Instructions for constructing a rodent joystick and a real time homecage behavioral system

By Brian Kardon, Teja Pratap Bollu

Latest version of these instructions will be here

Introduction

This guide describes in detail the process for building a rack-mountable homecage for running rodent behavioral assays. It includes a water dispensing system, a system for optogenetic (in)activation, a variety of behavioral sensors, including a rodent joystick, and a signal conditioning and data acquisition system. Most of the components are commercially available; we have listed the manufacturer, model, and a link (if available). Some have been custom machined or 3D printed – the specs for these components are made available at the following URL: https://github.com/GoldbergLab/RodentJoystick/blob/master/RodentJoystick-HardwareDesign/

This guide assumes a basic knowledge of soldering (including surface-mount soldering) and handling of electrical tools.

Part I: Constructing a joystick

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/ Supplier Part Number	Datasheet/Drawing/Modification
1	2-Axis Hall sensor	Sentron	2SA-10G	http://www.gmw.com/magnetic_sensors/sentron/2sa/documents/2SA10.pdf
2	Hall sensor PCB	N.A. (Custom Made)	N.A. (Custom Made)	Schematic and PCB here
3	Joystick housing	Hammon Manufacturing	1590MMBK	https://www.hammfg.com/part/1590MMBK
4	Parts for Gimbal Assembly	N.A. (Custom Made)	N.A. (Custom Made)	Part1, Part2 and Part 3 from here
5	"Umbrella" for Joystick	N.A. (Custom Made)	N.A. (Custom Made)	Umbrella from here.
6	Ball bearings, 0.125" ID, 0.250" OD, flanged, shielded	National Precision Bearing	NPB SSRIF418ZZ	http://www.nationalprecision.com/miniature-bearings/inch/radial_flanged_shielded/detail/SSRIF418ZZ/
7	Capacitor, 1 nF, 0603 case x3	Samsung/Digikey	1276-1091-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10C102JB8NNNC/1276-1091-1-ND/3889177
8	Capacitor, 0. 1 µF (100 nF), 0603 case	Samsung/Digikey	1276-6998-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B104KO8ZW6C/1276-6998-1-ND/7320640
9	Ultra-Flexible PVC Lead Wire, 38 AWG	Cooner Wire Company	NUF38-1650T-WHITE	https://www.coonerwire.com/pvc-hookup-wire-nuf-series/
10	Magnets x6	K&J Magnetics Inc.	D41-N52	https://www.kjmagnetics.com/proddetail.asp?prod=D41-N52
11	Machined Ball for Touch Sensor Electrode	N.A. (Custom Made)	N.A. (Custom Made)	
12	Stainless Steel 304 Hypodermic Tubing, 15 Gauge, 0.072" OD, 0.0625" ID, 0.00475" Wall, 36" Length	Amazon		https://www.amazon.com/gp/product/B004WPQJHC
13	Machined shafts for Bearings (Stainless Steel 316L Seamless Round Tubing, 1/8" OD, 0.069" ID, 0.028" Wall, 36" Length)	Amazon		https://www.amazon.com/gp/product/B004XN9LLE
14	Dental Acrylic (Flow-It ALC Flowable Composite)	Pentron	N11H	http://www.pentron.com/products/product_detail/flow_it_alc_flowable_composite
15	Coltolux LED UV curing light	Coltene	C7970100115	https://nam.coltene.com/products/restoration/curing-lights/coltolux-led/coltoluxR-led/
16	Superglue (Loctite 401)	Loctite	401	http://www.loctite.sg/sea/content_data/93806_NEWCA401EN.pdf

#	Part Description	Manufacturer/ Supplier	Manufacturer/ Supplier Part Number	Datasheet/Drawing/Modification
17	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF
18	Silver conductive paint	GC Electronics	22-023	http://www.gcelectronics.com/order/DataSheets/22-023,%2022-024%20Silver%20Print%20II%20Conductive%20Paint.pdf
19	DB-9 Female Receptacle Solder Cup	Norcomp/Digikey	209FE-ND	https://www.digikey.com/product-detail/en/norcomp-inc/171-009-203L001/209FE-ND/858108
20	Rubber grommets x4	Pico	6115PT	https://www.amazon.com/gp/product/B0002ZG3XG/
21	Magnetic tape	Thorlabs	MSHFP	https://www.thorlabs.com/thorproduct.cfm?partnumber=MSFHP
22	1/16" drill bit			
23	1/8" drill bit			
24	1/4" drill bit			
25	1/4” reamer			
26	Vise			
27	4-40 Hex bolts & nuts x2			
28	1/4"-20 x 1” low-profile bolt for JS case			

Building Instructions

General notes

Assembling a usable joystick requires a very high degree of attention to detail and care. As noted below, several of the parts need to be very carefully aligned at every step in the process, or the joystick will not produce a linear, symmetrical voltage vs. position relationship for the full range of motion, and may not provide a smooth force vs. displacement relationship for the animal. We recommend making several joysticks in parallel, and more than you need, since it is likely that at least some of the delicate steps and parts will fall victim to small errors. After the initial learning curve, experienced builders find that around 4 out of 5 joystick builds result in a high enough quality joystick to deploy.

1. Assembling hall effect sensor

The first step in making the joystick is populating a Hall sensor base PCB with capacitors and the Hall sensor IC. The schematic and the board layout are linked in the Materials section.

Materials needed for this section:

- Hall sensor base PCB
- 0.1 uF (100 nF) capacitor, 0603 case
- 1 nF capacitor, 0603 x3
- Hall Effect sensor chip (2SA-10G)
- 38 AWG Cooner wires x4 (~3” long, stripped and tinned at both ends)
- Dental Acrylic

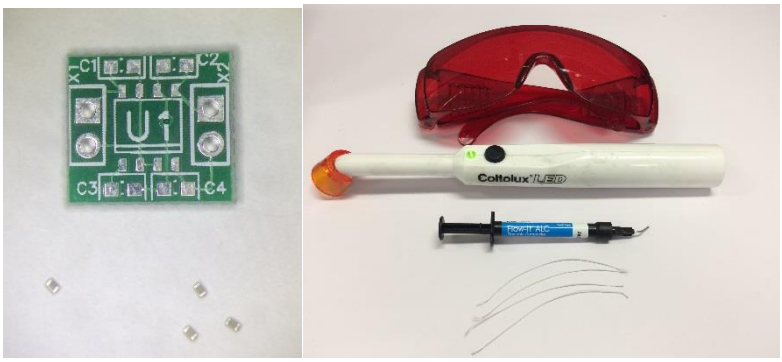

Figure 1 Hall sensor materials. Clockwise from top left: Hall sensor base PCB, dental acrylic glasses, UV lamp, and dispenser, Cooner wires, 1 nF capacitors, 0.1 uF capacitor

Instructions

Solder capacitors and Hall sensor chip onto Hall sensor board

- C1 = 0.1 uF
- C2 = C3 = C4 = 1 nF
- **Ensure that hall chip is oriented so chip edges are very close to parallel with the PCB edges (**Figure 2**)**
- **Ensure that hall chip is very close to horizontal against the PCB (**Figure 3**)**

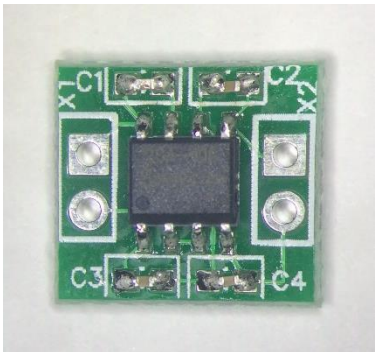

Figure 2 Hall sensor PCB with components soldered. Note the careful alignment of the Hall sensor IC

Add leads

- Fill the four through-holes on the board with solder
- Re-melt the solder and insert the bare end of a wire up to the insulation in each hole. Orient the wire so it is pointing laterally away from the PCB as shown.
- Cover entire solder joint & a little of the wire insulation with dental acrylic
- Cure it with the UV light

Trim excess wire/solder from bottom of board

- Board must lay flush on gimbal platform
- If board doesn't sit flat, run the bottom gently over a file a few times
- CAREFUL not to damage the board traces on the back
- See Figure 4 for the finished Hall sensor board

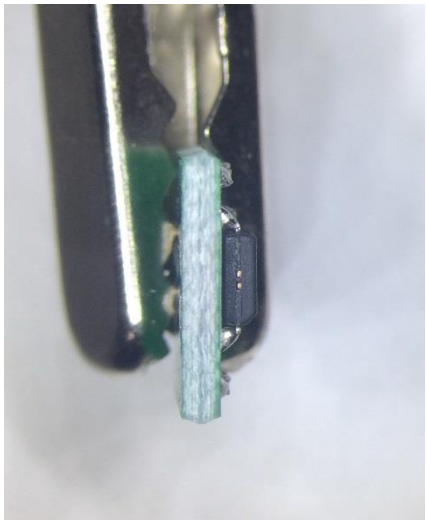

Figure 3 Hall sensor PCB with side view of chip. Note the careful alignment of the Hall sensor IC.

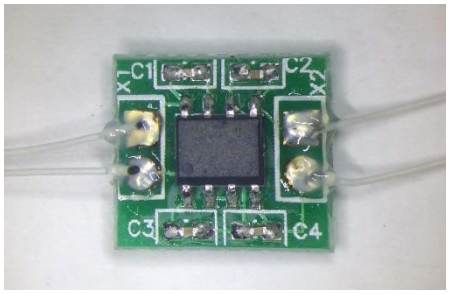

Figure 4 Hall sensor with leads soldered and coated in acrylic

2. Making the Joystick Electrode

The next step is to create a joystick electrode. This electrode will consist of a metal tube with a small electrically isolated ball at the top. Two leads that run through the tube will eventually connect the ball to the joystick PCB via a DB9 connector. The electrode serves as the joystick manipulator as well as a capacitive touch sensor.

Materials

- Machined capacitive ball
- Cooner wire
- 1/8" steel tube
- 5-minute epoxy
- Silver conductive paint
- Dremel with
- 1/16” drill bit, abrading bit, cutting wheel bit
- Calipers
- Multimeter
- Tweezers

Figure 5 Joystick electrode materials. Clockwise from top left: silver paint, tube, calipers, dremel, dremel bit, cutting wheel, abrading head, Cooner wires, capacitive ball. Not pictured: epoxy

Instructions

Filing rod to length

- Measure 2.15" of the tube
- Secure tube gently in vise, being careful not to crush it
- Use dremel saw to saw off tube
- Use a metal file or a dremel with an abrading bit to remove material from end until tube has a length of 2.10 +/- 0.01"
- Make sure ends are free of metal burrs that could damage the wires

Cutting a side hole

- Fix tube gently in a vise
- Use 1/16" dremel bit to drill hole in **only one side** of tube approximately 1/2" away from bottom of rod
- Use a small file/blade/tweezers to remove any burrs from the edge of the hole that might interfere with or damage wires
- **Careful – tube is weakened at the side-hole spot**
- See Figure 6 for finished joystick electrode tube

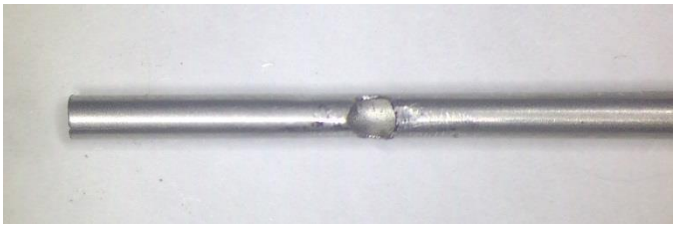

Figure 6 End of the joystick electrode tube, showing a completed side hole. Note the absence of sharp burrs on the edge of the hole.

Stripping, joining, and tinning electrode leads

- Cut two 6" lengths of wire
- Remove approximately 3/16” of insulation from both sides of the wires (suggested tools: tweezers or soldering iron tip)
- **Check that conductor is not damaged by stripping**
- Twist the bare ends of the two wires together on one side
- Tin the two free ends of the wires, and the one twisted-together end.
- Make sure the twisted-together & tinned end of the wires is not too large to fit in tube of the capacitive ball.

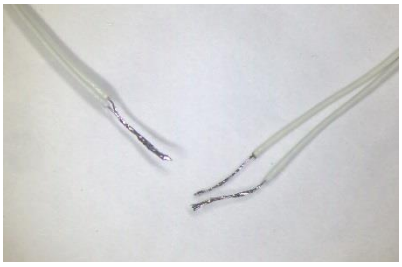

Figure 7 Joystick electrode leads completed, showing the wires twisted together at one end

- See Figure 7 for completed electrode leads

Inserting wires into capacitive ball using silver paint

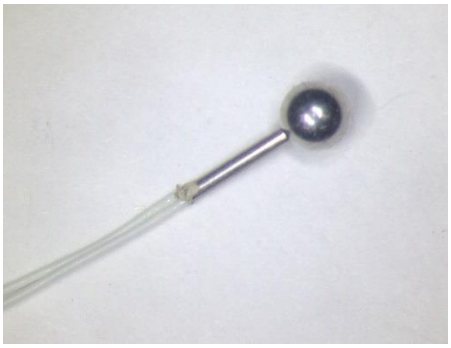

Figure 8 Capacitive ball with leads inserted

- First check that twisted & tinned wire pair fit into the neck of the capacitive ball.
- Shake up silver paint to mix
- Coat tinned wire with silver paint
- Paint tip of capacitive ball neck with silver paint
- Insert wires into neck of the ball
- Wait for paint to dry
- Note that paint alone will NOT result in a strong mechanical connection, so handle carefully
- See Figure 8 for result of this step.

Apply epoxy to strengthen and insulate joint

Figure 9 Capacitive ball with leads and a coat of epoxy. Note that the epoxy spreads out enough at the base of the ball to prevent it from contacting the tube when inserted, but not so much as to encroach on the touch-sensing area on the top and sides

- Mix small amount of two-part epoxy (equal parts) with a fine-tipped applicator like a pin
- Apply epoxy to joint between wires and ball neck
- Spread along wires and barely up to the ball
- Allow epoxy to set while ball is upside down (leads pointing upwards). This allows gravity to pull epoxy slightly onto the base of the ball, which helps prevent contact between the ball and the electrode tube.
- **Ensure that epoxy electrically insulates the neck of the ball so that it will NOT make electrical contact with the tube. ALL silver paint and metal below ball must be covered**
- **Ensure that epoxy does not stray TOO far up the sides of the ball itself; this could interfere with touch sensing.**
- **Ensure that epoxy layer doesn't have bulges that will prevent the neck of the ball from inserting into the electrode tube.** It is possible, though difficult, to trim the epoxy layer later if bulges form during drying.
- See Figure 9 for result of this step.

Threading wires through tube

- Use cutters to eliminate any extra overhanging epoxy
- Thread wires through electrode rod – insert them on far side of the tube from the side hole
- Use tweezers to pull wire out through side-hole
- Gently pull wires until the ball settles onto the end of the tube
- If epoxy prevents the ball from getting close to the end of the tube, gently trim obstructing parts off.
- Pull ball slightly out again, and add 2nd layer of epoxy in same place as the first layer. **Do not wait for it to set.**
- Pull gently on the wire leads to reseat the ball at the end of tube. Push on the ball at the same time to assist.
- Wipe off excess epoxy below ball. **Careful not to wipe epoxy onto touch-sensitive sides and top of ball**.
- Spin around to visually check that the ball is approximately centered on rod. Adjust if it is not.
- **Use a multimeter to check that the two wire leads are electrically connected to the ball, but NOT to the tube.**

- Allow the epoxy to set – make sure gravity does not pull the ball out of place during setting.

Final test of electrode

- Use a multimeter to check that the two wire leads are electrically connected to the ball, but NOT to the tube.

3. Cleaning/drilling out joystick gimbal assembly parts

The next step is to prepare the four parts of the gimbal for assembly. The gimbal consists of a platform that holds the Hall sensor, a cross that helps affix the gimbal accurately and securely in the baseplate, and a rectangle and square rotating pieces that provide the two degrees of freedom via the bearings that suspend them.

