Hardware notes:

Description of parts and assembly instructions:

Parts fabricated from flat material:

X-base.fcstd (6 mm thick clear or colored acrylic)

overall dimensions are 260 mm x 90 mm

Y-base.fcstd (½ inch marble, wood, aluminum, or other stiff material)

overall dimensions are 410 mm x 305 mm

sample_base.fcstd (5mm thick clear acrylic)

overall dimensions are 175 mm x 185 mm

The measurements and screw hole positions for each part are found in the supplied freecad (.fcstd) files. To maximize stability of the microscope stand, the large piece (Y-base) can be cut from a piece of ½ inch thick polished marble floor tile. Marble is recommended because it is very rigid and not expensive (about $12 for an 12x24 inch piece). Furthermore it is not much more difficult to cut and drill than acrylic or wood, though special drill bits and saw blades are strongly suggested. (To ensure the material does not crack, drill and cut slowly, and be sure the material is well supported. A small amount of cooling water should be supplied during cutting and drilling.)

Microscope mount.

Parts:
- 18” long segment of 1” diameter black pipe threaded on at least one side (you need ~38 cm)

  Sanding the pipe will make adjustments easier, but this is not absolutely necessary.
- floor flange for 1” pipe
- 25 cm segment of 1” diameter electrical conduit

  (note that conduit is less heavy than black pipe and the diameter differs)
- 2-pipes.stl 3D-printed pieces
- big_lens_mount.stl 3D printed piece
- 6 hose clamps to secure the printed parts to the pipes

Tightly screw a 1” diameter length of black pipe into a floor flange. Then add the 90 degree connector piece (2-pipes), the second pipe, and the lens mount. The hose clamps are tightened only after the microscope is completely assembled. Note that the freecad files are also included. These can be edited (i.e. if a lens with a different diameter is used).

<u>Y-Base and Y-axis.</u>

Parts:
- Y-base (made from marble or other material as described above)
- 4 metal rod holders (aluminium)
- <u>Y_motor_mount.stl</u> (3D-printed)
- Y-screw bearing
- 4 rubber stick-on feet (at least 10 mm high)

The Y-base is at the bottom of the translation stage. As noted above the Y-base piece can be made from laminated wood, acrylic, stone, or aluminum. Laminated wood (i.e. low cost shelving) is easiest to work, but depending on the laboratory environment, it may not last as long as other materials. Acrylic is somewhat flexible, and aluminum is relatively expensive. Polished marble tile is ideal, since it is flat, stiff, water resistant, inexpensive, and readily available. Once the base is prepared, mount the four rod holders, the Y-motor mount (at the back) and the y-screw bearing (at the front). The screws should all be left loose at this point. The holes should all be larger than necessary so there is scope for minor adjustments. You can also screw on the microscope mount and then add the four feet. There is no need to install the two rods, and the other Y-translation hardware at this point.

<u>Preparation of the X-base and alignment of the Y axis</u>

Parts:
- X-base – acrylic piece described above
- one aluminum bar (220 mm)
- 4 bearings preinstalled in bearing mounts
- spring nut installed in its mount
- 2 rods (240 mm long) for the Y axis

- screw (240 mm long) also for the Y axis
- motor for the Y-axis
- motor-screw coupling piece

The X-base is above the Y-base, and travels forward and backwards along with the X and Z translation assemblies. The CNC kit includes screws with special heads that fit into the slot in the 220 mm aluminum bar. These screws are used to connect the bar to the back, top side of the X-base and the rear set of bearings. The acrylic X-base piece goes between the bar (on top) and the bearing holder (on the bottom). Bolts hold the assembly together on the bottom side, but there is no need to tighten them yet. With the rear set of bearings in place, screw the front set of bearings and the spring-nut assembly to the bottom side of the X-base. (The spring-nut assembly is attached to the middle of the X-base on the bottom side.) The front bearings and the spring nut assembly should be attached to the X-base using 3/4” (~20mm) screws. With these parts attached, add the lower set of rods for the Y-axis. These should be inserted into the Y-axis rod-holders that are attached to the Y-base and the bearings attached to the X-base. By repeatedly tightening the various parts, testing the resistance by hand and making adjustments, find the position where the whole assembly moves along Y with minimal friction. Then add the screw, motor and motor coupling piece to the Y axis. Turn the screw by hand to move the X-base from one end of the Y axis to the other (this does not hurt the motor). Again, make adjustments as necessary so that the whole assembly moves with as little friction as possible. If there is significant resistance loosen the screws for the bearings and/or the spring-nut and then re-tighten. This is an iterative process, and it may take a few cycles of moving from one end to the other and loosening and tightening screws before the assembly moves smoothly over the entire range. When you are done, tighten everything well.

