not cross (see panel 1 and two of the figure below). Next connect the power cable of the micro air pump to the circuit board as seen in panel 3. On the circuit board the pins are labeled PUMP_POW but you likely won't be able to see that one the instrument is assembled how we have assembled it. The two pins are near the front right hand corner of the PCB as viewed when the base is flat on the table. Connect the pump such that the black (GND) wire is facing out and the red wire (+3v3) is facing in towards the center of the PCB.



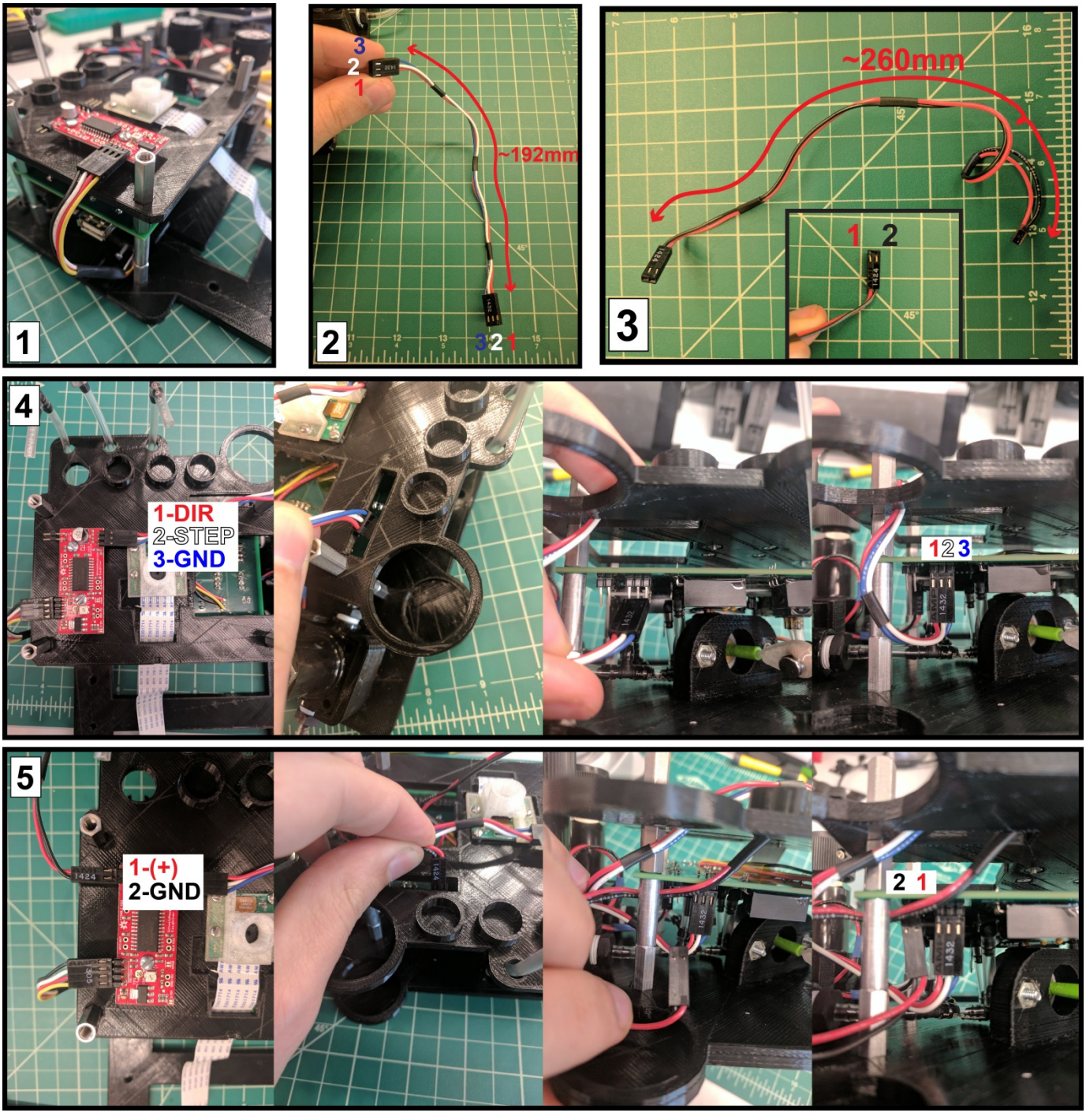
Finally, make sure that the pressure sensor connections are still attached.