Materials:

- Gimbal platform
- Gimbal square
- Gimbal rectangle
- 1/16", 1/8”, and 1/4” drill bit
- 1/4” Reamer
- Bearing (for checking fit)
- Electrode tube (for checking fit)
- Magnet (for checking fit)

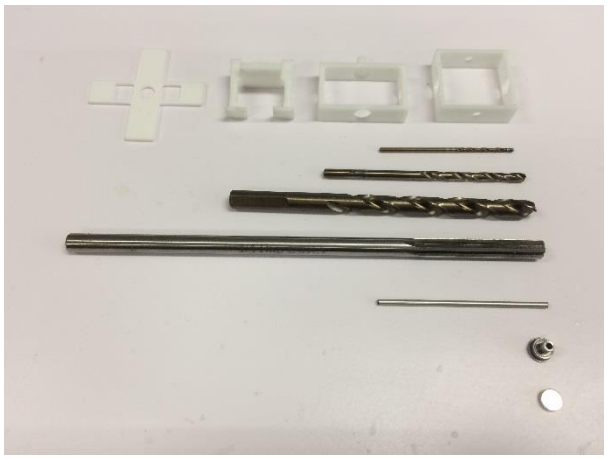

Figure 10 Gimbal preparation materials. Clockwise from top left: Cross (not used until next step), gimbal platform, gimbal rectangle, drill bits (1/16" 1/8" and 1/4"), ¼” reamer, sample tube, sample bearing, sample magnet

Instructions:

Clean and inspect 3D printed parts

- The 3D printing process can leave small burrs and other imperfections.
- Examine parts and smooth/remove/fix any imperfections prior to using parts.
- Check that right angles are very close to 90°; significantly warped parts are likely to produce a failed joystick.

Gimbal platform: clearing out holes

- Use 1/8” drill bit **manually** to clear out the two 1/8" hole in the “shoulders” of the gimbal platform.
- Note: Using a power drill can result in a large amount of wobbling of the drill bit that can create holes that are too wide with non-vertical sides. This can introduce fatal levels of misalignment later. Using the drill bit manually is tedious, but more accurate. Using a tap wrench to hold the drill bit can make this easier on the hands.
- Take care not to change each hole’s orientation as you widen it; it’s best to clear out both holes simultaneously with the drill bit to ensure that the two shoulder holes remain coaxial. **It is critical that the holes remain closely aligned, or the gimbal won’t rotate smoothly.**
- Carefully widen hole until bearing shaft just fits through easily
- See Figure 11 for results of this step.

Figure 11 Bearing shaft fits easily into one of the two gimbal platform shoulder holes.

Gimbal square: clearing out holes

- Use 1/8” drill bit manually to clear out the two 1/8" holes in the gimbal square piece **if necessary** (see below).
- As before, drill both holes simultaneously to maintain them in a coaxial orientation
- Carefully widen hole until bearing shaft just fits through easily
- Use 1/4" drill bit to manually clear out the two 1/4” holes.
- Carefully widen holes until bearing fits in **snugly**

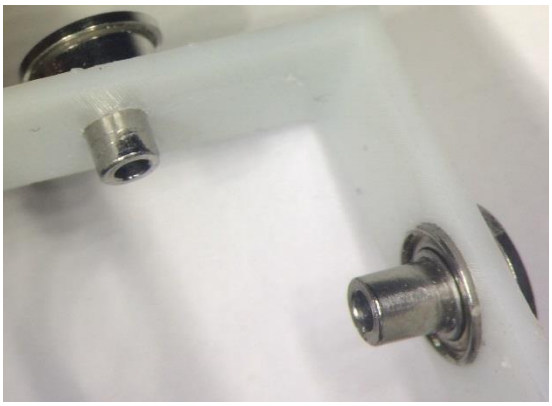

Figure 12 Gimbal square, showing bearings successfully fitting in two of the holes.

Gimbal rectangle: clearing out holes

- Use 1/4" drill bit manually to clear out the three 1/4” holes in the gimbal rectangle piece **if necessary** (see next step).
- Carefully widen short-side holes until bearing fits in **snugly**
- Carefully widen bottom long-side hole until a magnet fits **snugly**
- Clear out hole in electrode post hole with 1/16” drill bit
- **As you clear out the post hole, it must remain vertical or joystick will be non-vertical**
- Make sure electrode post can fit in **snugly**
- Ream out magnet hole on the inside of the rectangle. Be careful to hold the reamer vertically to avoid slanting the holes
- Ream directly through the magnet hole in one side of the rectangle through to the magnet hole on the other side of the rectangle.
- Put magnet in to make sure it fits snugly in each hole

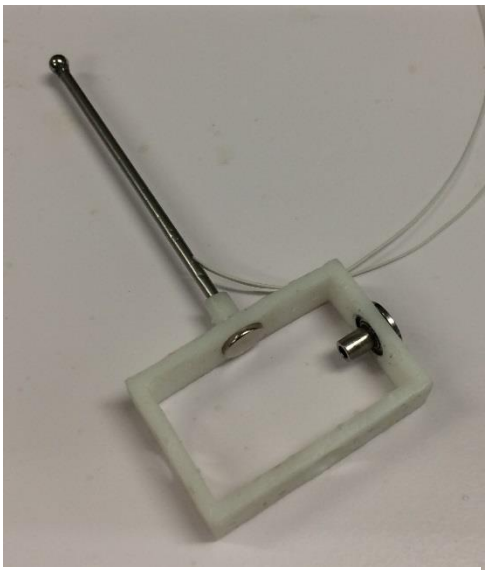

Figure 13 Gimbal rectangle, showing bearing, post, and magnet successfully fitting.

4. Assembling joystick

The final step for creating the joystick is to assemble the previously created parts (the electrode, the gimbal, and the base), connect the joystick leads to the DB-9 connector, and house the joystick in the case.

Materials:

- Gimbal parts (platform, square, and rectangle, cleaned and prepared)
- Ball bearings with shafts x4
- Completed Hall sensor PCB
- Completed JS electrode
- Magnetic tape
- Magnets x6
- Baseplate
- Plastic cross
- Super glue
- Epoxy
- Glue/epoxy applicator
- DB9 Female Solder Cup
- 4-40 Hex bolts & nuts x2
- JS case
- Case screws x4
- Rubber grommets x4
- Plastic umbrella
- 1/4-20 x 1” mounting bolt

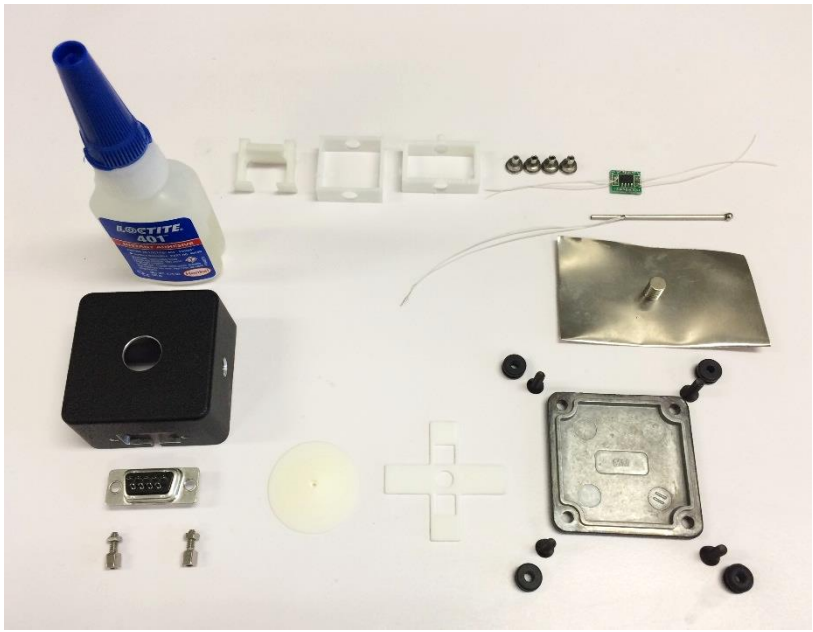

Figure 14 Materials for assembly of joystick. Clockwise from top left: Superglue, gimbal pieces, bearings, Hall sensor, electrode, magnetic tape, magnets, baseplate w/ screws & grommets, cross, umbrella, DB-9 connector & screws, and housing top. Not pictured: ¼-20 x 1” mounting bolt

Instructions

Seating Hall sensor

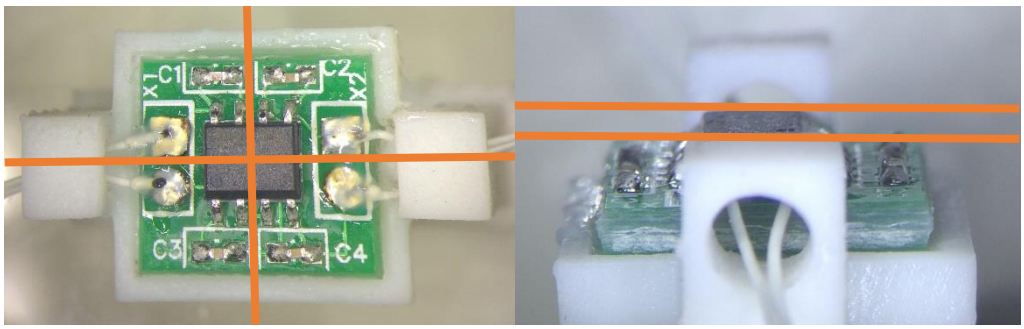

Figure 15 Alignment of Hall sensor chip

- Thread the four Hall sensor wires through holes in shoulders of platform gimbal
- Seat Hall sensor board flat on platform
- Mix epoxy
- Add a dab of epoxy in the center of the platform
- Press the Hall sensor down into place as you gently draw the wires through gimbal platform holes
- **CRITICAL:** Adjust the position of the Hall sensor PCB until the Hall sensor IC is perfectly square with gimbal platform in all dimensions. Any significant skewing, tilting, or off-center positioning will result in poor joystick position output. Note that the position of the PCB itself is irrelevant – it’s the Hall sensor chip itself that must be as close to perfectly oriented as possible. It can be helpful to allow the epoxy to partially set before fine-tuning the position of the Hall sensor, as the more-viscous partially-set epoxy will prevent the Hall sensor from shifting after alignment
- Let Hall sensor epoxy set

Preparing magnetic tape to hold top equilibrium magnet

- Cut small piece of magnetic tape in the same shape as the inside surface of the long side of the rectangle piece of the gimbal (1.10” x 0.32”)
- Place tape on inside bottom of rectangular piece
- Firmly press down magnetic tape until it is adhered to the rectangle piece.
- See Figure 16 to see the results of this step.

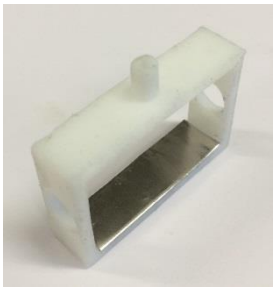

Figure 16 Rectangle piece with magnetic tape inserted

Attaching square & rectangular pieces

- Gently thread the two pairs of Hall sensor wires through the two 1/4" holes in square piece
- Thread each pair of wire leads through a bearing. Insert the bearing into the 1/4" holes so the bearing shaft inserts into the gimbal platform shoulder holes.
- **Ensure square and platform pieces rotate extremely smoothly and freely against each other – you shouldn’t feel any kinks or hitches. You may need to make small adjustments to the position of the bearings and the position of the platform on the bearings to achieve smooth rotation.**
- Insert square piece into rectangle piece, and add bearings to connect
- **Ensure rectangle and square also rotate extremely smoothly and freely against each other**
- See Figure 17 and Figure 18 for results of this step.

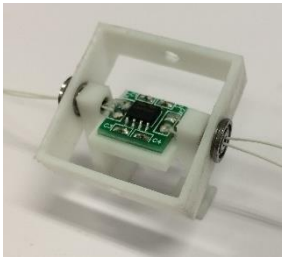

Figure 17 Gimbal square suspended on platform

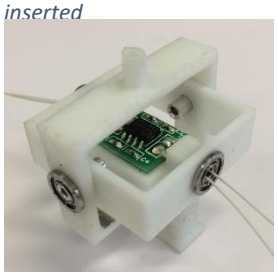

Figure 18 Gimbal square and rectangle suspended on platform

Mount cross on baseplate

- Seat cross in baseplate
- **Make sure two square holes on plastic cross are not on top of words/markings on baseplate. In the correct orientation, the cross should lay flat. It may be necessary to file down the ends of the cross a little to achieve a good fit.**
- Add superglue with toothpick on edges of cross & baseplate ONLY on sides of cross without holes

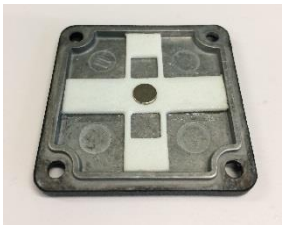

Figure 19 Cross with equilibrium restoring magnet glued into baseplate

Add equilibrium-restoring magnets

- Add superglue on center hole
- Press magnet into center hole
- **Ensure the magnet lays horizontally. Misalignment of this magnet can result in a non-central equilibrium position**
- Add another magnet **IN THE SAME ORIENTATION** as the baseplate equilibrium magnet on the rectangle piece in the hole on the opposite side from the magnetic tape
- Press fit the magnet until it is flush with the rectangle bottom
- Add second magnet on the bottom of the rectangle, to make a stack of two. This increases the equilibrium-restoring force of the joystick.
- See Figure 19 and Figure 20 for the results of this step.

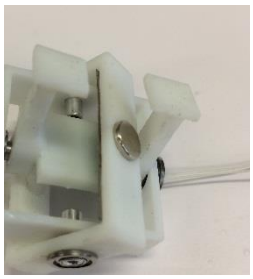

Figure 20 Gimbal rectangle with two equilibrium restoring magnets inserted. The first magnet is not visible.

Seat gimbal on baseplate

- Push-fit gimbal feet into holes in plastic cross in baseplate
- **Ensure that the arms of the platform are vertical and perpendicular to baseplate**
- Superglue down feet of platform
- Wait for superglue to dry
- See Figure 21 for the results of this step.

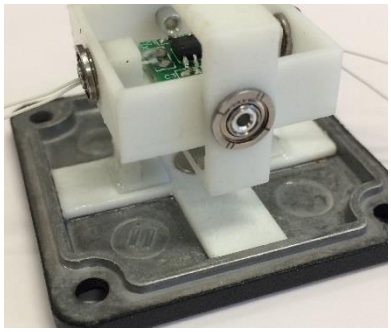

Figure 21 Gimbal seated on baseplate

Add Hall sensor magnets

- Press first magnet firmly into the top hole of the rectangle (this is made less challenging by using a non-magnetic stick to insert the magnet). Optionally glue the magnet it in if it isn't staying in with friction alone
- Make sure the magnet surface is parallel to the inner surface of the rectangle piece.
- Add two more magnets (making a total of three) into the top of the rectangle piece. This increases the magnitude of the signal from the Hall sensor, and therefore improves the signal to noise ratio.

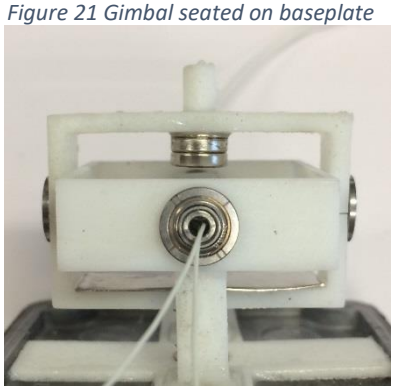

Figure 22 Gimbal with Hall sensor magnets installed

Place joystick electrode into rectangle piece

- Insert the bottom (non-ball side) of the electrode into the collar sticking up out of the rectangle piece.
- Make sure that the electrode leads are facing the side of the Hall sensor PCB with capacitors 1 and 2.

Centering joystick

- **This is a critical, delicate step! The quality of the joystick output is very sensitive to this step!**
- Repeat for each of the two degrees of freedom:
- Check whether the Hall sensor magnets are centered directly above the Hall sensor in equilibrium position
- Also use a ruler to check the verticality of joystick
- Adjust the position of the bearings in the square/rectangle (depending on which degree of freedom you are adjusting) to change position of Hall sensor magnets and angle of joystick.

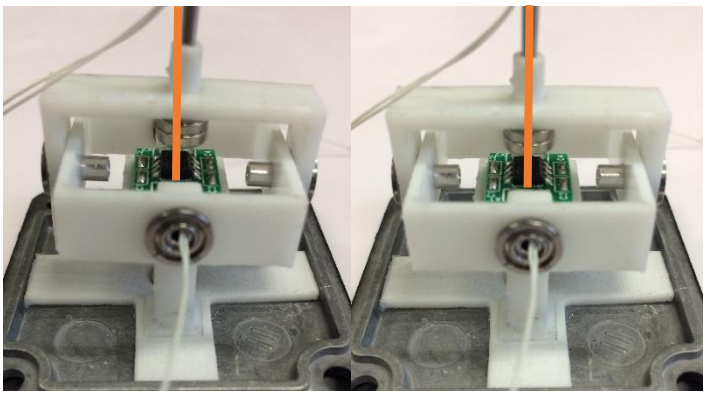

Figure 23 Gimbal centering process (one degree of freedom shown). Before centering (left), after centering (right)

- Prioritize the position of the Hall sensor magnets over joystick verticality, but maximize both. Some joystick non-verticality can be overcome by adjusting the housing screws later. However, if the Hall sensor magnets are not carefully centered over the Hall sensor at equilibrium, then the position output will be irrevocably distorted.
- Note that you must maintain a tiny air gap between the rectangle and square pieces to avoid introducing more friction into the joystick motion.