X axis assembly

Parts: - left-side_90.stl, right-side_90.stl – 3D-printed parts that secure the ends of the X-axis.
- X-spacer.stl -spacer for the X-motor

- four rod ends
- one 220 mm aluminum bar (horizontal piece)
- two 115 mm aluminum bars (vertical pieces) These should be cut from longer bars.
- four corner brackets
- four rod holders (for the X-axis)
- Motor for the X-axis
- motor coupling piece

The X axis sits above the X-base. Create a rectangle from aluminum rods that builds up from the bar attached to the top, back side of the X-base. The short bars run from top to bottom, and the long bars run from side to side (inside the short bars). Secure the inside edges of all four corners using corner brackets. Screw the four rod holders onto the short aluminum bars, two on each side. There is no need to tighten them yet. The X-axis uses the two triangular 3D-printed pieces (left-side_90 and right-side_90). The motor goes on the right side of the X-axis assembly and the X-spacer is used to translate it slightly to the right. Don't worry about the alignment yet. It is important that any protruding bits of filament be removed (with sandpaper) from the printed pieces before they are added.   The printed pieces and the motor should all be screwed to the short rods.

<u>Adding the Z-axis assembly.</u>

Parts:
- two 260 mm rods
- screw (260 mm)
- Z-axis assembly

The Z-axis assembly is preassembled in the CNC kit. To add it, run the two rods and the screw through the left side of the X-axis assembly and then through the Z-axis assembly. The motor on the Z-axis assembly should up at the top. You will probably need to fine tune the positions of the rod holders and the X-axis motor. As with the Y-axis, manually screw the X-axis from side to side making small adjustments until the translation is smooth throughout. Then tighten all the screws well.

Mounting the circuit boards

Parts: pi-holder.stl 3D-printed piece

The two circuit boards should be mounted before you begin to make electrical connections. The Pi is attached to the pi_holder piece with zip ties and glued to the Y-base. The arduino is attached to the back side of the X-axis assembly with two screws.

Sample holder

Parts:
- 96_well_holder.stl (3D printed) only holds 96 well plates
- clear acrylic piece (sample_base.fcstd) 5mm thick 175 mm x 185 mm clear acrylic
- corner1.stl (3D-printed piece)
- two copies of corner2.stl (3D-printed)
- 6 neodynium magnets 10 mm in diameter
- plate_holder_cyl.stl (3D-printed)

The 96 well plate sample holder can simply be printed. The remaining directions are for making the adjustable sample holder (capable of holding plates of other formats). Screw the printed cylindrical piece to the clear acrylic piece and then glue with with acetone or superglue. The corner1 piece should be glued to the acrylic so it is flush to the left side and 56 mm from the back side. Glue (with epoxy) 3 magnets into each of the two 3D-printed corner2 pieces. Check the orientation of the magnets before adding the glue to be sure that the two finished corner2 pieces attract. These will be placed above and below the acrylic. When complete, the sample holder is installed by manually screwing the the Z-axis near the top of its translation and then pushing the cylindrical coupling all the way into the tool holder from the bottom side. The sample holder should be aligned by eye (the software will correct for misalignment) and then tightened in place with the screw on the z-axis assembly.

