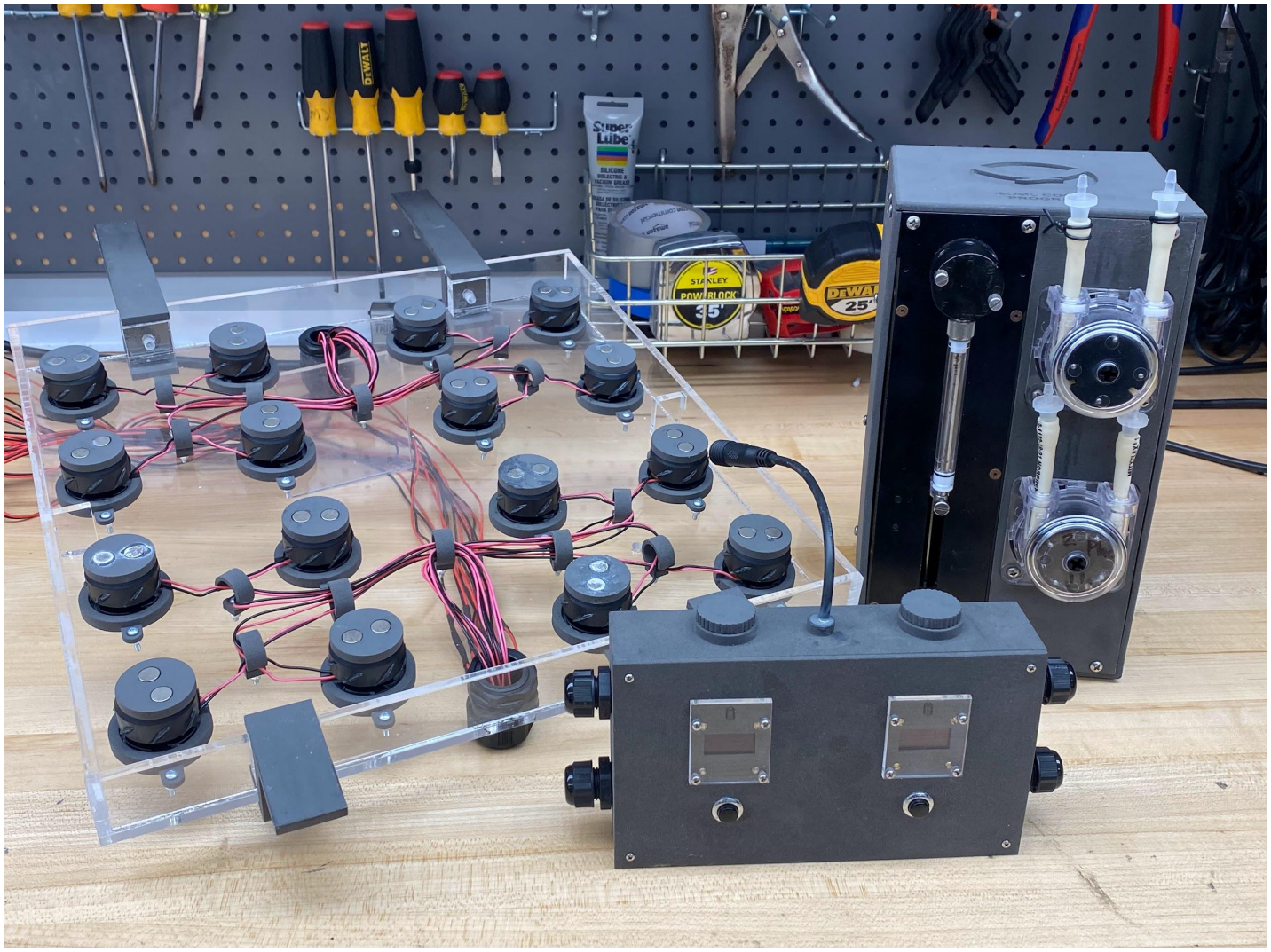
Sequential Treatment Application Robot Subsystem Build Guide



Authored by Nash Soderberg
Models and Renderings by Ian Enochs and Nash Soderberg

Table of Contents

1. Build Resources and Materials

Although these systems were designed with the intention of being accessible to those without any prior knowledge or experience with circuitry and electronics, familiarity with a few skills may be necessary for the construction and modification of this design such as soldering, 3D printing, laser cutting, and basic familiarity with a CAD software of the builders choice.