Gluing 1st set of bearings

- Gently apply superglue with outside edge of bearing where it makes contact with square/rectangle (depending on degree of freedom) piece of gimbal
- Use a fine-tipped applicator (a toothpick or similar)

- Gently apply superglue to bearing shafts
- **Be careful not to superglue the inner and outer parts of the bearing together!**
- Allow glue to dry
- Test if joystick is "bouncy" – joystick should rebound & oscillate when disturbed
- Consider retesting that the joystick electrode has appropriate electrical connectivity before gluing it down – this is the last time you can easily replace it if it has become broken.
- Superglue down electrode wires
    - Dab glue on top surface of rectangle, press wires tightly against the electrode mounting collar
- Superglue joint between electrode tube and rectangle piece

Soldering joystick connector

Figure 24 Completed DB-9 connector with all six wires soldered in and covered in acrylic

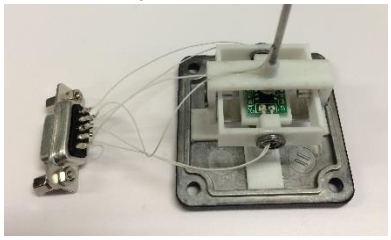

Figure 25 Joystick connected to DB-9

- DB-9 female with solder cups
- Screw in hex screws with nut on either side
- Fill solder cups #1-#5, as well as cup #9 generously with solder
- Optional: Cut all leads down to a smaller size – this is a judgement call. Shorter wires leave less margin for error if a wire breaks. Longer wires are harder to pack into the case without obstructing the joystick motion.
- Solder the following connections into the DB-9 connector:
    - cup #1 – Either joystick electrode wire
    - cup #2 – Hall sensor GND wire
        - The GND wire can be identified using a multimeter connectivity tester. The GND wire will be electrically connected to pin 8 of the Hall sensor IC, and the corner-facing terminal of the C1 capacitor
    - cup #3 – Hall sensor GND wire
        - The 5V wire will be electrically connected to pins 2, 3, and 7 of the Hall sensor IC, as well as the non-corner-facing terminal of the C1 capacitor
    - cup #4 – Hall sensor X position wire
        - Either Hall sensor wire that is **not** GND or 5V can be connected here (X and Y position signals can be easily swapped in software later)
    - cup #5 – Hall sensor Y position wire
        - The remaining Hall sensor wire
    - cup #9 – The remaining joystick electrode wire
- Apply dental acrylic to faces of solder cups - cover all the solder, and a little on the wire insulation
- **Make sure that the dental acrylic doesn't form a protrusion large enough that when the DB-9 is installed in the case, it will interfere with the motion of the gimbal.**
- Cure dental acrylic with the UV light
- See Figure 24 and Figure 25 for the results of this step

Encase joystick

- Insert the 1/4-20 x 1” mounting bolt into the inside of the side hole in the case and thread it all the way through to snug. It should go in the right-hand side of the case when the DB-9 hole is facing you and the joystick hole is on top.
- Carefully thread the six wires through the slot in the DB-9 hole of the case.
- Fasten the two DB-9 screws firmly into the casing. The inner nuts on each screw should allow the DB-9 to stand off a bit from the case, which helps prevent the joystick from bumping into the wires sticking out of the solder cups.
- Repeat for each base plate corner hole:
    - Insert a rubber grommet on one of the base plate corner holes between the base plate and the top of the housing
    - Insert a screw into the same hole from below the base plate.
    - **Make sure there are no wires caught in or around the grommet** – tightening the screw down on a wire will likely damage or sever the wire.
    - Tighten the screw **only** until it is just secure – do not overtighten!
- Use tweezers to gently push all exposed wire into the casing
- **Make sure joystick wires don't impede joystick's free motion**
    - Test joystick by gently displacing it then releasing it.
    - The joystick’s motion should be very bouncy (each bounce should last roughly 2-4 seconds before it settles into equilibrium)
    - Note that the range of motion parallel to the rectangle piece will naturally be smaller than in the other dimension because of the geometry of the case. The joystick motion will be limited by the hole in the bottom of the cage, so this restriction is not relevant and doesn’t need to be corrected.
    - If the joystick’s motion seems damped or restricted, it is likely because some of the wires are pressing against the gimbal.
        - Use tweezers to gently rearrange the wires until they are no longer restricting the motion of the gimbal.
        - If the wires become a persistent problem for joystick motion, you can also open the case back up and use some superglue to fix the middle of the wires to the baseplate to control their positioning. Take care to leave enough slack so the gimbal can move freely.
- See Figure 26 and Figure 27 for the results of this step.

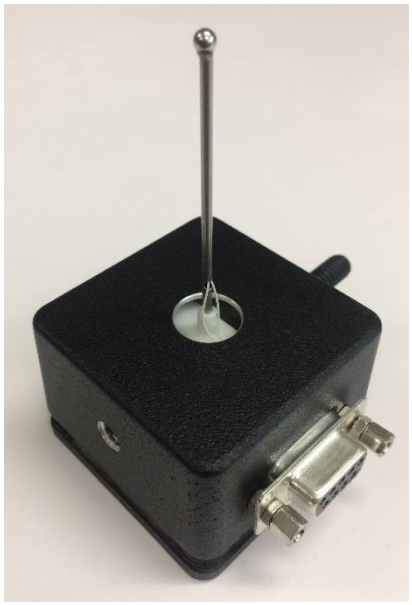

Figure 26 Finished joystick

Figure 27 Finished joystick exhibiting a good bounce

Part II: Mount joystick on micromanipulator

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/ Modification
1	Completed joystick			
2	1/2" XY Dovetail Translation Stage with baseplate	Thor Labs	DT12XY	https://www.thorlabs.com/thorproduct.cfm?partnumber=DT12XY
3	1/4”-20 M6 countersunk cap screw	Thor Labs	(included with DB12XY)	
4	Hex head bolt, washer, and locking washer	Thor Labs	(included with DB12XY)	
5	RA bracket	N.A. (Custom Made)	N.A. (Custom Made)	AttachJSMicroManipulator from here
6	8-32 x 1/4” bolt			
7	1/4” x 20 nut x2			

Building Instructions

General notes

The micromanipulator provides a mounting connection between the joystick and the homecage, and provides the ability to precisely center the joystick in the cage-bottom hole, which permits accurate calibration and a uniform maximum joystick displacement in all directions.

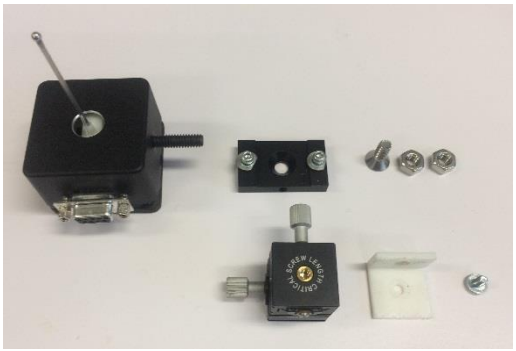

Figure 28 Materials for mounting joystick on micromanipulator. Clockwise from to pleft: Completed joystick, DT12B mounting adaptor, 1/4"x20 M6 countersunk cap screw, 1/4"x20 nut x2, 8-32x1/4" bolt, RA adapter, DT12 translation stages x2 (already attached)

1. Connect the two DT12 translation stages to each other
2. Attach the mounting adaptor to the translation stage
   - Insert the hex head bolts, washers, and locking washers that come with the mounting adaptor into the two holes on either side of the center hole in the DT12XY baseplate. The locking washer should fit neatly into the hole. Do not tighten all the way.
   - Insert the 1/4”-20 M6 countersunk cap screw into the center hole in the DT12XY baseplate. The threaded end will eventually be pointing upwards away from the micromanipulator.
   - Slide the baseplate onto one of the two translation stages and center it
   - Tighten the hex head bolts until the baseplate is secure

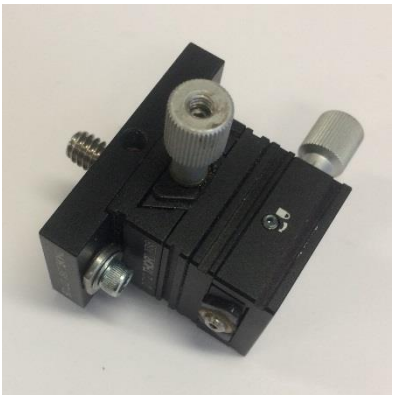

Figure 29 Assembled micromanipulator

3. Mount the joystick on the micromanipulator

- Attach the large side of the RA bracket to the translation stage that does NOT have the DT12XY baseplate attached using the 8-32x1/4” bolt. This will be the bottom side of the micromanipulator. Tighten with a screwdriver.
- Insert the 1/4”-20x1” mounting bolt of the joystick housing into the other (smaller) side of the RA bracket.
- Thread on the other 1/4”-20 nut and tighten with a wrench.
- Ensure that the joystick housing sides are closely aligned with the RA bracket sides, so the joystick will be vertical when mounted.
- Visually check that the joystick is parallel to the micromanipulator top screw. If it isn’t, small adjustments can be made to the joystick housing screws, and the connection between the micromanipulator and the joystick to align it.
- See Figure 30 for completed mounting of joystick on micromanipulator

Figure 30 Joystick mounted on micromanipulator

Part III: Building a joystick board

Full list of Materials

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Joystick Breakout PCB	N.A. (Custom Made)	N.A. (Custom Made)	Schematic and PCB here
2	Capacitor, 10 pF, SMT x2	Samsung/Digikey	1276-2154-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10C100JB8NCNC/1276-2154-1-ND/3890240
3	Capacitor, 1 nF, 0603 case x3	Samsung/Digikey	1276-1091-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10C102JB8NNNC/1276-1091-1-ND/3889177
4	Capacitor, 10 nF, SMT x2	Samsung/Digikey	1276-1103-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B103JB8NNNC/1276-1103-1-ND/3889189
5	Capacitor, 0. 1 µF (100 nF), 0603 case	Samsung/Digikey	1276-6998-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B104KO8ZW6C/1276-6998-1-ND/7320640
6	Capacitor, 0.22 µF, radial leads	Samsung/Digikey	1276-1996-1-ND	https://www.digikey.com/product-detail/en/samsung-electro-mechanics/CL10B223JB8NNNC/1276-1996-1-ND/3890082
7	Capacitor, 0.47 µF, 0402 case x2	Samsung/Digikey	1276-2082-1-ND	https://www.digikey.com/en/supplier-centers/s/samsung-electro-mechanics-america
8	Resistor, 160 Ω, 0402 case	Vishay-Dale/Digikey	541-160YCT	https://www.digikey.com/product-detail/en/vishay-dale/CRCW0402160RFKEDHP/541-160YCT-ND/2825954
9	Resistor, 1 kΩ, 0402 case x5	Panasonic/Digikey	P1.00KLCT	https://www.digikey.com/product-detail/en/panasonic-electronic-components/ERJ-2RKF1001X/P1.00KLCT-ND/97341
10	Resistor, 2.6 kΩ, 0402 case	Panasonic/Digikey	P2.61KLCT	https://www.digikey.com/product-detail/en/panasonic-electronic-components/ERJ-2RKF2611X/P2.61KLCT-ND/194243
11	Resistor, 3.3 kΩ, 0402 case x2	Rohm/Digikey	RHM3.3KCDCT	http://www.digikey.com/product-detail/en/MCR01MRTF3301/RHM3.3KCDCT-ND/4083740
12	Resistor, 9 kΩ, 0402 case	Panasonic/Digikey	P9.10KLCT	https://www.digikey.com/product-detail/en/panasonic-electronic-components/ERJ-2RKF9101X/P9.10KLCT-ND/17467224
13	Resistor, 22 kΩ, 0402 case	Panasonic/Digikey	P22KJCT	http://www.digikey.com/product-detail/en/ERJ-2GEJ223X/P22KJCT-ND/146939

#	Part Description	Manufacturer/ Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
14	Voltage comparator IC, SMT	TI/Digikey	TL331IDBVR	http://www.ti.com/lit/ds/symlink/tl331.pdf
15	Op Amp IC, SMT	TI/Digikey	LM358	https://www.digikey.com/product-detail/en/texas-instruments/LM358DR/296-1014-1-ND/404838
16	Voltage regulator	STMicroelectronics/Digikey	L7805CV	https://www.digikey.com/product-detail/en/stmicroelectronics/L7805CV/497-1443-5-ND/585964
17	Touch sensor IC, SMT x2	Atmel/Digikey	AT42QT1011	http://www.atmel.com/images/Atmel-9542-AT42-QTouch-BSW-AT42QT1011_Datasheet.pdf
18	Transistor x2	Micro Commercial Co/Digikey	2N3904	https://www.digikey.com/product-detail/en/micro-commercial-co/2N3904-AP/2N3904-APCT-ND/950591?utm_adgroup=Semiconductor%20Modules&gclid=EAIaIQobChMIpO3hideR2gIVFFcNCh0mPwH6EAAYASAAEgIVBvD_BwE
19	2-pin header x4	Hirose Electric/Digikey	DF3A-2P-2DSA	http://www.digikey.com/product-detail/en/DF3A-2P-2DSA/H2094-ND/141512
20	3-pin header x2	Hirose Electric/Digikey	DF3A-3P-2DSA	http://www.digikey.com/product-detail/en/DF3A-3P-2DSA/H2095-ND/141515
21	4-pin header	Hirose Electric/Digikey	DF3A-4P-2DSA	http://www.digikey.com/product-detail/en/DF3A-4P-2DSA/H2096-ND/141518
22	DB-9 connector, male, through hole	Amphenol/Digikey	A34064-ND	https://www.digikey.com/product-detail/en/te-connectivity-amp-connectors/5747871-2/A34064-ND/1123840
23	DB-15 connector, female, RA through hole	Amphenol/Digikey		https://www.digikey.com/product-detail/en/amphenol-commercial-products/17EBH-015-S-AM-0-10/17EBH-015-S-AM-0-10-ND/1242549
24	Heat sink	Aavid	HS115-ND	https://www.digikey.com/product-detail/en/507302B00000G/HS115-ND/5849
25	Heat sink compound, Silicone (type Z9)	GC Electronics	10-8109	http://www.gcelectronics.com/order/DataSheets/10-8109%2010-8108%2010-8107-10%2010-8107-100%2010-8106%20Silicone%20(Z9).pdf

Building Instructions

General notes

The joystick board collects and conditions the signals from the various sensors, including the joystick, and passes the resulting signals to the sb-RIO. The schematic contains the locations of where the components

have to be soldered. If soldering, especially surface mount soldering, is new to you, there are many good guides available on the internet.

1. Soldering the SMT components
2. Soldering the through-hole components

Part IV: Building the lick port with lick sensor and solenoid valve

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Lick spout, Coulbourn Instruments	Coulbourn Instruments	H24-01-TB-01	http://www.coulbourn.com/v/vspfiles/assets/manuals/habitesth-serieshardwareuserguide.pdf
2	1/16” ID food-grade plastic tubing	US Plastics	56400	http://www.usplastic.com/catalog/item.aspx?sku=56400&gclid=EAIaIQobChMIlcKbn7_m1gIVCYVpCh3DSwUWEAQYASABEgIvWvD_BwE
3	1/16” barbed plug	VWR	P0-1NK	https://us.vwr.com/store/product/14459897/barbed-plugs-eldon-james
4	Solenoid valve	The Lee Company	LHDA2433215H	http://www.theleeco.com/electro-fluidic-systems/solenoid-valves/lhd/3-port-ported-style.cfm
5	Photointerrupter switch	Lite-On Inc./Digikey	LTH-301-32	https://www.digikey.com/product-detail/en/lite-on-inc/LTH-301-32/160-1936-ND/3198349
6	3-pin receptacle	Hirose/Digikey	DF3-3S-2C	http://www.digikey.com/product-detail/en/DF3-3S-2C/H2084-ND/141482
7	4-pin receptacle	Hirose/Digikey	DF3-4S-2C	https://www.digikey.com/product-detail/en/DF3-4S-2C/H2085-ND/141485
8	Crimp terminals	Hirose/Digikey	DF3-2428SC	https://www.digikey.com/product-detail/en/DF3-2428SC/H1500-ND/141644
9	Stranded, insulated wire, approximately 26 AWG			
10	Heatshrink tubing			

Building Instructions

General notes

The lick port consists of a lick spout, a solenoid valve, and a lick sensor, and associated cables. The lick sensor and the solenoid are controlled via the joystick PCB. The procedure for the lick sensor is very similar to the nosepoke sensor. Note that while this research used a beam-break lick sensor, we have subsequently transitioned to using a capacitive lick sensor.