Next connect the free tubings from the base to the solenoid valves directly above them. Using needle nose pliers first attach the inner tubing to the inner solenoid valve directly above it. The tubing should be connected to the middle port of the valve. (see panel 1 and 2) Next connect the outer tubing to the middle port of the outer solenoid valve so that the connections appear as in panel 3 of the figure above. Again, the tubing should not cross and should be inspected to make sure there are no tears or punctures after connection.

(Step 15) Connect the EasyDriver stepper motor controller

First connect the stepper motor wire assembly to the EasyDriver controller (panel 1 in figure below). The wire coloring should appear as in panel 1 with the yellow wire towards the eventual front of the instrument and the black wire towards the rear of the instrument. Next, generate two wire cables assemblies, one for the EasyDriver to Raspberry Pi GPIOs (panel 2) and one to power the EasyDriver. The first cable assembly is 3 wires (1-red 2-white and 3- blue) and be approx. 192 mm long. (Panel 2) The next cable assembly is two wires (1-red 2-black) and is approx. 260mm long. (Panel 3)

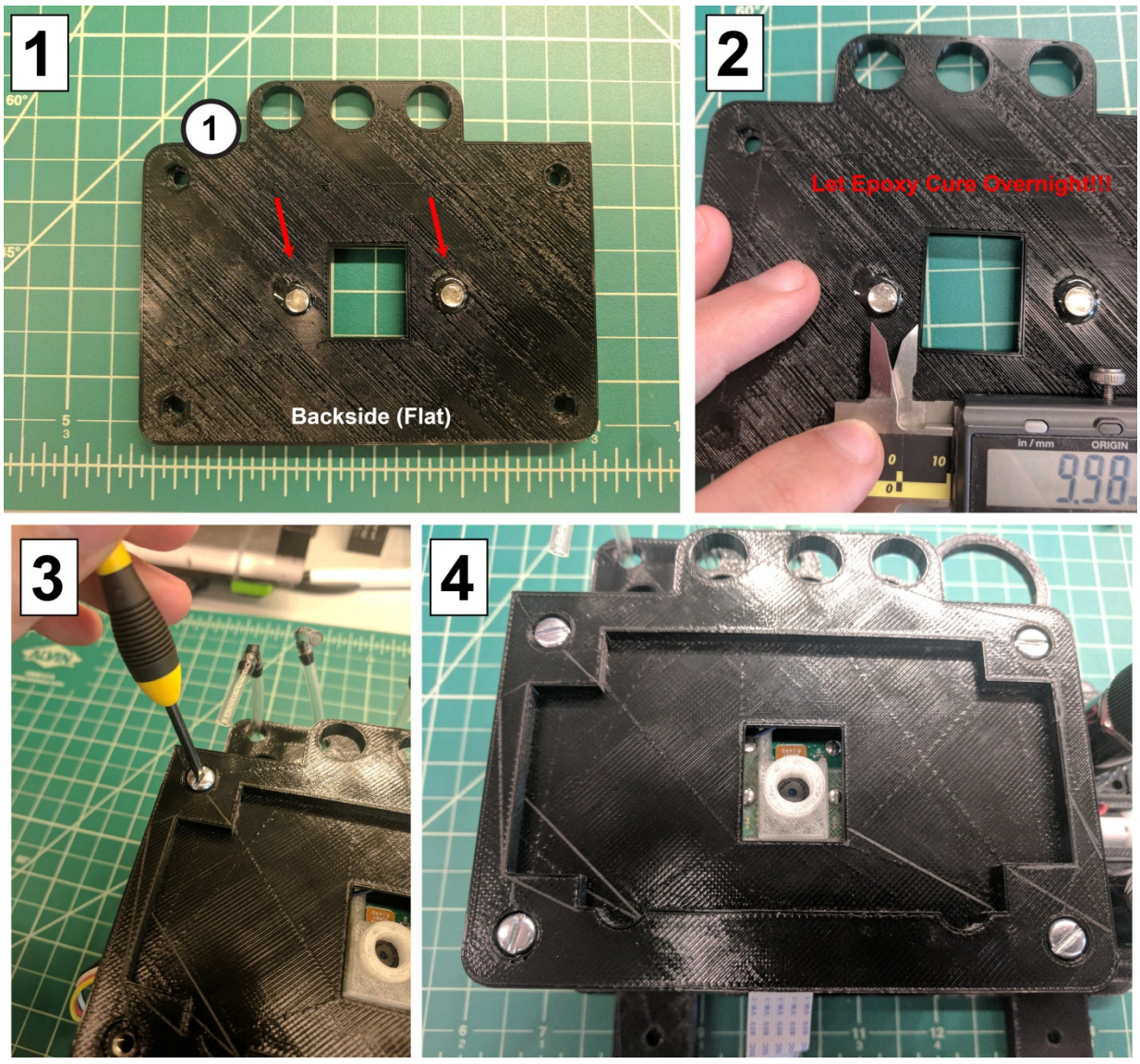


Connect the first cable assembly (red, white, blue) to the EasyDriver stepper motor controller with the configuration seen in panel 4 of the figure above. Next thread the other end of the cable assembly through the thin slot at the rear of the instrument down below, and connect it to the circuit board as

seen in the far right picture of panel 4. Finally, connect to second cable assembly (red and black) to the power connection of the EasyDriver as seen in the far left image of panel 5. Again, thread the other end of this cable through the thin slot in the rear of the instrument and connect it to the circuit board as seen in the picture at the far right of panel 5.

(Step 16) Top level assembly