Connecting the motors and switches

Parts:
- 6 microswitches, wire, heat shrink
- z-block.stl (3D printed piece not needed on all systems)

Connect the motors to the Arduino following the manufacturers directions. Then connect the other devices as shown in Figure 1b. The end switches require careful assembly and planning. It is important to keep the switch wires physically separated from the motor wires as much as possible. Induced current can trigger an alarm and stop the machine. If the switch wires and the motor wires must touch, it is best that they cross at a 90 degree angle. Be sure to allow enough scope so that the wires are not stressed when the machine moves to its limits, but not so much that the wires can snag or get caught between the moving parts. Also, before you begin the solder wires to the switch terminals, you must identify the set of normally open terminals on the switch (so the circuit is closed when the switch is depressed). Carefully solder the wires to the six microswitches and cover the exposed ends with heat shrink. The switches should be wired so that they are <u>normally open</u>. The switch wires should then be connected to the terminals labeled Xend, Yend, and Zend on the Arduino board. Some boards have only one Zend terminal. If this is the case wire the two Z switches in parallel and then connect them to the Zen terminal. The positive directions are up (for z), towards the back (for y), and toward the right (for x). The switches can be glued with Shoe-Goo to the rod holders on the x and y axes. Be sure to remove any grease from the surfaces before adding the adhesive. For the z-axis, the switches should be glued to the z-axis assembly with superglue. In all cases, the switches should be positioned such that the main body of the switch is flush with the edge of the piece it is being attached to. On some systems, the z axis translates to the point where the two grey plastic pieces come into contact. On others, there is a significant gap between the grey pieces at the end of the translation. In the latter case, the z-block can be used as a spacer. You will see the location of three switches and the z-block (white cube) in Figure 1a.

<u>Connecting the camera:</u>

Parts: - microscope lens

- picamera V2

- flex cable (24 inches long)

- sensor_holder_big_scope.stl 3D-printed part (should either printed in black or painted black)

Carefully remove the tiny lens on the pi camera. The lens typically has two tiny drops of sticky adhesive holding it in place. After removing as much of the adhesive as possible with a pin, carefully unscrew the lens while holding the camera with a small pair of pliers. Once the lens is off, install the microscope in the lens_holder (attached to the horizontal pipe) and the picamera in the sensor holder. Then connect the camera to the Raspberry Pi via the flex cable. Note that it is possible to focus the image even if the sensor holder is not precisely the correct length. Maintaining the focus when you change the zoom setting, however, requires that the sensor holder be precisely correct. If the focus is lost when changing the zoom, try raising the sensor holder by a half millimeter. The sensor can also be brought closer to the lens by sanding a small amount of material from the lower end of the sensor holder. These fine adjustments can also be made after the entire system is complete.

Light switch circuit and three-color light:

Parts:
- solenoid_holder.stl   (3D printed part that holds the dual switch module)
- outlet_holder.stl   (3D printed part that holds the outlet)
- light_parts.stl   (3D printed parts for the light)

The two light circuits are controled by the GPIO ports 17 and 18 on the Raspberry Pi. The light 2 switch in AMiGUI also turns controls the 24 volt output of the Arduino board. The Raspberry Pi light circuits use an inexpensive two channel 5V DC relay module that is capable of switching both AC and DC current. Four wires connect the relay module to the Raspberry Pi: ground, 5V DC power, GPIO 17, and GPIO 18). A standard two plug, three-prong outlet was purchased, and the copper tab that separates the hot side of the two outlets was removed from the outlet. Using a standard 3-prong plug and wire, connect the ground and neutral wires to the outlet. Now connect the 120 V AC wire (with the wire unplugged of course!) to the two inputs on the high voltage side of the relay. Now connect the two normally closed, switched high voltage outputs to the two power terminals on the outlet. A 3D printed piece was designed to hold the outlet. This should be glued to the Y-base along with the 2-relay circuit. Connected in this way the lights will turn on as soon as the system is powered up. The light can be turned on and off via AMiGUI, and they will stay off if AMiGUI is closed. The lights will come back on, however, if the Raspberry Pi is shut down. This is to remind users to turn off the power to the whole system after the pi is shut down.

The three-colored light is made from three 12V LEDs which are wired in parallel to the small 12V power supply. These are mounted within a 3D printed housing. The light assembly must be printed from white PLA. The thin top of the assembly diffuses the light. The top parts of the light and the LEDs can be affixed with superglue. Screws attach the base to the round top section and allow adjustment of the light angle. As noted in the main text, while the colored light is somewhat better for examining crystals (the facets capture light from different angles), precipitates and cells are best viewed with an off-center white light. Having two computer-controlled light circuits allows one to quickly switch from one light source to another.