Figure 31 Materials for lick port/sensor/valve. Clockwise from top left: Wire, heatshrink tubing, water spout, solenoid valve, 1/16" tubing, 1/16" plug, crimp terminals, 3-pin and 4-pin receptacles, phototransistor interrupt switch

1. Extract the transmitter & receiver from the plastic photointerrupt switch housing

- Use a cutting tool (for example a Dremel with a cutting wheel) to carefully remove the transmitter and receiver from the plastic housing. Take care not to damage the transmitter and receiver.
- Paint the back side of both the transmitter and receiver black to block spurious light signals from the environment.
- See Figure 32 for the results of this step.

2. Cut and strip wire leads

- Cut two ground wires, and two transmit/receive wires, approximately 8 inches each. Color coding is recommended.
- Use a wire stripper to strip the ends of the wires.
- See Figure 34 for the results of this step.

Figure 32 Transmitter (left) and receiver (right) extracted from their housing (top) and coated

3. Solder wires to transmitter and receiver

- The receiver needs an “LickOut” wire (lick signal) and a ground wire, and the transmitter needs a 5V wire and a ground wire.
- See Figure 33 to identify terminals of the transmitter and receiver.
- Solder the ground wire, LickOut, and 5V wires onto the corresponding terminals.
- Cover bare metal connections with heatshrink tubing.
- See Figure 37 for the results of this step

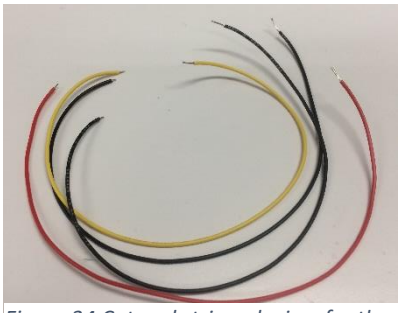

Figure 34 Cut and stripped wires for the lick sensor

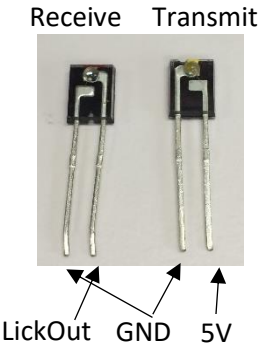

Figure 33 Identifying the terminals of the lick sensor transmitter and receiver

4. Add receptacle

- Add crimp terminals to the three stripped ends of the lick sensor wires
- Optional: braid wires
- Insert the crimped ends of the wires into the 3-pin receptacle in the order shown in Figure 35

Figure 35 Lick sensor wire receptacle, showing connection order. Red = 5V, Black = Ground, Yellow = signal out

5. Glue lick sensor to lick spout

- Use superglue to affix the transmitter and receiver on either side of the lick spout so the beam from the transmitter’s lens passes right in front of the lick spout hole and then into the receiver’s lens.
- Make sure that the wires stick close together and close to the sides of the lick spout for about 2 inches, or the spout won’t fit in the custom lick spout holder later.
- Line up the lenses so the beam will pass the lick spout hole at a distance of approximately 1 mm.
- See Figure 38 for the results of this step.

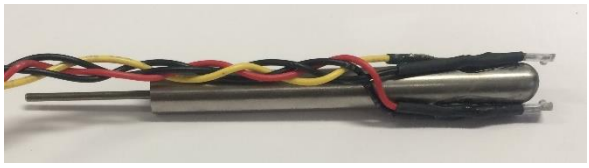

Figure 38 Lick sensor attached to water spout

6. Add wires to solenoid valve

- Cut two wires to a length of approximately 8” each.
- Strip both ends of the wires.

Figure 36 Assembled lick sensor

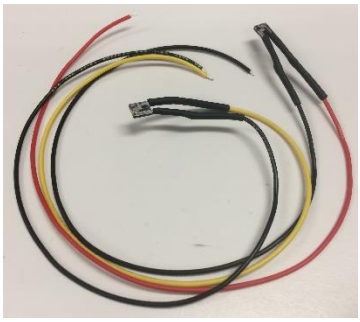

Figure 37 Transmitter and receiver with wires and heatshrink tubing

- Solder the wires onto the solenoid valve. The solenoid valve is nonpolar, so the order of the wires is not important.
- Add heatshrink tubing to the bare wire joints for insulation and strength.
- Add crimp terminals to the other ends of the wire, and insert into the 3-pin receptacle as shown in Figure 39.

Figure 40 Solenoid valve with wires connected

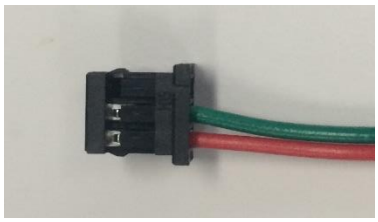

Figure 39 Solenoid valve wires inserted into receptacle. Only the bottom and middle spots should be filled, although the order doesn't matter.

7. Add tubes to solenoid valve

- Cut an approximately 1" section of 1/16" tubing.
- Push the 1" piece of tubing onto the valve outlet closest to the wire terminals, then add a 1/16" plug to seal that outlet
- Cut two more approximately 12" lengths of tubing
- Push the two 12" lengths of tubing onto the other two valve outlets.
- See Figure 41 for the results of this step.

8. Connect the valve to the lick spout

- Push the free end of one of the 12" sections of tubing from the valve onto the lick spout tube that extends from the bottom. Push the tubing far enough on to make a good seal.
- See Figure 42 for the completed assembly of the solenoid valve, lick spout, and lick sensor.

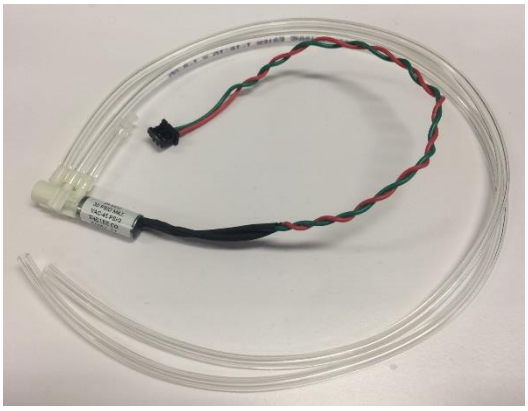

Figure 41 Solenoid valve with wires and tubes connected

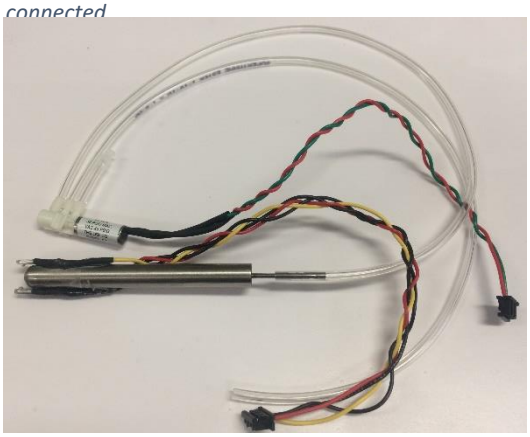

Figure 42 Completed solenoid valve/water spout/lick sensor assembly

Part V: Building a fixed post touch sensor

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Machined ball for touch sensor electrode	N.A. (Custom Made)	N.A. (Custom Made)	N.A. (Custom Made)
2	Stainless Steel 304 Hypodermic Tubing, 15 Gauge, 0.072" OD, 0.0625" ID, 0.00475" Wall, 36" Length	Amazon		https://www.amazon.com/gp/product/B004WPQJHC
3	Machined shafts for bearings (Stainless Steel 316L Seamless Round Tubing, 1/8" OD, 0.069" ID, 0.028" Wall, 36" Length)	Amazon		https://www.amazon.com/gp/product/B004XN9LLE
4	Ultra-Flexible PVC Lead Wire, 38 AWG	Cooner Wire Company	NUF38-1650T-WHITE	https://www.coonerwire.com/pvc-hookup-wire-nuf-series/
5	Fixed post holder	N.A. (Custom Made)	N.A. (Custom Made)	
6	Dental Acrylic		Flow-It ALC Flowable Composite, P/N: N11H	
7	Coltolux LED UV curing light	Coltene	C7970100115	https://nam.coltene.com/products/restoration/curing-lights/coltolux-led/coltoluxR-led/
8	Superglue (Loctite 401)	Loctite	401	http://www.loctite.sg/sea/content_data/93806_NEWCA401EN.pdf
9	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF
10	Silver conductive paint	GC Electronics	22-023	http://www.gcelectronics.com/order/DataSheets/22-023,%2022-024%20Silver%20Print%20II%20Conductive%20Paint.pdf
11	2-pin receptacle	Hirose/Digikey	DF3-2S-2C	https://www.digikey.com/product-detail/en/DF3-2S-2C/H2083-ND/141479
12	Crimp terminals	Hirose/Digikey	DF3-2428SC	https://www.digikey.com/product-detail/en/DF3-2428SC/H1500-ND/141644
13	Stranded insulated wire, approximately 26 AWG			
14	Heatshrink tubing, small (optional)			

Building Instructions

General notes

The procedure for creating the fixed touch post is almost the same as creating the joystick electrode. Therefore, rather than repeat the instructions, refer to the section “2. Making the Joystick Electrode” above, and to the differences listed below.

1. Fabricating the fixed post tube

- The length of the fixed post tube should be at least 1 inch, but the exact length is not important.
- The tube does NOT need a side-hole. The leads can come directly out the bottom of the tube.

2. The fixed-post holder

- Since the tube does not sit on a gimbal as in the case of the joystick electrode, the post needs some support and stabilization. This is provided by a custom 3D printed fixed post holder.
- Slide the post holder onto the tube. Do NOT glue it on yet.

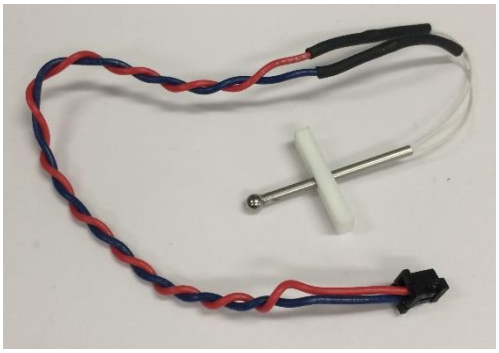

Figure 43 Completed fixed post touch sensor

3. The connector

- Rather than a DB-9 connector, the fixed post connects to the joystick board via a twisted pair of wires that lead to a 2-pin receptacle, which plugs into a header on the JS board.
- Carefully strip and solder the free ends of the Cooner wires from the fixed post onto two 26 AWG wires twisted into a pair, approximately 8” long.
- Add heatshrink tubing or dental acrylic to reinforce the connections between the Cooner wires and the 26 AWG wires.
- Apply crimp terminals to the other ends of the 26 AWG wires, and insert them into the 2-pin receptacle. The order doesn’t matter.
- See Figure 43 for the completed fixed post touch sensor

Part VI: Building the nosepoke sensor

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Photointerrupter switch	Lite-On Inc./Digikey	LTH-301-32	https://www.digikey.com/product-detail/en/lite-on-inc/LTH-301-32/160-1936-ND/3198349
2	Resistor, 200Ω, axial lead	Stackpole Electronics/Digikey	CF14JT200RCT-ND	https://www.digikey.com/product-detail/en/stackpole-electronics-inc/CF14JT200R/CF14JT200RCT-ND/1830333
3	3-pin receptacle	Hirose/Digikey	DF3-3S-2C	http://www.digikey.com/product-detail/en/DF3-3S-2C/H2084-ND/141482
4	Crimp terminals	Hirose/Digikey	DF3-2428SC	https://www.digikey.com/product-detail/en/DF3-2428SC/H1500-ND/141644
5	Stranded, insulated wire, approximately 26 AWG			
6	Heatshrink tubing			

Building Instructions

General notes

The nosepoke sensor detects when the mouse pokes its nose through the hole in the cage that leads to the lick spout. It operates by shining an infrared (IR) beam from a transmitter LED on one side of the hole to a receiver phototransistor on the other side. When the mouse pokes its nose in, the IR beam is interrupted. Note that circuitry on the joystick PCB is necessary for biasing and interpreting the transmitter and receiver.

Figure 44 Nosepoke sensor materials. Clockwise from top left: three spools of 26 AWG stranded wire, heatshrink wrap, crimp terminals, 3-pin receptacle, IR transmitter & receiver. Not pictured: 200 Ω resistor.

1. Detach the transmitter/receiver from each other

- Cut away the plastic bridge connecting the transmitter/receiver

2. Cut and strip wire leads

- Cut three ground wires (~4”), a transmit/5V wire (~7”), and a receive wire (~8”). Color coding is recommended.
- Use a wire stripper to strip the ends of the wires.
- See Figure 45 for the results of this step.

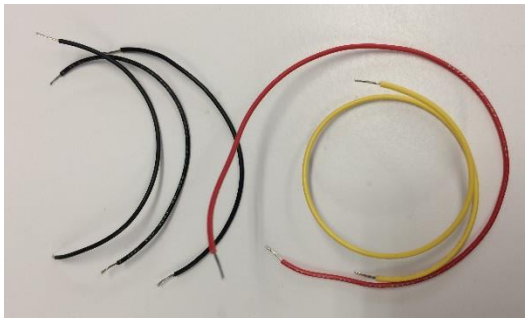

Figure 45 Cut and stripped wires for the nosepoke sensor

3. Add wires and resistor to transmitter and receiver

- The receiver needs an “NPout” wire (nosepoke signal) and a ground wire, and the transmitter needs a 5V wire and a ground wire. The transmitter also requires a 200 Ω current limiting resistor. We will incorporate this resistor as part of the transmitter’s power wire.
- See Figure 46 to identify terminals of the transmitter and receiver.
- Solder a ground wire onto each ground terminal
- Solder the NPout and 5V wires onto the corresponding terminals.

- Cut and strip a break in the 5V wire, then solder in the 200 Ω resistor to close the gap.
- See Figure 50 for the results of this step

4. Solder wires and resistor onto transmitter and receiver

- Solder the two ground wires together along with a common ground wire.
- Cover bare metal connections with heatshrink wrap.
- See Figure 47 for the results of this step.

5. Add receptacle

- Add crimp terminals to the three stripped ends of the nosepoke sensor wires
- Insert the crimped ends of the wires into the 3-pin receptacle in the order shown in Figure 48

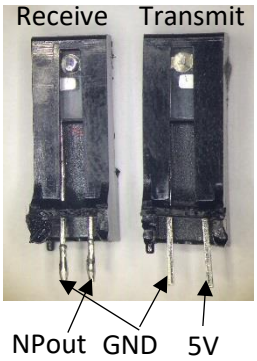

Figure 46 Identifying the terminals of the transmitter and receiver

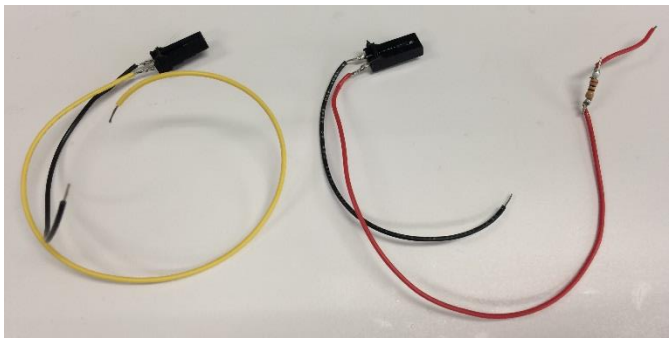

Figure 50 Nosepoke sensor with wires and resistor soldered

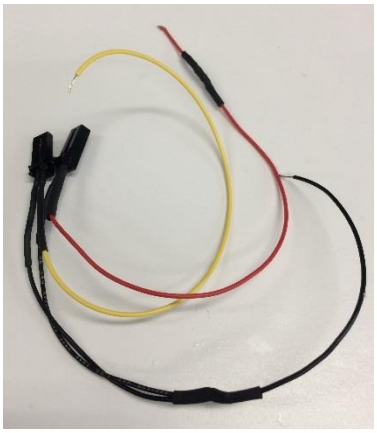

Figure 47 Ground wires soldered together, bare metal covered in heatshrink wrap

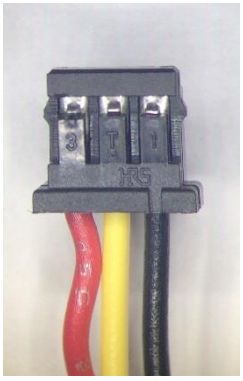

Figure 48 Nosepoke wire receptacle, showing connection order. Red = 5V, Yellow = signal out, Black = Ground

Figure 49 Completed nosepoke sensor

Part VII: Building the masking light

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	LED light strip			
2	2-pin receptacle	Hirose/Digikey	DF3-2S-2C	https://www.digikey.com/product-detail/en/DF3-2S-2C/H2083-ND/141479
3	Crimp terminals	Hirose/Digikey	DF3-2428SC	https://www.digikey.com/product-detail/en/DF3-2428SC/H1500-ND/141644
4	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF
5	Stranded, insulated wire, approximately 26 AWG			
6	Heatshrink tubing			

Building Instructions

General notes

The masking light is an LED with wires and a 2-pin connector. It plugs into the joystick board and will be attached to the homecage above the lick port. Its purpose is to prevent mice from visually discriminating between trials when the optogenetic laser is on or off due to laser light leaking from the cannula.