Begin this step by placing part no. 25 (qty=2) on the backside of the 3D printed part (1), as seen in panel 1 of the figure below. The backside is the completely flat side without the recessed internal region. Gently epoxy the magnets at the approximate positions seen in panel 2. ** You may need to do one at a time, as their magnetic strength is enough the pull them from the epoxy. The magnets should be epoxied approximately 10 mm from either side of the central window. Allow the epoxy to cure overnight. Once the epoxy has cured you can attach the top level to the instrument using part no. 30 BOM screws (8-32, ¼") at all 4 corners as seen in panel 3 and 4. If you have difficulty screwing the screws into the instrument, this is likely due to excess plastic within the holes of the top level 3D printed part. If this occurs, use a hobby knife to remove the plastic in a circular motion and be careful not to cut yourself.



(Step 17) Attachment of Touchscreen and Raspberry Pi to the instrument assembly

Start by generating the cables in panel 1 of the figure below. Start by splicing the microUSB cable (46 BOM). There are a few wires that are visible we will only use the red and black wires as these are for POWER. The other cables can be trimmed/cut. These cables will be used to connect to the micro-USB sockets on the Raspberry Pi and the Touchscreen control board (both of which are attached to the touchscreen) Leave about 50mm of the original USB cable intact past the microUSB plug before soldering longer red and black cables to the end you cut. Use a judicious length of shrink wrap to cover the splice and connect the opposite red and black wires to connection sockets and into 2-pin connection housings. The length of each cable doesn't need to be precise, however both cables should be longer than about 175mm.

Next, affix the 40-pin IDC cable to the Raspberry Pi in the configuration seen in panel 2. Ensure that the white wire of the cable is oriented toward the touchscreen cable connection and not the USB ports on the Pi. Also make sure that all 40 pins are in the receptacle and the cable is not offset.