Arduino-Pi timing connection:

The Arduino and Raspberry Pi are connected via a USB cable. In addition, a separate wire is used to ensure that the two boards remain in sync during image acquisition. GPIO pins on the Raspberry Pi accept 3.3 volt signals. The header connection labeled A3 on the Arduino board puts out a voltage closer to 5 volts. Both boards share a common ground. A 1 K ohm trim pot can be used as a voltage divider to adjust the output of pin A3 to 3.3 volts. The two outer pins of the trim pot should be connected to A3 and ground on the Arduino. Then using picocom (`apt-get install picocom`) to communicate with the Arduino, pin A3 should be energized.

`picocom /dev/ttyUSB0 -b 115200 -l` (connects to the Arduino board)

`$X` (allows manual control)

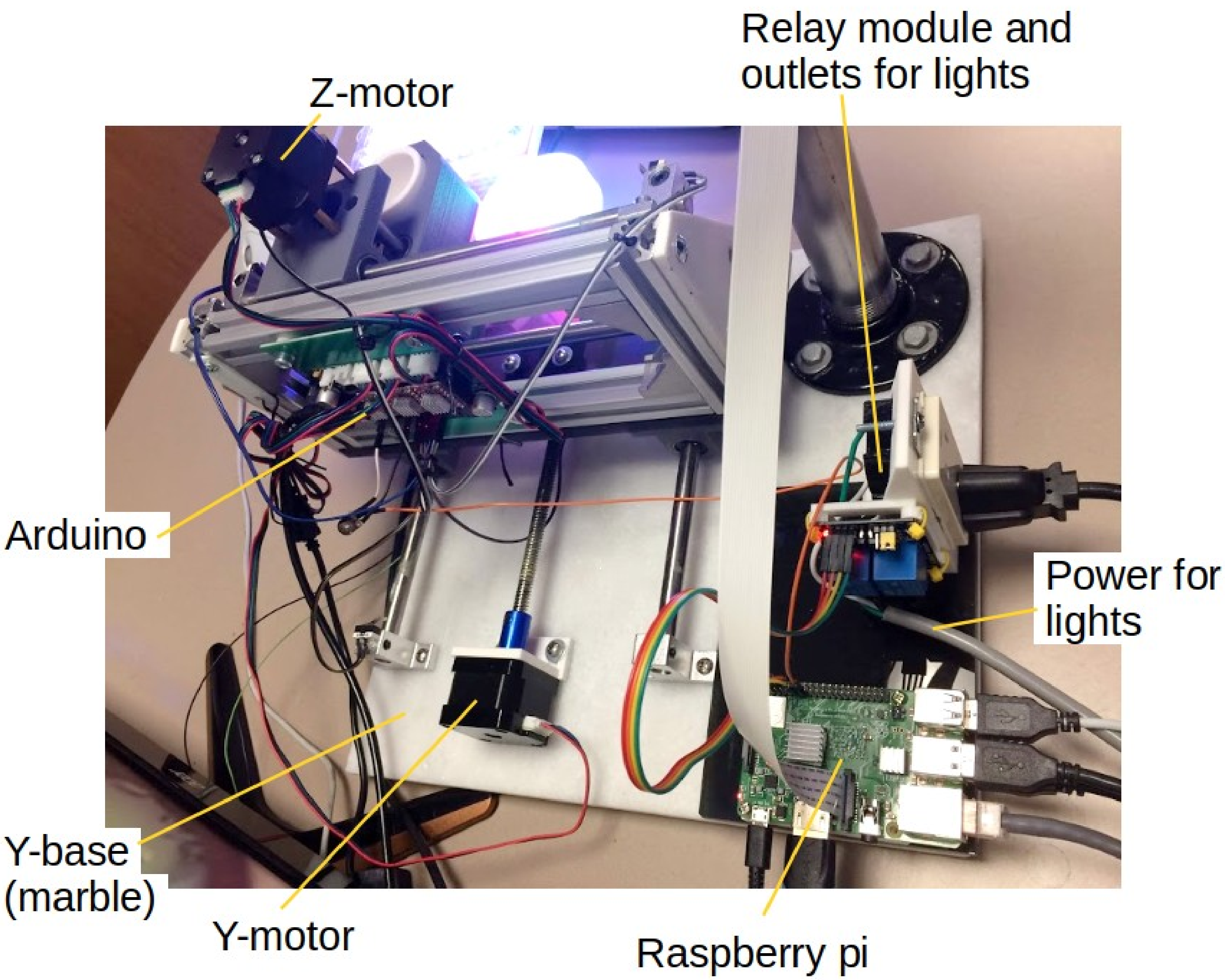
`m8` (energizes pin A3)