Figure 51 Materials for masking light. Clockwise from top left: wire, heatshrink tubing, crimp terminals, 2-pin receptacle, LED light strip

1. Cut one LED unit off of the strip

- Cut one of the LED units off of the strip along the printed divider lines.
- Peel and cut away the plastic coating on the edge of the LED unit that covers the copper terminals marked “+” and “-“
- See Figure 53 for the results of this step.

2. Solder wires onto the LED

- Cut and strip two wires approximately 8” long

- Solder one end of each wire onto the exposed terminals on the LED unit marked “+” and “-“. Color coding is recommended.
- Coat the exposed junction with epoxy or dental acrylic to insulate and strengthen the joint.
- See Figure 52 for the results of this step.

3. Add receptacle

- Add crimp terminals to the two stripped ends of the wires
- Optional: twist wires
- Insert the crimped ends of the wires into the 2-pin receptacle in the order shown in Figure 55.

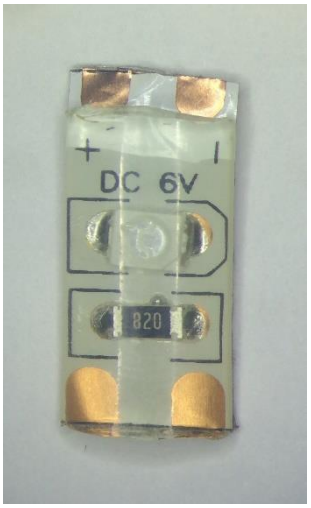

Figure 53 LED unit cut from strip, with terminals exposed

Figure 52 LED with terminals coated

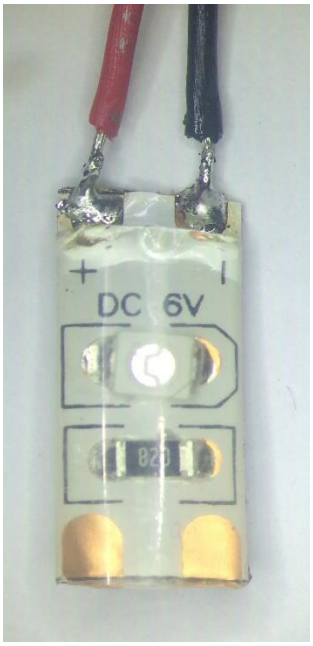

Figure 56 LED with wires soldered onto terminals. Note that the terminals are marked "+" and "-" to indicate which one should be connected to the 5V and GND wires

Figure 55 Receptacle for LED

Figure 54 Completed masking light

Part VIII: Building the water reservoir

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Lixit Flat sided water bottle		QLCSA-5	http://www.lixit.com/node/653
2	1/16” hose barb to NPT adapter			
3	Luer Lock female x female connector x2			
4	5-minute epoxy (HARDMAN® Extra-Fast Setting Epoxy)	Hardman	04001	http://www.royaladhesives.com/Files/Hardman-Structural/DOUBLE-BUBBLE_04001_RED_TDS.PDF

Building Instructions

General notes

The water reservoir is a modified consumer rodent water bottle. The reservoir has a hose barb port at the bottom to connect to the lick spout intake tube. It also has two luer lock ports – one for filling on top, and one for draining to a pre-set level. These can be connected to an automatic water system to easily maintain the appropriate water height in each bottle, and therefore maintain a constant dispense volume at the lick spout. The constant dispense volume can be calibrated by adjusting the duration of solenoid valve opening.

Figure 57 Reservoir materials. Clockwise from top left: Water bottle, luer lock connectors x2, hose barb x NPT adapter, epoxy

1. Disassemble the bottle

- Remove the bottle from its packaging
- Unscrew the cap, separate the rubber seal and the metal spout. Discard the spout.

2. Install bottom outlet adapter

- Using a utility knife, cut off the narrower rubber neck of the rubber seal, leaving a thin rubber gasket behind
- Insert the adapter in the opening in the bottle cap
- Using a combination of pushing, stretching, and screwing, push the rubber gasket onto the threaded part of the adapter, until both the adapter flange and the gasket are firmly flush against either side of the cap. If a large vise is available, it’s also possible to simply push-fit the adapter into the rubber seal using a vise, even without cutting off the seal neck or widening the opening.
- See Figure 58 and Figure 59 for the results of this step.

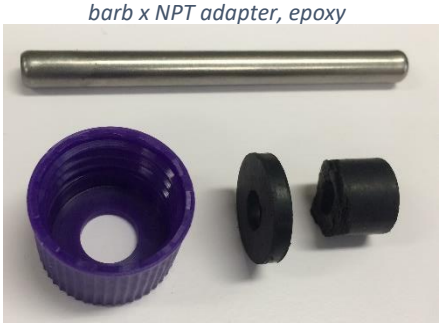

Figure 58 Neck removed from rubber seal. The metal spout at the top and the extra rubber on the right, can be discarded.

3. Add fill and drain ports

- Optional: remove the bracket to make it easier to manipulate the bottle.
- Drill a 1/4” hole in the top and flat side of the bottle. The side hole should be approximately 1 cm below the top surface of the bottle.
- Insert the luer lock connectors into the two holes.
- Use a generous amount of epoxy between the bottle and the luer lock connector and around the lip of the connector to make a watertight seal.
- See Figure 60 for the results of this step.

Figure 59 Adapter and seal installed in cap. Outside view, left, inside view, right.

4. Add pressure relief hole

- Drill a 1/16” hole somewhere on the top surface of the reservoir to relieve pressure during operation.

5. Screw cap back on and test seals

- Screw the cap back on
- Test to make sure the three ports are watertight by filling the bottle with water, blocking the ports off (attaching a piece of crimped tubing to each port is an easy way), and watching for drips when squeezing the bottle gently
- Make sure there are no plastic fragments left in the reservoir that could clog up the ports or tubing.
- See Figure 61 for the completed water reservoir.

Figure 60 Luer lock fill and rain ports inserted and epoxied

Figure 61 Completed water reservoir

Part IX: Assembling the home cage

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Joystick mounted on micromanipulator		N.A. (Custom Made)	
2	Protective umbrella		N.A. (Custom Made)	
3	Joystick board		N.A. (Custom Made)	
4	Fixed post touch sensor		N.A. (Custom Made)	
5	Nosepoke sensor		N.A. (Custom Made)	
6	Lick port		N.A. (Custom Made)	
7	Masking light		N.A. (Custom Made)	
8	Machined home cage			
9	Water reservoir		N.A. (Custom Made)	
10	L brackets x2		N.A. (Custom Made)	
11	Walls x2		N.A. (Custom Made)	
12	Lick sensor metal support panels x2		N.A. (Custom Made)	
13	Lick spout holder		N.A. (Custom Made)	
14	1/4"-20 nut			
15	4-40 x 3/8" length screws x10			
16	4-40 nuts x8			
17	8-32 bolts and nuts x2			
18	4-40 D-Sub hex head screw x2			
19	8-32 x 3/8” thumb screw			
20	Copper sheet		6" X 24"/ 10 Mil (30 ga.) Copper Sheet	https://basiccopper.com/6x2410milcos.html

Building Instructions

General notes

The completed homecage contains all the components assembled in the previous sections. It is designed to be part of a scalable, high throughput, largely automated mouse training and neurobiology and behavior research system. Note that it can be helpful to have a block to set the homecage on so the components underneath aren't supporting any weight. It can also be helpful to have a heavy block in the back end of the cage to prevent it from tipping.

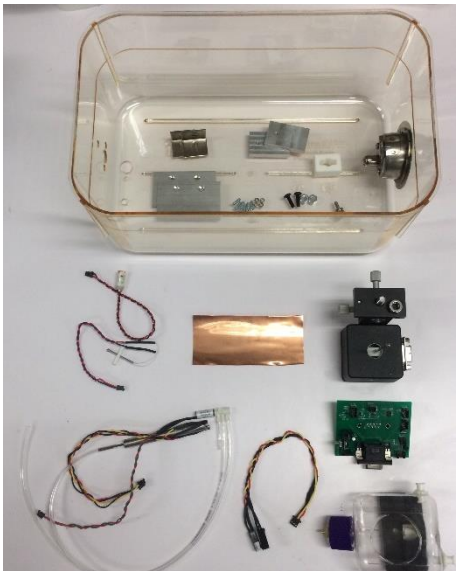

Figure 62 Home cage materials. Clockwise from top left: Homecage (top not pictured), L brackets, walls, lick port support panels, bolts & nuts, spout holder, joystick, joystick board, reservoir, nosepoke sensor, lick port, fixed post touch sensor, copper sheet

1. Drill holes for the lick port support panels:

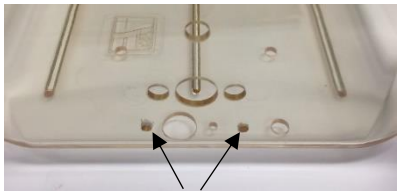

Figure 63 Two holes for lick port support panels on front of cage

- Mark two points 3/4" above the bottom front edge of homecage, and 1 1/4" apart, centered on the nosepoke hole.
- Drill 1/8" holes on the two marks
- Using two 4-40 screws, screw each lick port support panel onto the front of the home cage. See Figure 64 for the results of this step.

2. Install the lick port:

Figure 64 Lick port support panels installed (view from inside)

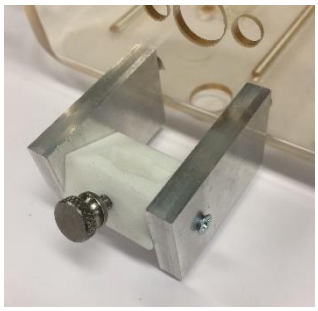

Figure 65 Water spout holder installed

- Insert the lick spout holder between the two lick port support panels, and screw it in with two 4-40 screws.
- Add a thumbscrew to the top hole on the lick spout holder. This will fun ction as a setscrew to hold the lick spout at the desired position. You may need to clear out the hole with a drill to get the thumbscrew in.
- Insert the lick spout into the lick spout holder, angle it so a mouse can just access it from the nosepoke hole, and tighten it into place with the thumbscrew. See Figure 66 for the results of this step.

3. Adding the nosepoke sensor and masking light:

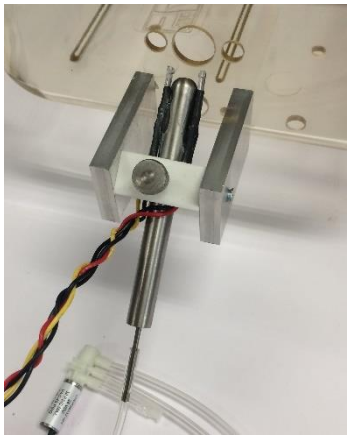

Figure 66 Lick port installed

- Press the nosepoke sensor transmitter and receiver through the two holes on either side of the nosepoke hole.
- You may need to either widen the nosepoke holes slightly, or round the corners of the nosepoke sensor slightly to allow it to fit – a Dremel tool works for this.
- There should be approximately 1/4" of the sensor exposed on the inside of the cage.
- Ensure the transmitter and receiver are facing each other

- Apply superglue on either side of the LED on the masking light
- Press masking light onto hole in top center of homecage, above the nosepoke hole, allow the glue to dry.
- See Figure 68 for the results of this step.

Figure 67 Joystick with umbrella

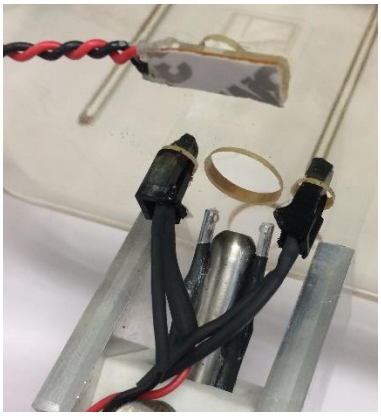

Figure 68 Nosepoke sensor and masking light installed

4. Add protective umbrella on joystick electrode

- The umbrella prevents bedding from falling out of the cage hole and into the joystick housing.
- Drill out the center hole on the protective umbrella with a 1/8” drill bit.
- Gently insert the electrode into the umbrella until it is roughly 1/4” above the joystick housing. Glue it in place with dental acrylic.
- See Figure 67 for the results of this step.

5. Mounting joystick under cage

- Insert micromanipulator mounting screw and joystick post into the two holes on the bottom of the cage at the front. Loosely secure the micromanipulator with the 1/4” nut.
- Check to make sure that the top of the joystick ball is 11/16” above the cage floor.
- Make sure joystick and micromanipulator remain vertical, and the micromanipulator and joystick housing remain square to the cage, as you tighten the nut
- Tighten the nut well with a wrench so it won't shift. You may want to use threadlock to prevent slipping.
- Use the two adjustment knobs on the micromanipulator to precisely center the joystick in the joystick hole.
- See Figure 69 for the results of this step.

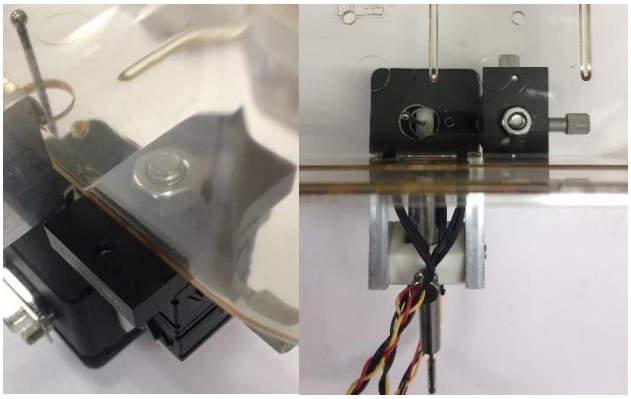

Figure 69 Joystick mounted on cage. Left: View from outside. Right: View from above (Note that the umbrella is missing in this photo).

6. Add fixed post:

- Take care not to bump the delicate joystick electrode during this process.
- Gently push post through the hole next to the joystick hole in the cage bottom from below. If there is any resistance, stop and widen the hole slightly with a 1/8” drill bit. Do not force the delicate capacitive ball through the hole!
- Superglue post spacer to underside of the cage. Do not glue the post to the spacer yet, as the height needs to be precisely adjusted.
- Position the fixed post electrode so the fixed post ball is about 1/2 an electrode ball below the joystick ball. This offset gives the animal better stability for manipulating the joystick.

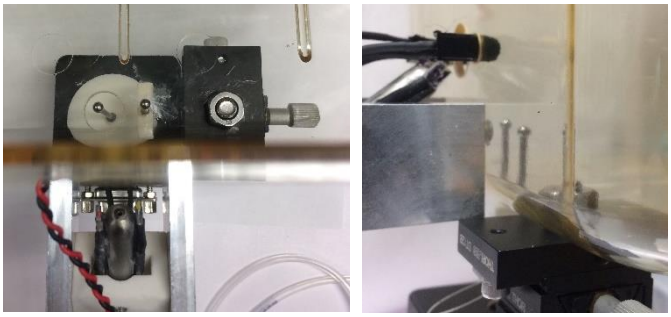

Figure 70 Fixed post touch sensor. Left: Top view. Right: Side view.

- Make sure the fixed post is vertical
- Glue fixed post electrode in place – ensure that the post doesn't shift or tilt as the glue dries.
- See Figure 70 for the results of this step.

7. Plug in JS board

- Gently plug the joystick board DB9 connector into the joystick DB9 connector. Make sure you don't change the alignment of the joystick in the process.
- Recommended: Screw joystick board into joystick housing DB9 connector using approximately 1/2" 4-40 screws
- Connect cables as shown in Figure 72.
- See Figure 71 for the results of this step.