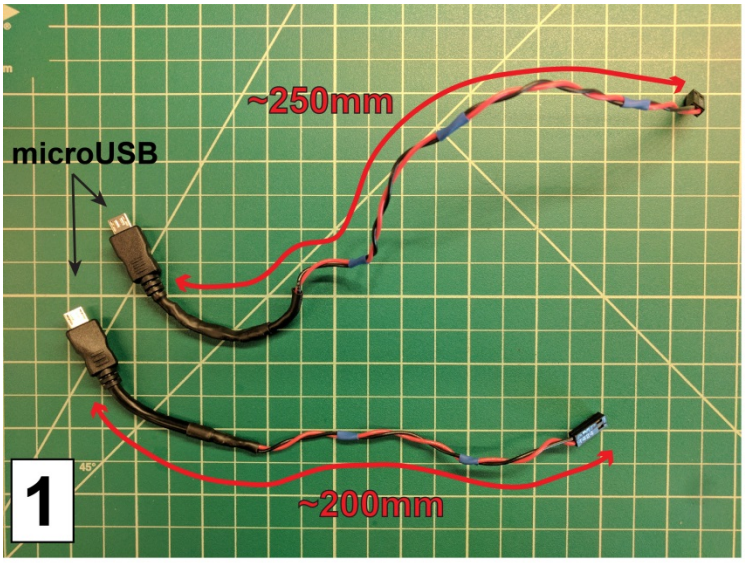
Next, plug in the microUSB cables you generated (panel 1) into the Pi and the touchscreen control board. (Panel 3)

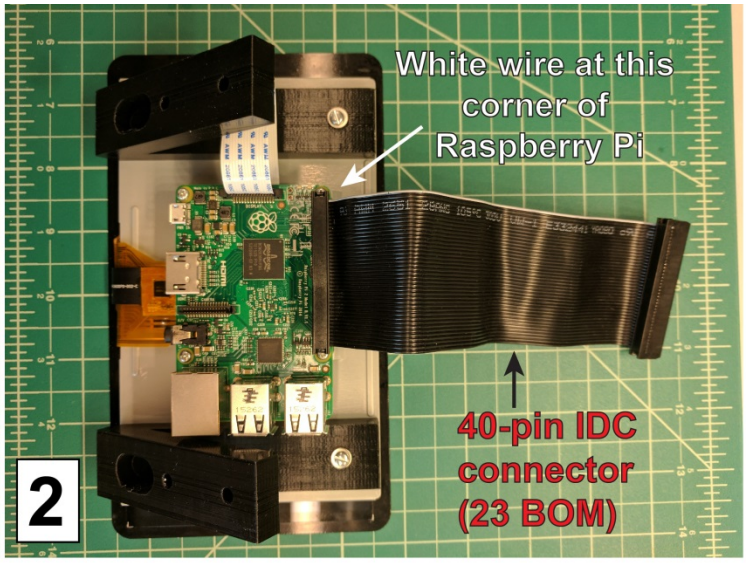
Next, connect the raspberry pi camera to the raspberry pi. (Red arrow, Panel 4) The exposed pins of the white cable should be oriented towards the HDMI display port on the Pi, NOT towards the USB and Ethernet ports. See the raspberry pi camera documentation for correct cable connection.

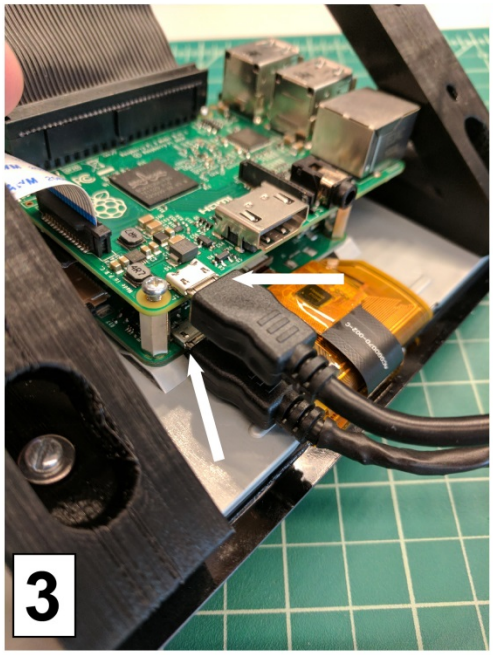
Next, attach the other end of the 40-pin IDC connection cable to the PCB in the instrument assembly. The cable has a slot that should fit within the slot of the receptacle on the circuit board. (Green arrow, Panel 5)