`m9` (de-energizes pin A3 – but you don’t need to do this now)

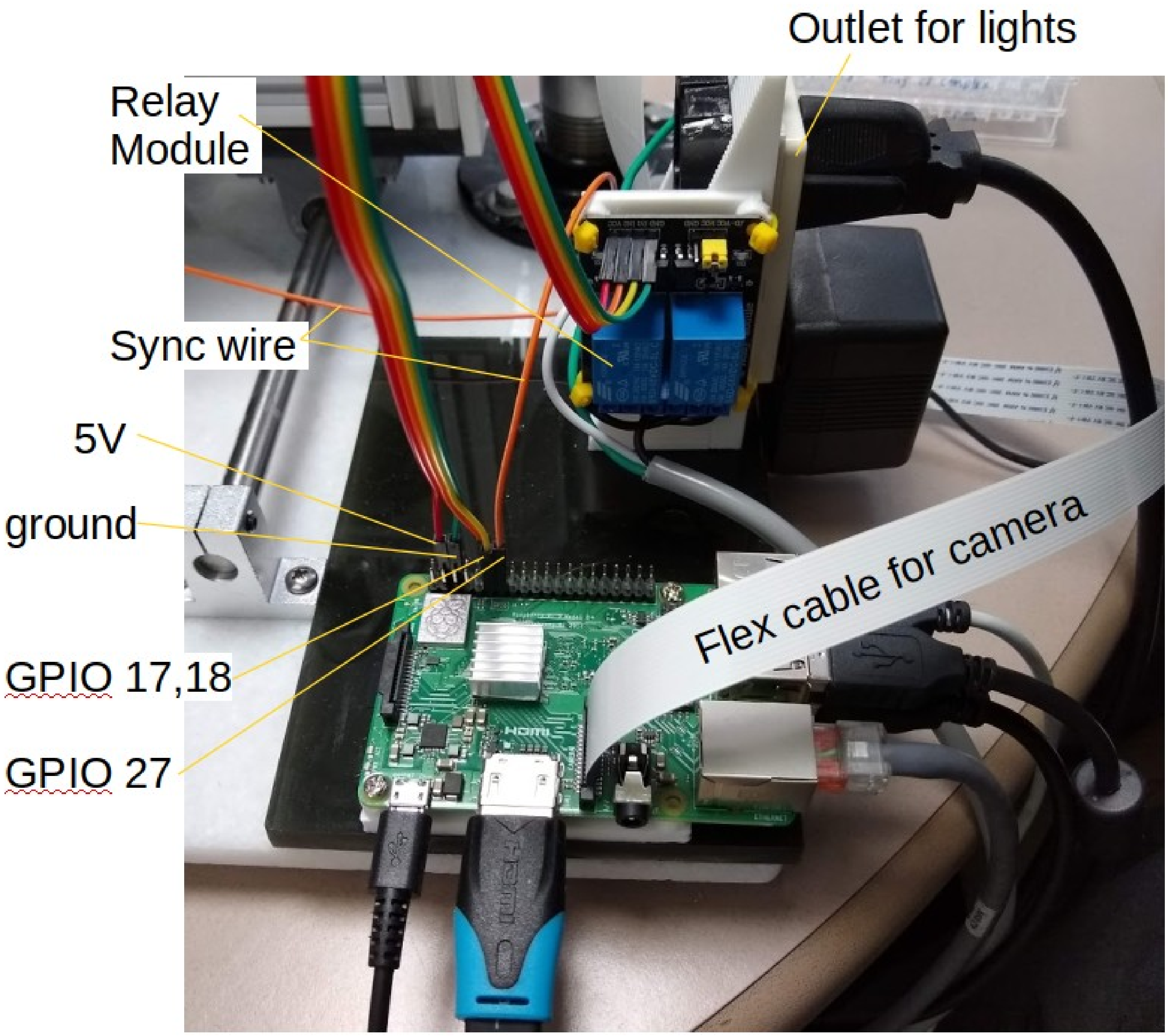
Once the Arduino A3 pin is powered, the resistance of the trim pot output (usually the middle pin) can be adjusted so that the output pin reads 3.3V to ground. Then the center pin should be connected to the header corresponding to GPIO27 on the raspberry pi.   The raspberry pi B+ pin layout can be found at https://www.raspberrypi.org.