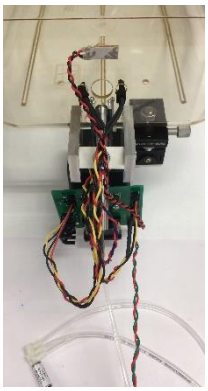

Figure 71 All sensors installed

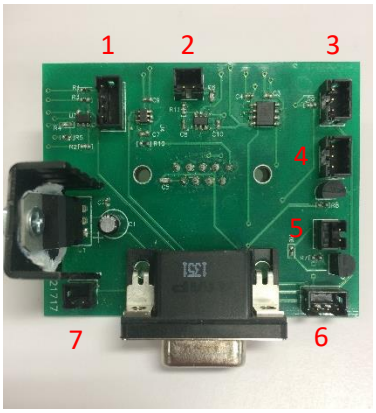

Figure 72 Joystick board connectors:
1: Lick sensor
2: Fixed post touch sensor
3: Nosepoke sensor
4: Solenoid valve
5: Masking light
6 & 7: No connection (extra)

8. Add walls:

- Countersink one side of wall holes to prevent the screw head from sticking out
- Screw wall into L-bracket
- Screw L-bracket into cage bottom so mouse has approximately 1 1/2" of space between walls to walk through.
- Take care not to damage joystick and fixed post electrodes.
- See Figure 73 for the results of this step.

Figure 73 From left to right: Wa

9. Add gutter:

- The gutter will redirect any water drips away from the joystick and electronics.
- Cut a roughly 2"x6" rectangle of the sheet copper
- Fold a lip up along the long sides to contain drips
- Cut away the lip along about 1/2" of the start of the gutter, to provide an attachment flap
- Glue or tape the gutter to the lick port support panels underneath the lick port

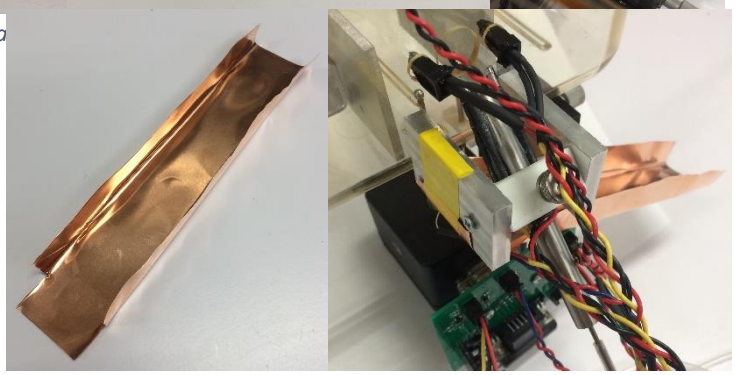

Figure 74 Gutter. Left: Formed, Right: Installed

- Flare out the sides of the lip under the lick port to maximize the protected area
- See Figure 74 for the results of this step.

Figure 76 Custom cover and cage lid

10. Assemble cage lid

- The cage lid consists of a commercially available cage lid machined to have a large opening on the top. A custom cover fits in the large opening in the cage lid, and has a long slot to allow freely moving mice to be attached to electrodes or fiber optics. The reservoir also attaches to front of the cage lid
- Mark the corresponding locations of the four holes around the perimeter of the opening in the lid on the custom cover.
- Drill four 1/8” holes where the four marks are on the custom cover
- See Figure 75 for the custom cover with drilled holes
- Remove the protective film from both sides of the custom cover
- Screw the custom cover onto the cage lid with 4-40 x 3/8” screws, and secure with nuts.
- Remove the adhesive backing on the mounting bracket for the water reservoir and firmly press it onto the front lip of the cage lid off to one side.
- See Figure 77 for the results of this step.

Figure 75 Custom cover with four holes drilled

Figure 78 Cage lid with custom cover

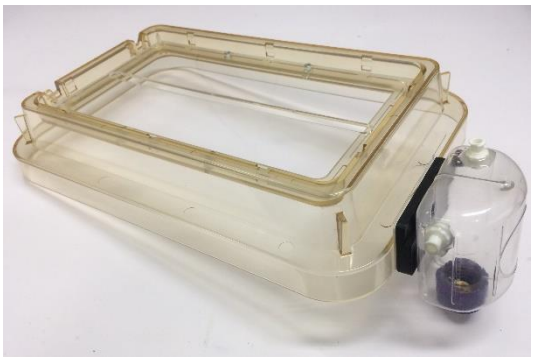

Figure 77 Completed cage lid

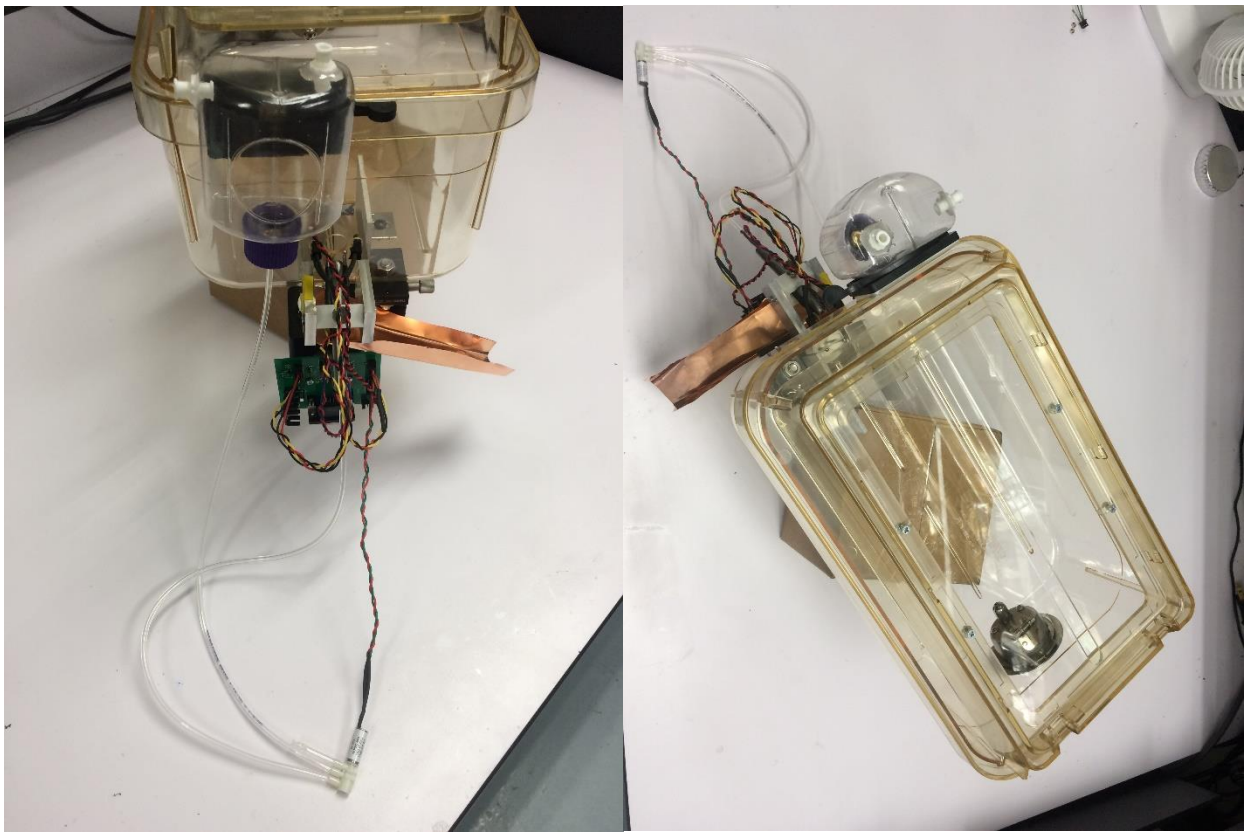

Figure 79 Completed home cage

Part X: Building the optogenetic system

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Doric Laser Diode Fiber Light Source, 2 channel, 450 nm		LDFLS_450/075_450 /075	http://doriclenses.com/life-sciences/laser-diode-fiber-light-sources/910-laser-diode-fiber-light-source-2-channel-model.html#/ld_wavelengths-450_nm_75_mw/ld_wavelengths_2-450_nm_75_mw
2	Fiber commutator		FRJ_1x2i_FC-2FC	http://doriclenses.com/life-sciences/fiber-optic-rotary-joints/809-1x2-fiber-optic-rotary-joints-intensity-division.html
3	Mounting plate for commutators		N.A. (Custom Made)	
4	Fiber optic cable, male to male SMA, Thor Labs		FG200UCC 200um 0.22NA	
5	Fiber optic cable, male SMA to ferrule insert			
6	Doric commutator mounting bracket		Holder_FRJ_large	http://doriclenses.com/life-sciences/holders-for-rotary-joints/819-holder-for-frj1x2-frj1x4-erj-aerj-hrj-oe-and-ledfrj-1ch.html
7	1/4”-20 x 1” screws			
8	1/4”-20 nuts			

Building Instructions

General notes

The optogenetic system consists of a laser light source. The light is sent via fiber optic cable to a fiber optic cranial implant on a mouse. To allow the mouse to freely turn in the cage, an optical commutator is used in the optical path. The commutator mounts on a custom plate that sits in the rack above each homecage.

Figure 80 Optogenetic system materials. Clockwise from top left: Custom mounting plate, laser light source, commutator, commutation mounting bracket, 1/4"x20 bolts and nuts, fiber optic cable (black, male SMA to ferrule), fiber optic cable (orange, male to male)

1. Screw commutator into mounting bracket

- See Figure 81 for the results of this step.

2. Bolt bracket to custom mounting plate

- Use the 1/4"x20 bolts and nuts to fix the commutator roughly in the middle of the opening in the plate.
- Note that the bracket should go on top, so in the unlikely event that the screws loosen and come out, the commutator will not fall.
- See Figure 82 for the results of this step.

3. Connect the fiber optic cables.

- The male-male cable should go on top (the non-rotating port). The other end of this cable will connect to the laser light source.
- The male-ferrule cable should go on the bottom (the rotating port). The other end of this cable will connect to the implant.
- See Figure 84 for the results of this step.

Figure 81 Commutator screwed into bracket

4. Use tape to hold excess cable in place

- Take the extra fiber optic cable that connects the laser to the commutator and coil it on the top of the mounting plate.
- Use tape to fix the coil in position so it won't shift during the experiment.
- Note that changes in the radius of curvature of the fiber optic cable during the experiment will cause the light power level reaching the implant to change.
- See Figure 83 for the results of this step.

Figure 82 Commutator and bracket mounted to custom plate. Left: View from top. Right: View from bottom

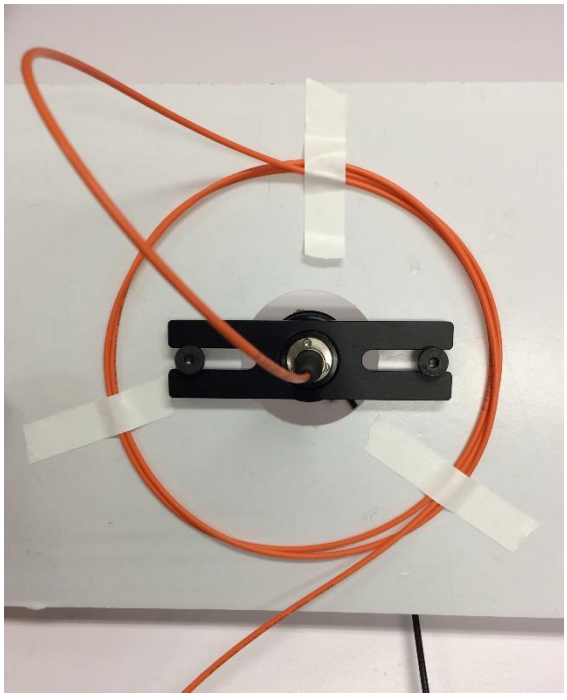

Figure 83 Cable management

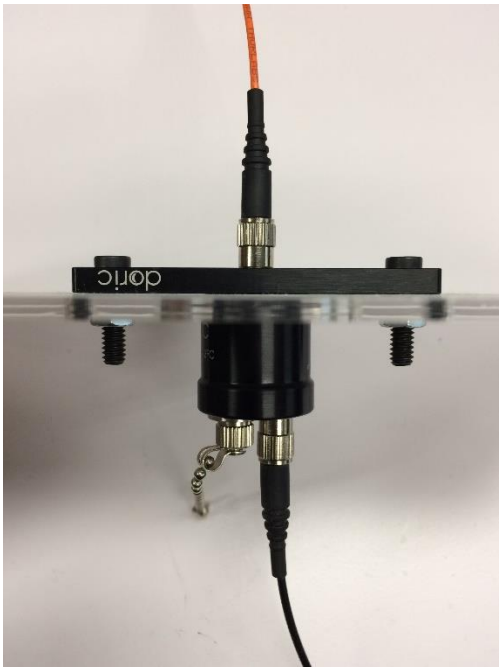

Figure 84 Fiber optic cables connected

Part XI: Building the RIO breakout board

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	RIO breakout board		N.A. (Custom Made)	
2	DB-15 RA male panel mount through-hole receptacle x4			
3	BNC panel mount receptacle, female x4			
4	Thermistors, surface mount x28		PRF18BB471QB5RB	https://www.digikey.com/product-detail/en/murata-electronics-north-america/PRF18BB471QB5RB/490-8499-1-ND/4380762
5	Schottke Diodes, surface mount x28		TBAT54S	https://www.digikey.com/product-detail/en/toshiba-semiconductor-and-storage/TBAT54SLM/TBAT54SLMCT-ND/6109133
6	50 pin ribbon cable header x2			
7	20-22 AWG wires for power x2			

Building Instructions

General notes

The RIO breakout board is a component of the DAQ system. It plays two roles – protecting the analog and digital IO ports of the expensive sbRIO board, and routes the sbRIO IO channels into four groups and connects them to DB-15 and BNC receptacles so they can be easily connected to the homecages and laser light sources. Each RIO breakout board services a single sbRIO board, and supports up to four homecages.

1. Solder the SMT components
2. Solder the through-hole components
3. Cut and strip power wires
    - Cut and strip two wires, about 1 foot each.
    - Color coding is recommended – color scheme used here: red=high, white=low
    - Solder into power connection through holes in RIO breakout board.

Part XII: Building the data acquisition system (DAQ)

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Single board RIO		sbRIO-9636	http://sine.ni.com/nips/cds/view/p/lang/en/nid/210421
2	Completed RIO breakout board		N.A. (Custom Made)	Schematic and PCB here
3	Ribbon cables x2			
4	RIO power connector (NI Minfit Pigtail 2C 12 inches)		152834A01	
5	Wire, 18-22 AWG			
6	4-40x3/8” screws x49			
7	4-40x1/4” screws x3			
8	4-40 nuts x8			
9	4-40 x 1/2" spacers x3			
10	4-40 x 1” spacers x3			
11	Heatshrink tubing			
12	Enclosure (Rackmount Chassis 19" 2U 84HP 340MM) with custom front panel openings		20860127	https://www.digikey.com/product-detail/en/schroff/20860127/1439-1130-ND/4209859
13	Power supply		P37-15T	http://www.polytrondevices.com/products/power-modules/linear-encapsulated-power-modules
14	Universal power cord x2		03130	https://www.cablestogo.com/product/03130/6ft-18-awg-universal-power-cord-nema-5-15p-to-iec320c13-taa-compliant
15	Panel mount power receptacle with switch		76400003	http://www.qualtekusa.com/images/AC_Receptacles/pdfs/76400003.pdf
16	Panel mount ethernet receptacle			
17	DB-15 cables, CNC Tech x4		731-10061-00200	https://www.digikey.com/product-detail/en/cnc-tech/731-10061-00200/1175-1157-ND/3064888
18	Completed homecage x4			
19	Control & storage computer			
20	Ethernet cable, ~1 foot			
21	Ethernet cable, long enough to reach network access point			
22	LabVIEW 2013			
23	Rodent VI LabVIEW software			

Building Instructions

General notes

The data acquisition system consists of a single-board RIO DAQ from National Instruments, which has a large array of digital and analog input/output (IO) channels, a custom PCB that protects and distributes those channels, an enclosure for the DAQ, DB-15 cables to connect the DAQ to each homecage, and a control/storage computer which controls the DAQ via LabVIEW software, and stores the sensor data it receives. Each DAQ system can host up to four homecages.