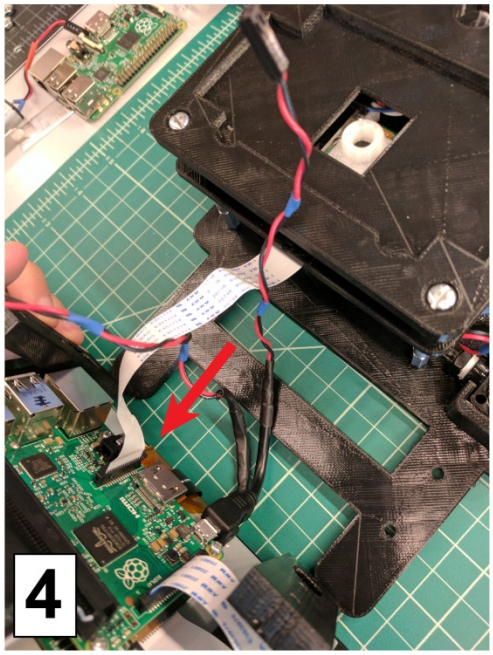
Next, scrunch the touchscreen and pi computer up against the instrument assembly and screw 4 8-32 ½" screws through the base into the touchscreen mount legs. (yellow arrows, Panel 6) This part can be a bit tricky. Try not to pinch any cables and be careful not to rip out the camera cable from the pi, this is a fragile cable and the plastic receptacle on the raspberry pi is known to break as well.

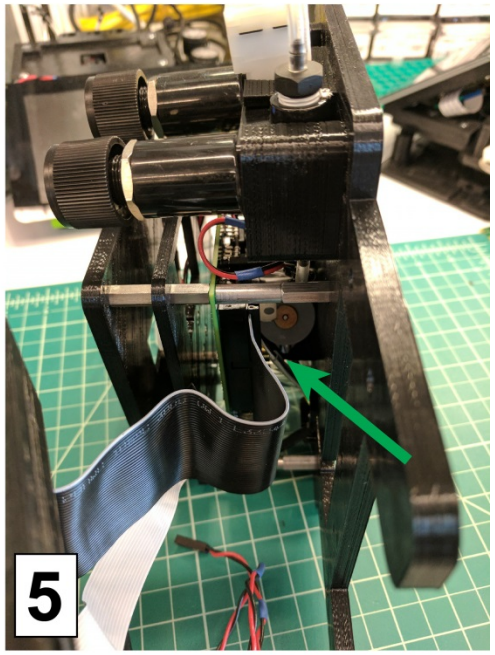
Finally, thread the two power cables under the pi between the touchscreen mount legs and plug them into the male header pins soldered on the PCB. (blue arrows, Panel 7) When viewing the instrument from the front (touchscreen) the + terminal of the power cables should be facing OUT and the GND terminals facing inward. Check the PCB for labels of the pins. Refer to panel 7 for correct orientation.