Here are a few more images to show how everything comes together.

Rear view of the translation stage

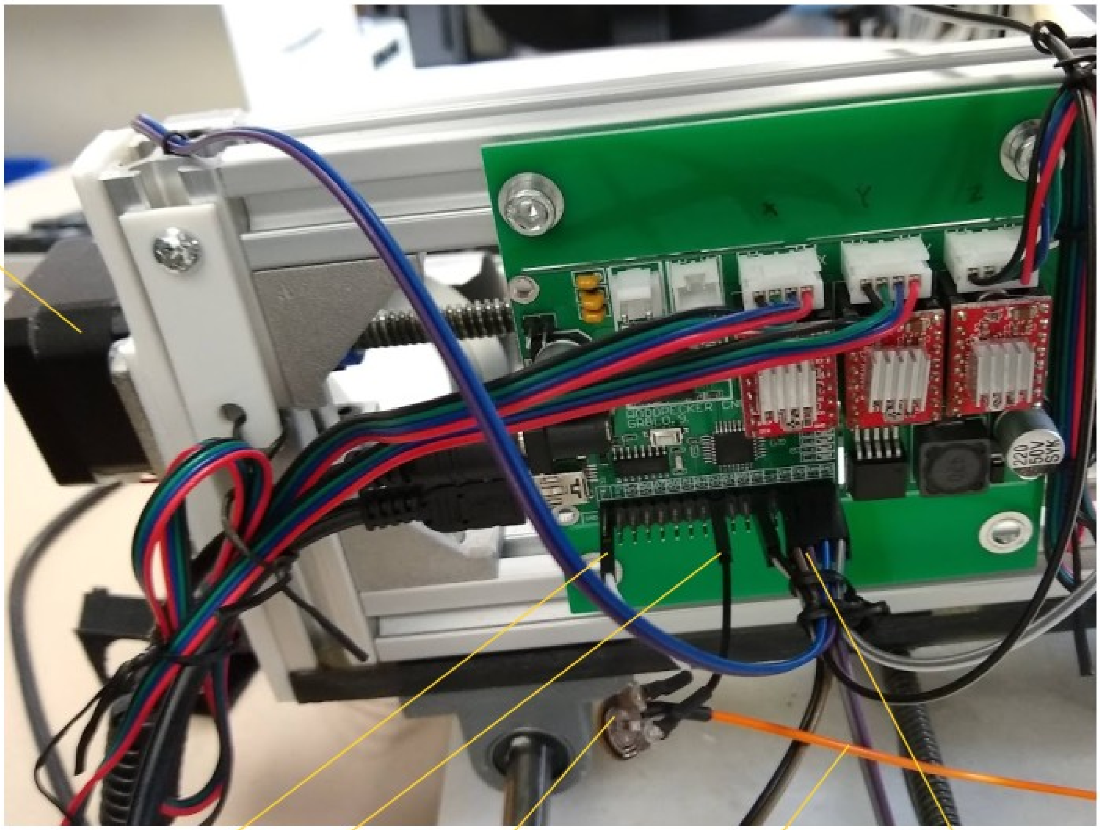


Raspberry Pi and Relay module connections



Arduino connections

(view is from the back side of the microscope stage)



Three color light shown without its top cover.

Light with cover