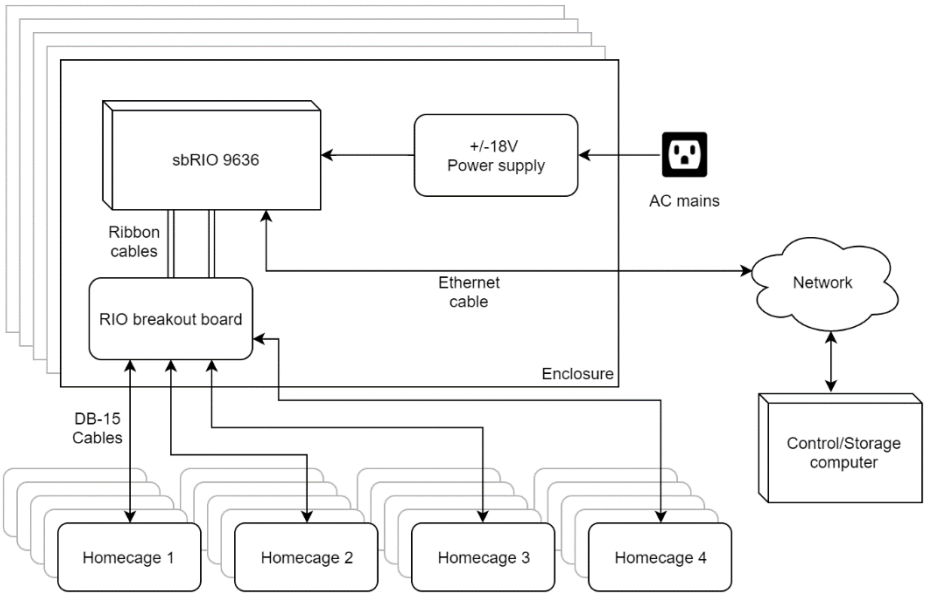

Figure 85 DAQ system schematic

Figure 86 sbRIO supplies. Clockwise from top left: sbRIO-9636 x2, NI Minifit Pigtail x2, NI 50 pin ribbon cable x2, mounting hardware (not used)

Figure 89 Required cords: 2 short ethernet cords, 2 power cords

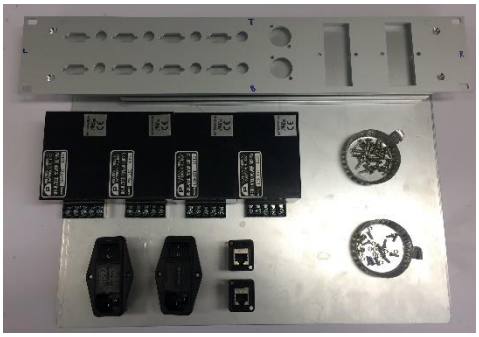

Figure 90 Enclosure materials. Clockwise from top left: custom cut front, sides, and back panels, enclosure hardware, 4-40 screws and nuts, ethernet jacks x2, power jacks x2, power supplies x4

1. Assemble base and sides of enclosure
   - See manufacturer instructions
2. Mount power supplies on enclosure base
   - Each power supply has four 4-40 mounting holes.
   - Drill four mounting holes (1/8”) for each power supply along the right side of the base plate of the enclosure
   - Screw each power supply in using 4-40x1/4” screws
   - See Figure 87 and Figure 88 for the results of this step.

Figure 88 Four power supplies mounted

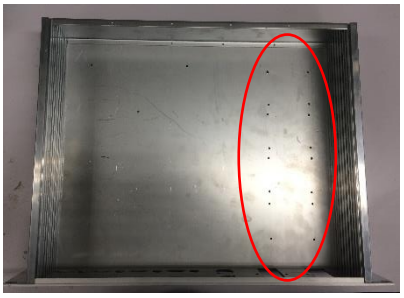

Figure 87 Enclosure base plate with power supply mounting holes drilled

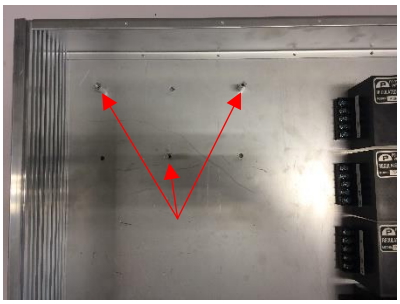

Figure 93 Baseplate with three standoffs installed. Note that the image shows the other three holes drilled - these will be unused and unnecessary.

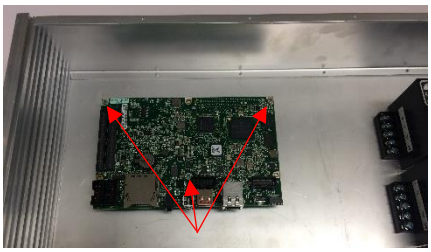

Figure 92 sbRIO #1 installed on standoffs

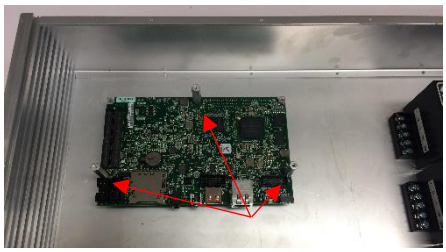

Figure 91 2nd layer of standoffs installed

3. Mount sbRIOs on enclosure base

- Drill mounting holes (1/8”) for three of the six mounting holes in the sbRIO board. See Figure 93.
- Note that the mounting standoffs provided by National Instruments do not provide enough clearance for the ribbon cables when mounting two sbRIOs on top of each other.
- Note that unless you have male to female standoffs, you can only use three mounting holes for each sbRIO.
- Screw the shorter three standoffs into the enclosure base
- Mount an sbRIO on top of the three standoffs. See Figure 92.
- Screw the longer three standoffs into the three unused mounting holes on the first sbRIO. See Figure 91.

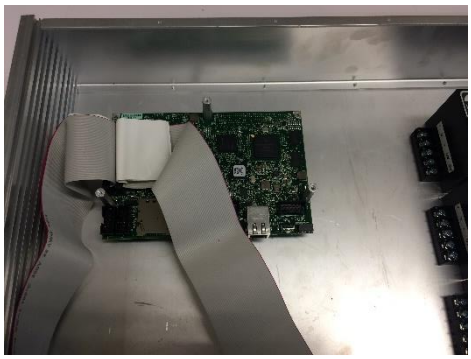

Figure 96 sbRIO #1 installed with ribbon cables

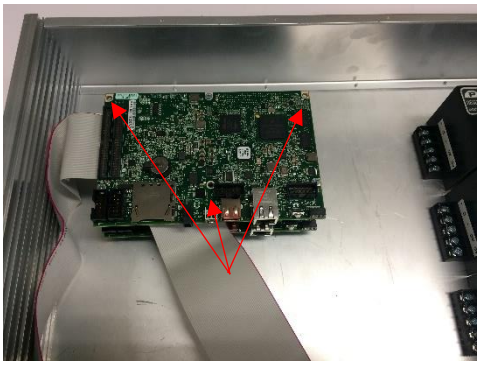

Figure 94 sbRIO #2 installed

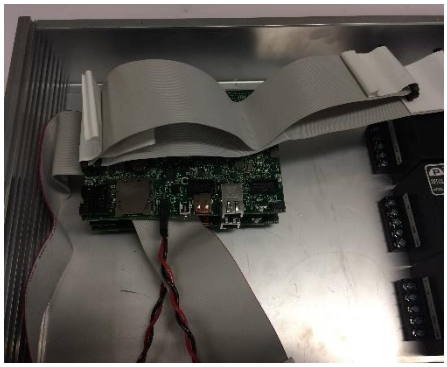

Figure 95 sbRIO #2 ribbon cables plugged in

- Plug two ribbon cables into the two 50-pin headers on the sbRIO board. These cables carry the DIO and AIO channels to and from the sbRIO. Make sure the side of the ribbon marked red is on the side of the header with channel #1. See Figure 96.
- Screw the 2nd sbRIO onto the 2nd layer of standoffs. Take care that the ribbon cables from the first sbRIO are neatly exiting the space between the sbRIOs. See Figure 94.
- Plug the other two ribbon cables into sbRIO #2. Again take care that the orientation is correct. See Figure 95.

4. Mount RIO breakout boards on enclosure faceplate

- Insert the RIO breakout board DB-9 and BNC ports into the faceplate cutouts.
- Secure the RIO breakout boards with 4-40x3/8” screws on either side of each DB-9 port

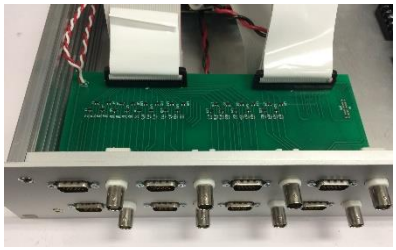

Figure 97 Two RIO breakout boards installed with ribbon cables.

- Plug the four ribbon cables into the RIO breakout boards. In the orientation shown, the left ribbon cables from the sbRIOs go into the left headers on the RIO breakout boards. Pin #1 goes on the right.
- See Figure 97 for the results of this step.

5. Cut and strip power wires

- Cut three pairs of 12” wires (two each for AC hot, neutral, and ground), and three pairs of 6” wires (two each for AC hot, neutral, and ground). Color coding is recommended – the color scheme used here is
  - AC hot = black
  - AC neutral = white
  - AC ground = green
- See Figure 99 for the results of this step.

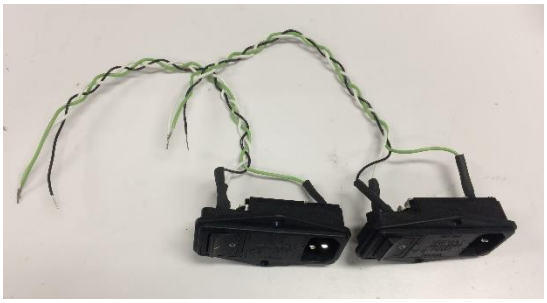

Figure 98 AC power receptacles

6. Solder wires onto power receptacles, and mount on faceplate

- Solder the longer wires onto the two power receptacles. Use heatshrink tubing to protect the solder joint.
- Use 4-4o screws and nuts to mount each receptacle on the faceplate.
- See Figure 98 for the results of this step.

Figure 99 Power supply wires, cut and stripped

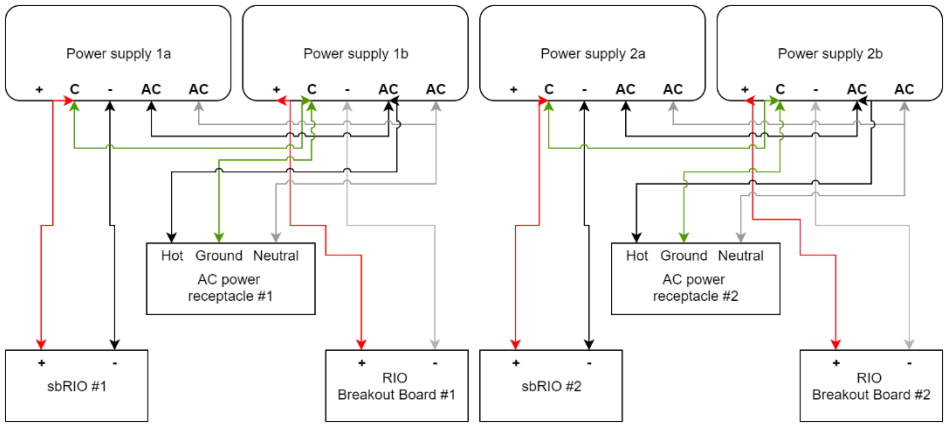

Figure 100 Power supply connection schematic. Compare to corresponding photo.

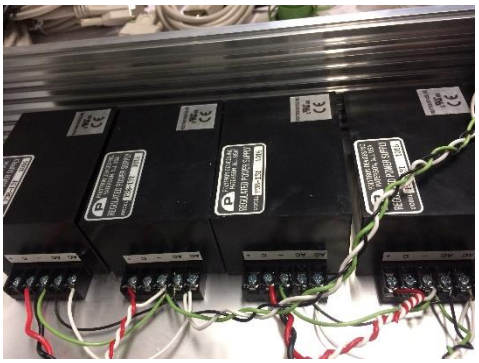

Figure 101 Power supply connection photo

7. Connect power wires to power supplies.

- Connect the wires to the screw terminals on the power supplies as shown in Figure 100 and Figure 101.

8. Connect sbRIO and RIO breakout board power cables
   - Plug minfit power connectors into each sbRIO power jack.
   - Connect bare wire ends of the sbRIO power cables and the RIO breakout board power cables to power supplies as shown in Figure 100 and Figure 101.
9. Mount ethernet jacks in enclosure, and connect to sbRIO boards
   - Mount ethernet jacks on faceplate with 4-40 screws and nuts
   - Connect each sbRIO ethernet jack to the panel-mounted jack using the short ethernet cables.
10. Optional: close enclosure with lid.
11. Connect to sbRIO using LabVIEW, and compile software onto FPGA.

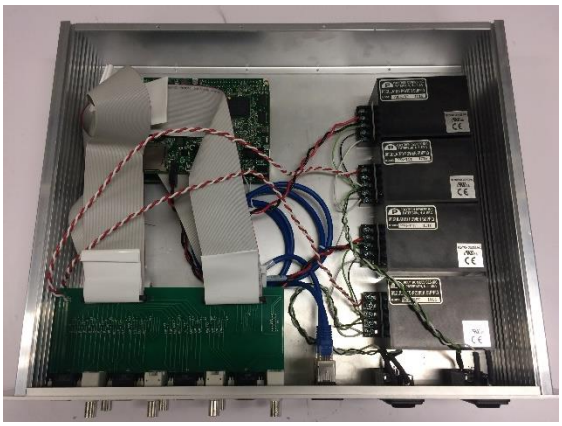

Figure 102 Completed DAQ system

Part XIII: Building the water distribution system

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	1/16” ID tubing			
2	1/8” ID tubing			
3	1/4” ID tubing			
4	1/2” ID tubing			
5	Luer lock T connectors			
6	Luer lock to 1/16” barb adapter			
7	Luer lock to 1/8” barb adapter			
8	1/4” barb T		57024-04	
9	3/8” NPT male coupler			
10	Thread sealant tape			
11	Pneumadyne 8-station 3/8” NPT aluminum manifold		M10-125-8	https://www.pneumadyne.com/station-npt-input-aluminum-manifold-p-2633.html
12	Supply pump: Brushless DC Pump		AD20P-1230D	
13	Return pump: Flojet 3.8 GPM 45 PSI self-priming pump		04300501	
14	Globe valve x2: Milwaukee Valve 125 SWP 200 WOG 3/8” NPT to 3/8” NPT		502 1/8”-3”	
15	Plastic bucket with a lid, roughly 2 gallons			

Building Instructions

General notes

This closed loop water recirculation system is designed so it is easy and quick to accurately refill all the reservoirs in a rack on a daily basis; this allows the water dispense volume to remain calibrated down to the uL over the course of the experiment. These instructions, and the schematic in Figure 103, are for a water system for 8 homecages. This design can be easily scaled up or down to accommodate a different number of homecages.

Important: Whenever there are NPT threaded connectors, you must seal the

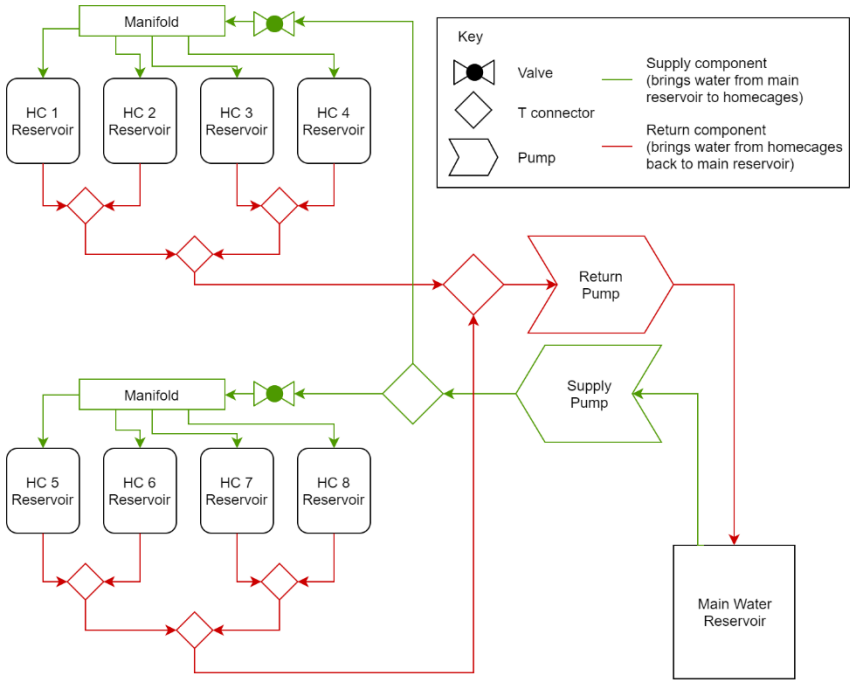

Figure 103 Water distribution system schematic

thread with thread sealant tape and tighten with a wrench for a watertight seal.