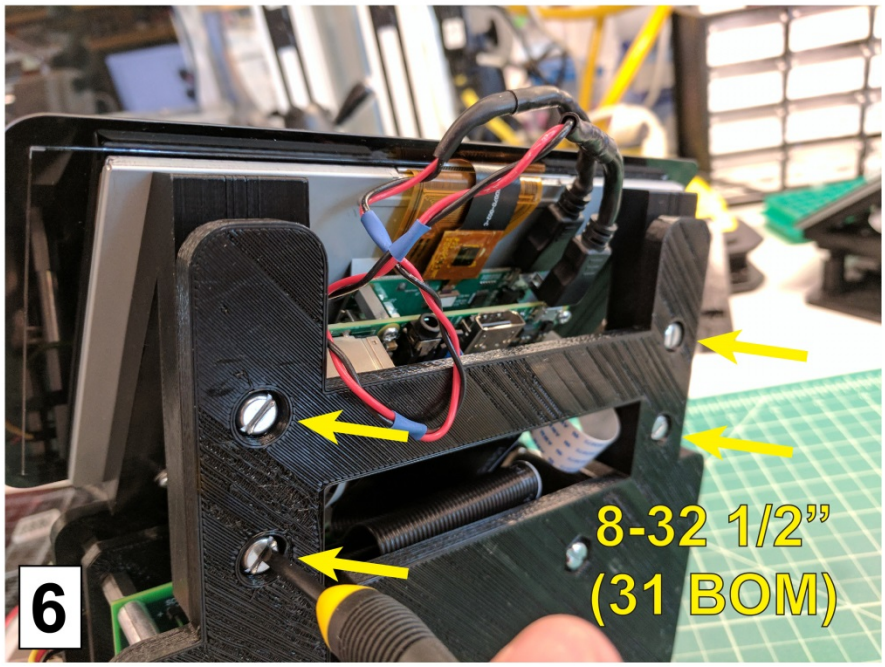

microUSB
~250mm
~200mm
1

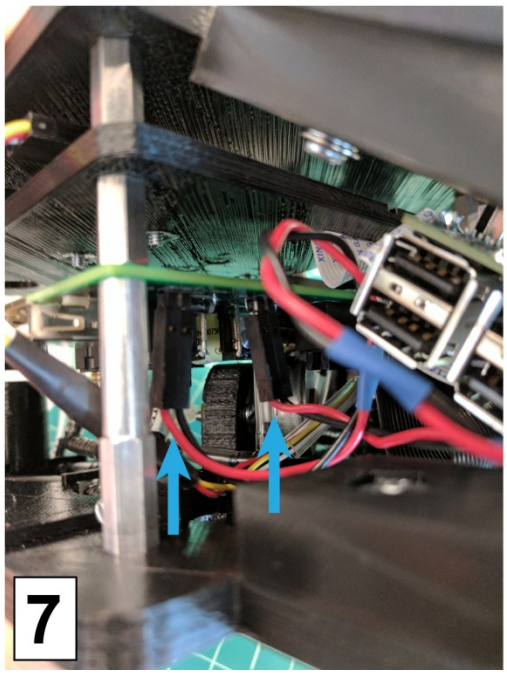

White wire at this corner of Raspberry Pi
40-pin IDC connector (23 BOM)
2


3


4

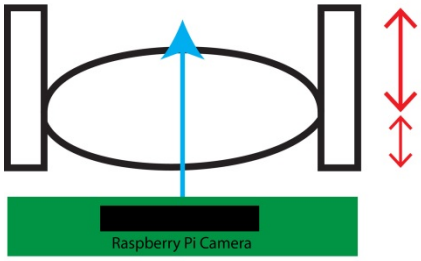

5


8-32 1/2”
(31 BOM)
6


7

(Step 18) Place the lens in the lens housing

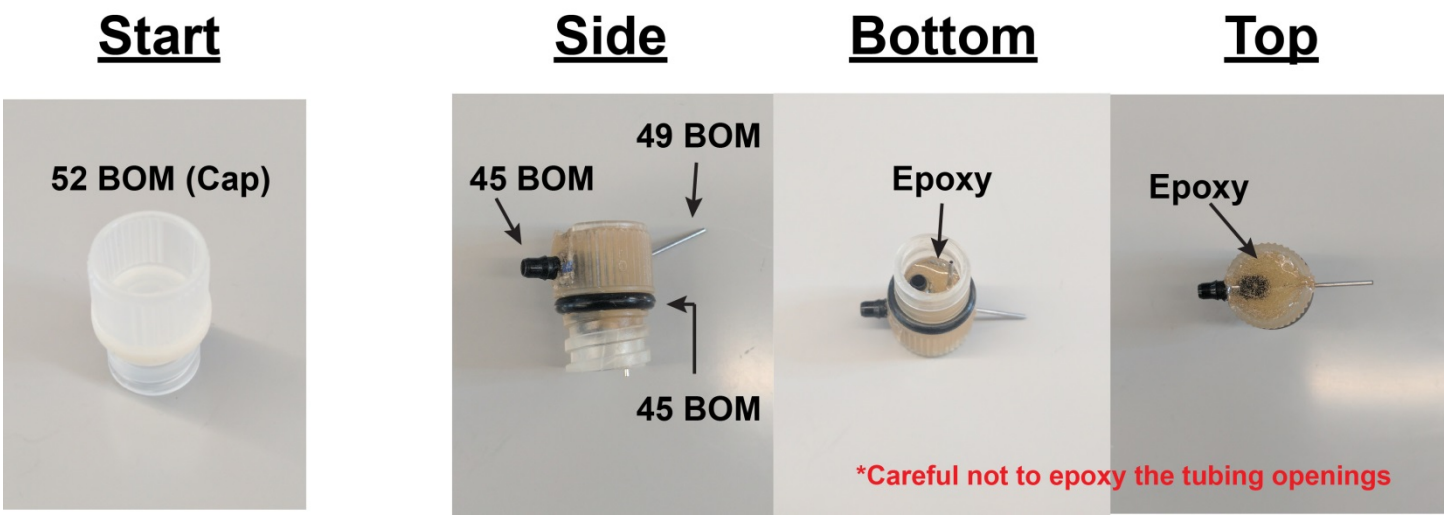
Place the lens in the lens housing. See figure below. The lens has directionality; the side with the central piece that is more recessed should be facing up when placed within the lens housing. See the cross sectional figure below (Left). Keep in mind that there is nothing holding the lens in place, be careful not to invert the instrument with the lens in the housing as it will likely fall out and get lost.



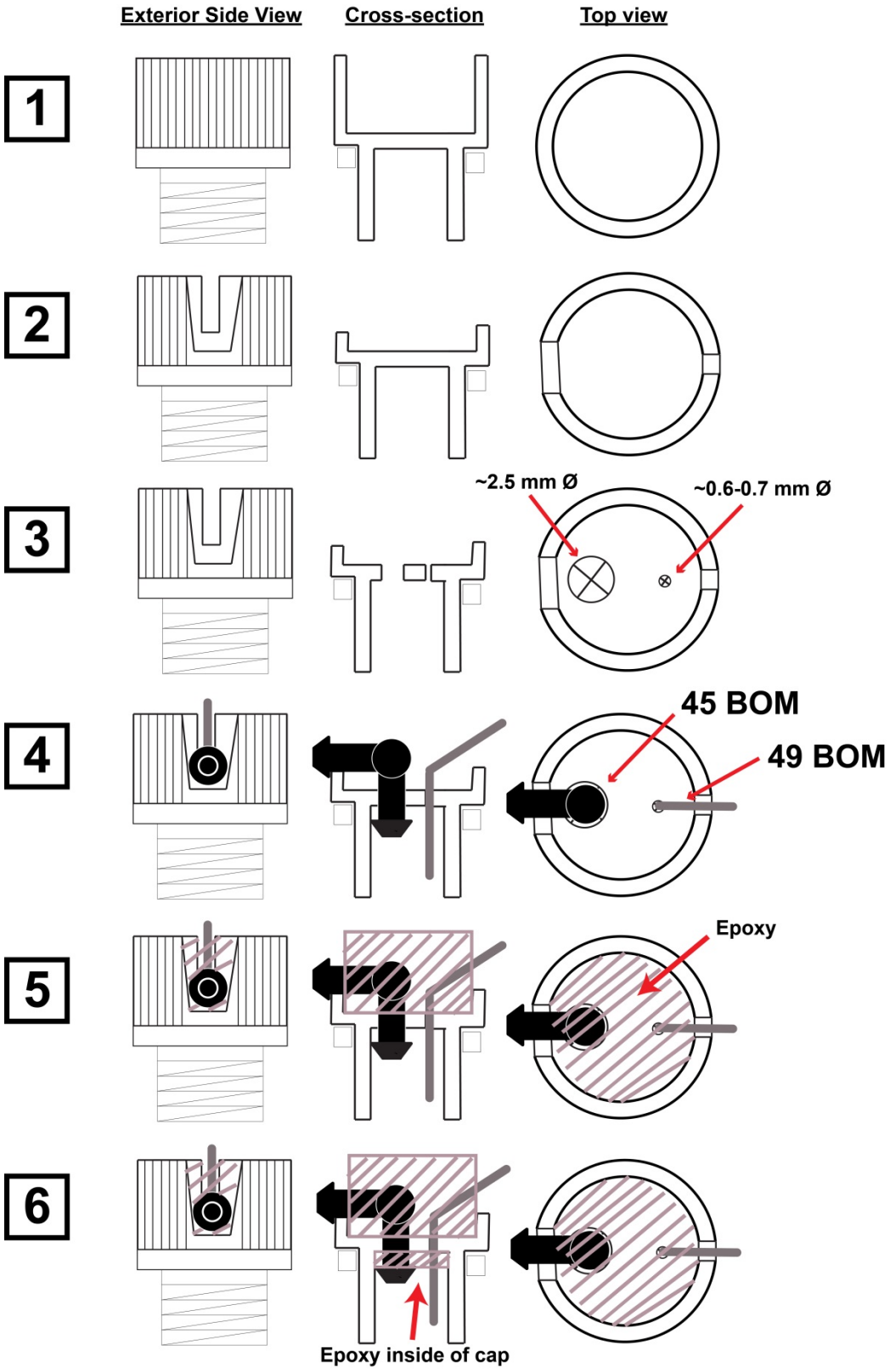
The instrument is now fully constructed.