1. Cut return tubing sections to length

- The tubing lengths required for this setup depend on the rack geometry in which they will be installed, and convenient mounting locations for the pumps. Refer to Figure 104 for the topology of the tubing.

2. Connect return tubing

- The return tubing forms a branching tree structure, with luer lock T connectors at each branch, and luer lock to barb adapters connecting the tubing to the Ts. A 3/8” to 1/4” barb adapter steps up tubing diameter towards the diameter of the return pump inlet.
- Firmly connect all tubing onto all the barbs (make sure tubing passes over all the ridges on each barb for a watertight connection), and screw in all the luer lock connections.
- Refer to Figure 104 for the return tree tube connections

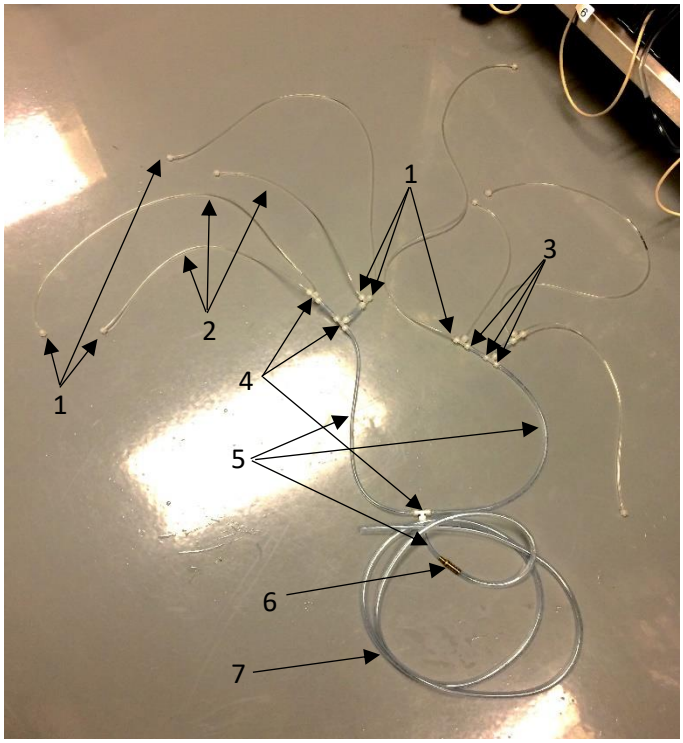

Figure 104 Return tubing. Examples of each component are numbered above and identified below.
1. Luer lock to 1/16” barb adapters
2. 1/16” tubing
3. Luer lock to 1/8” barb adapters
4. Luer lock T connectors
5. 1/8” tubing
6. 1/8” to 1/4” adapter
7. 3/8” tubing

3. Connect return tubing to return pump

- Using a 1/4” to 3/8” barb adapter, and a short segment of 3/8” tubing, connect the return tree to the return pump.
- Attach a section of 3/8” tubing to the return pump outlet – this will lead to the main water reservoir.
- Optional: Mount the pump on a panel that allows it to neatly fit in one of the rack spaces.
- The white strips on either side of the pump are foam strips that reduce the transfer of vibration to the rack when the pump is turned on.
- See Figure 106 for the pump setup. Note that the pump is mounted on a black plastic panel in this figure.

4. Assemble manifold

- Screw in 3/8” NPT to 1/16” barb adapters into the eight ports of each manifold.
- Block off four ports on each manifold with a small piece of 1/16” tubing and plug
- Screw in a 3/8” NPT male coupler to the end port on each manifold
- Screw the globe valves onto the couplers

Figure 105 Assembled manifold

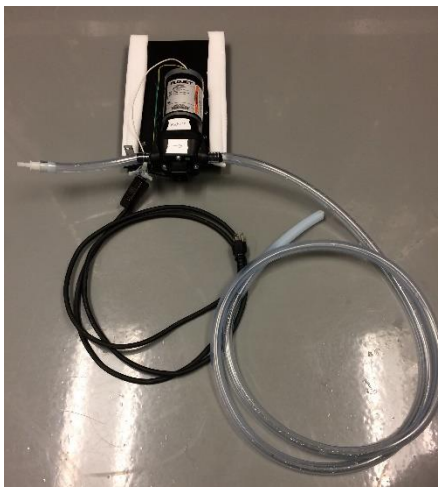

Figure 106 Return pump, showing the inlet tube on the left, the outlet tube on the right.

- Screw a 3/8” NPT to 1/8” barb adapter onto each globe valve
- See Figure 105 for the results of this step. Note that the manifold is mounted on a black plastic rack-adapter panel in this figure.

5. Cut supply tubing sections to length

- As with the return system, the tubing lengths will depend on the geometry of the setup.
- Refer to Figure 107 for the topology of the supply system

6. Connect supply tubing

- Refer to Figure 107 for tubing connections

7. Recommended: Add priming valve

- To make priming the supply pump easier, add a T in the main supply line and add a valve that can be opened to manually pull liquid through the supply pump (see part #7 in Figure 107)

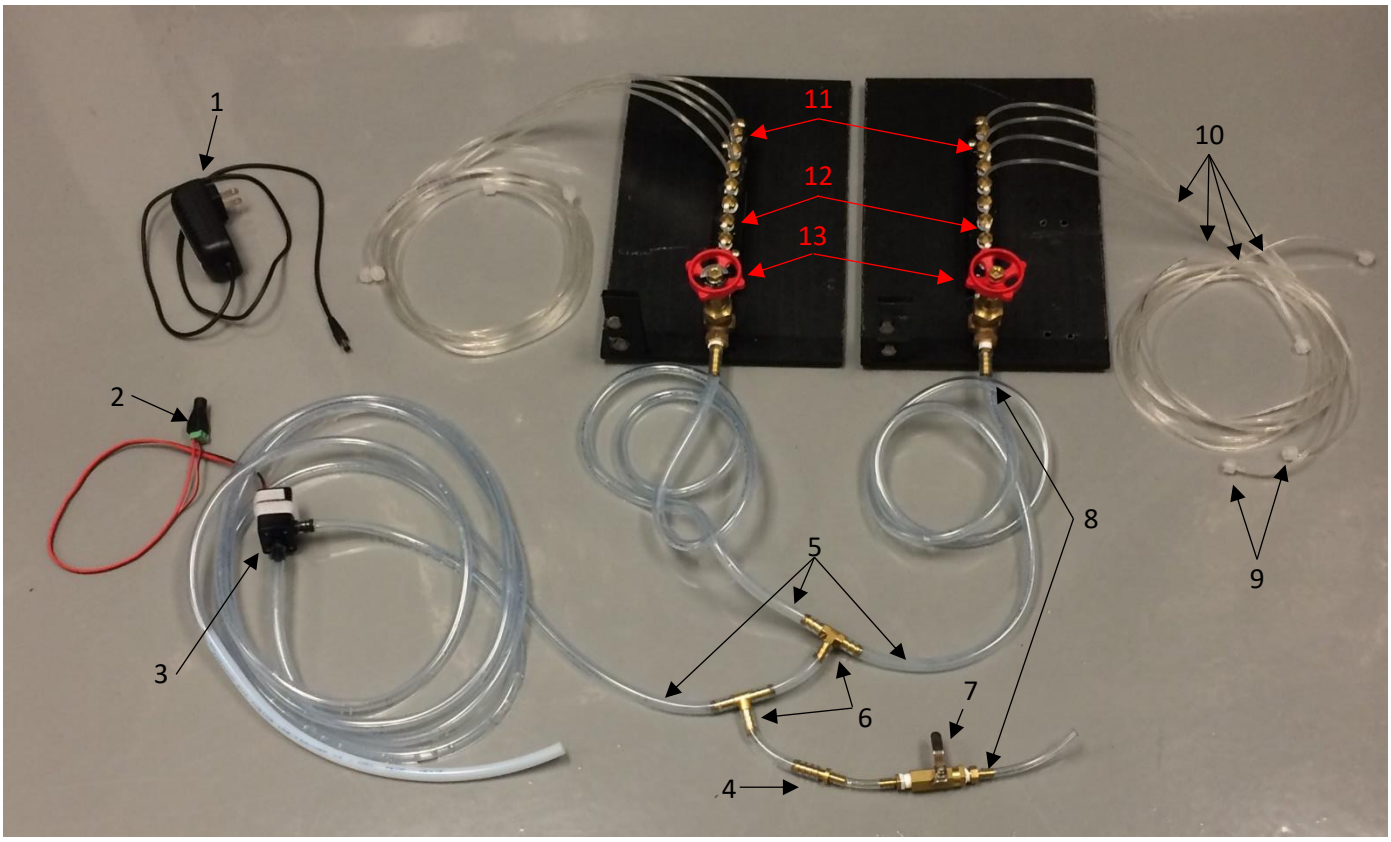

Figure 107 Supply system. Examples of each component are numbered above and identified below.
1. Pump power supply
2. Barrel to screw terminal adapter for pump power supply
3. Supply pump (with white Velcro for mounting)
4. 1/4” barb to 1/8” barb adapter (due to lack of supplies)
5. 1/4” tubing
6. 1/4” barb T
7. Priming valve
8. 3/8” NPT to 1/8” barb adapter
9. Luer lock to 1/16” barb adapter
10. 1/16” tubing
11. 3/8” NPT to 1/16” barb adapter
12. Short pieces of 1/16” tubing with 1/16” plugs
13. Globe valves
14. 3/8” NPT male coupler (not visible, connects valve to manifold)

8. Recommended: Mount manifolds on rack near home cages

- Organizing the tubing on the rack is made easier if the manifold is mounted in some manner on the rack.
- See Figure 109 or our custom rack-adapter mounting panel.

Figure 109 Manifold mounted on the rack

9. Construct main water reservoir

- Drill a 3/8” and 3/4” hole in the top of the water reservoir bucket.
- Fill high enough with potable water that both tubes will easily stay submerged.
- Insert the outlet tube from the return pump and the inlet tube to the supply pump into the two openings.
- Check to make sure the ends of the tubes won’t shift and emerge out of the water

Figure 110 Main reservoir with holes drilled and tubes inserted.

10. Hook up supply and return tubes to each homecage reservoir

- Run the 1/16” supply and return tubes through the rack to each homecage
- Connect the luer lock fittings so the supply tubes connect to the top of each reservoir, and the return tubes connect to the side of each reservoir.
- See Figure 112 for the results of this step

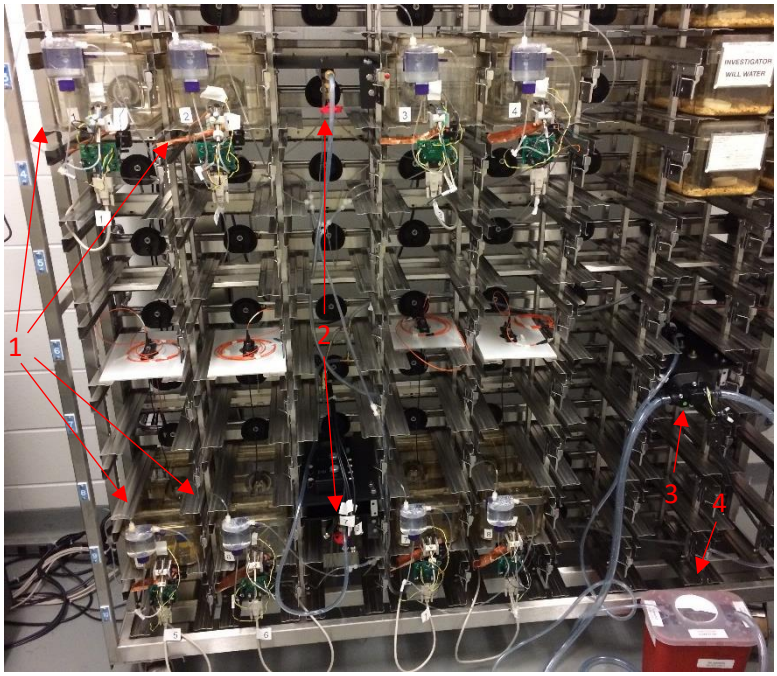

Figure 111 Completed water system installed on rack with 8 homecages
1. Homecages
2. Supply manifolds
3. Pumps (supply and return both mounted)
4. Main reservoir

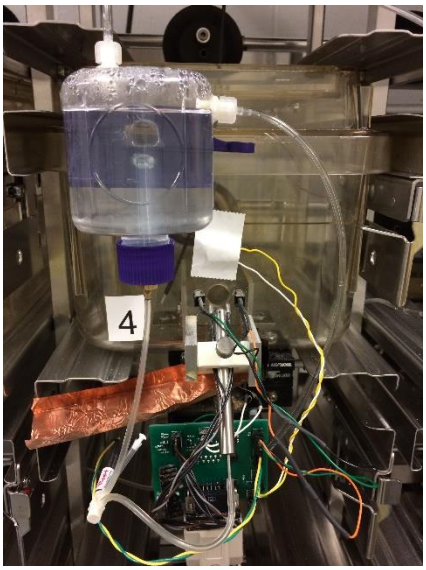

Figure 112 Homecage reservoir connected to supply (top fitting) and return (side fitting) tubes

Part XIV: Assembling the whole system

Full list of Materials

#	Part Description	Manufacturer /Supplier	Manufacturer/Supplier Part Number	Datasheet/Drawing/Modification
1	Completed homecages x8		N.A. (Custom Made)	N.A. (Custom Made)
2	Completed water system		N.A. (Custom Made)	N.A. (Custom Made)
3	Completed DAQ system		N.A. (Custom Made)	N.A. (Custom Made)
4	Completed optogenetics system		N.A. (Custom Made)	N.A. (Custom Made)
5	Control/storage server			
6	DB-15 cables x8			
7	BNC cables x8			
8	LabVIEW 2013			
9	LabVIEW control software			

Building Instructions

General notes

The entire system can be assembled on a standard mouse cage rack. The 8-homecage arrangement can be repeated for as many units as needed.

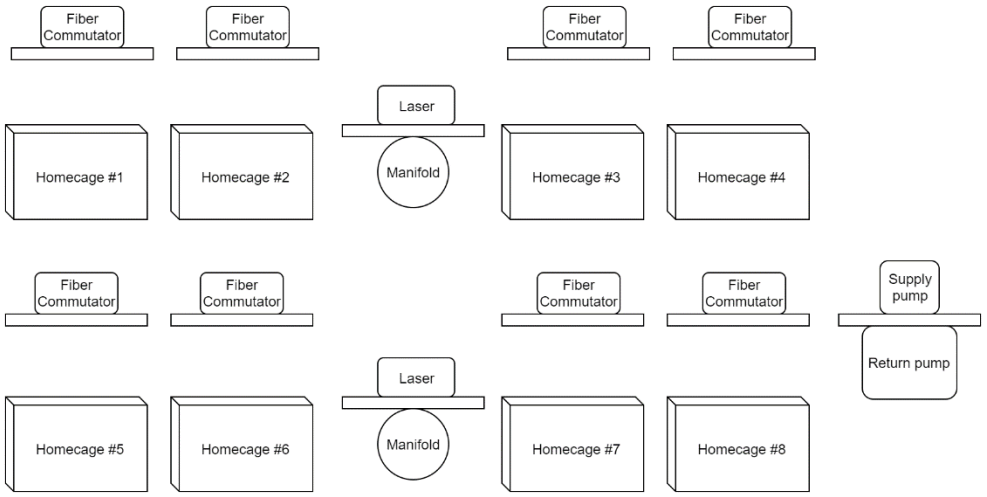

Figure 113 Rack arrangement for 8 homecages.

1. Install homecages and water system on rack
2. Install optogenetic system on rack
   - If possible, install the optogenetic lasers so that a leak from the homecage reservoirs wouldn't spill on the lasers.
3. Run ethernet cables from DAQ to network access point
   - Connect each DAQ enclosure to a network access point (router or network switch) with two ethernet cables, so each sbRIO can acquire an IP address and communicate over the network.
4. Run DB-15 homecages to DAQ
   - Connect each homecage to the DAQ with a DB-15 cable.
   - Numbering the cables, homecages, and DAQ outputs to correspond with each other is strongly recommended.
5. Run BNC cables from lasers to DAQ
   - Connect each laser to the DAQ with a BNC cable.
6. Connect server to network access point
   - Connect the server to the same network as the DAQs
   - The server should be able to communicate with each sbRIO via LabVIEW.

- Note that the NI software “NI MAX” is useful for discovering the IP addresses of each sbRIO on the network.