(Step 19) Custom cap fabrication

This part is tricky and requires a drill (dremel works fine) along with some very small diameter drill bits. I recommend the following bits: https://www.amazon.com/SHINA-Carbide-Jewelry-Engraving-Circuit/dp/B00OOM1QOE/ref=sr_1_4?ie=UTF8&qid=1499374501&sr=8-4&keywords=PCB+drill+bits They are pretty fragile and tend to break if not handled with the utmost care. In this step we will be making 3 of the following caps:



In this section it is helpful to see the finished product before proceeding. Essentially the custom caps will be used to seal the oil, cells, and microparticle vials (nunc cyrotubes, BOM 51 and 52). These caps have connections to the pressure system through the black elbow (45 BOM) and can deliver fluid to the microfluidic chip through a small diameter steel tubing connection (49 BOM). The cap can have an optional o-ring to seal against the cyro tube, however the 4.5ml cyrotubes already come with a clear o-ring that should seal the cap well against the tube. Feel free to add the buna N O-ring if desired.



STEP1 - First start with the cap from the 4.5mL nun cryotubes.

STEP2-Next using wire clippers, trim away a small opening on one side of the cap top ring and a slightly larger opening directly across from the first opening. (The small opening should accommodate the 45 degree small tubing and the slightly larger opening should accommodate the black elbow fitting once the tubings are fitted into drilled holes of the cap)

STEP3 – Drill two small holes near the openings of the cap that were just cut. A large hole diameter approx. = 2.5mm should be located next to the larger opening, a small hole diameter approx. 0.6-0.7mm should be drilled near the smaller opening.

STEP4 – Next fit the elbow fitting and the small 26 guage tubing into the holes that were just drilled. The elbow fitting will be a tight fit as it is barbed. If necessary CAREFULLY use a hobby knife to carve away at the holes in the cap until the elbow and 26Guage tubing fit snugly through the holes. You do not want to open up the holes too much.

STEP5 – mix and apply epoxy to the top of the cap while the elbow fitting and 26g tubing are inserted within the cap. Here it is helpful to have the cap within a vice as the 26g tubing will slightly be longer than the threading of the cap below thus the cap needs to be raised up from a flat surface and held in a vice or clamp. Make sure to not get any epoxy in either of the tubing openings. If any epoxy gets in start all over with a fresh cap, tubing etc. LET EPOXY CURE/SET for ~ 8hrs

STEP6 – next flip the cap over and app epoxy to bottom of the cap (inside the threaded portion of the cap) to surround the 26g tubing and the elbow fitting. AGAIN DO NOT GET ANY EPOXY IN THE TUBING OPENINGS. LET THE EPOXY CURE/SET for 8hrs.

The final cap should appear as in the picture above at the right (side, bottom, top)