This build requires the use of some machinery that can be expensive to invest in, namely 3D printers and a laser cutter. Demand for this technology is high however and it is becoming increasingly available in local communities, or through vendors on the internet. If the builder is having trouble locating a source for any of these machines, they should look into resources through universities and schools, public libraries, or local makerspaces.

If there are any difficulties with sourcing the exact materials or equipment listed in this build guide or the associated bill of materials, suitable alternative materials are commercially available and able to be used instead. The CAD designs and laser cut parts for these devices are all modifiable if the builder needs to retrofit them for their purposes.

I. 3D Printed Components

The 3D printed parts that were used in this design were made in house. Parts were designed in Autodesk's CAD program Fusion 360, and were printed on a Formlabs Fuse 1 SLS 3D printer using Nylon 12 material. Although 3D printing is becoming increasingly available, if such access is unrealistic there are several companies where these parts may be ordered online. Table 1 is a list of all required 3D printed components to make one stir plate, the associated controller, and one doser box:

Table 1: 3D Printed Part List

Part	File Name	Quantity
Controller box	stirControlBox.stl	1
Controller lid	stirControlLid.stl	1
Controller port screw	stirControlScrew.stl	2
Controller tank mount	stirControlClip.stl	2
Motor mount	fanMotorBase.stl	16
Magnet holder	magnerHolder.stl	16
Wire routing hook	wireHook.stl	12
Short mounting arm	armShort.stl	2
Long mounting arm	armLong.stl	2
Doser box	doserHousing.stl	1
Pump mounting panel	doserPumpMount.stl	1
Doser box vent	doserVentSide.stl	1

II. Laser Cut Components

This design utilizes laser-cut quarter inch acrylic to build the housing for the stir plate array, as well as to protect the screens for the controller box. The acrylic used for this project was purchased as 24 inch by 24 inch sheets, and it is possible to cut all necessary parts for one stir plate system out of two sheets of this size, with some unused area of the second sheet left over. The laser used for the original build is a Boss LS-2436 150W. If the builder does not have access to a laser cutter through any local resources, a CNC could also be used to cut from stock acrylic, or the pieces can be ordered from an online vendor. Below is a list of all required cut acrylic components to make one stir plate and associated controller, and the quantity of those parts. Please note that the doser box does not require any laser cut components. ***If the builder is cutting from 24 inch by 24 inch sheets of quarter inch acrylic, files compiled with all of the necessary parts efficiently laid out have been provided, and are at the top of the table***.

Table 2: Cut Acrylic Part List

Part	File Name	Quantity
Sheet 1	acrylicCutSheet1.dxf	1
Sheet 2	acrylicCutSheet2.dxf	1
Stir array bottom	stirHolderBottom.dxf	1
Stir array side	stirHolderSide.dxf	2
Stir array front	stirHolderFront.dxf	2
Stir array brace	stirHolderBrace.dxf	2
Stir array arm mount	stirHolderThread.dxf	4
Controller window	stirControlWindow.dxf	2
Sample stand top	sampleStandTop.dxf	16
Sample stand leg	sampleStandLeg.dxf	64
Beaker rack	beakerRackTop.dxf	1
Beaker rack leg	beakerRackLeg.dxf	2
Rack spacer 1	beakerRackL1.dxf	1
Rack spacer 2	beakerRackL2.dxf	1

III. Tools and Bill of Materials

This project is accompanied by a supplemental bill of materials for all of the electronics, hardware, and consumables required for the construction of a STAR unit, which includes parts necessary for the stir plate system. The component names are listed in column C, and their associated part numbers are enumerated in column D. This build manual will reference components by both of these identifiers for ease of reference. The bill of materials does not list tools that are useful or necessary for construction, these are listed below:

- soldering iron
- flathead screwdriver (3/32”)
- phillips screwdriver (#1)
- nutdrivers (7/16”, 1/4”)
- masking tape
- 30 gauge ½” syringe
- flush cutters
- heat gun
- ¼-20 tap

2. Building the Stir Plate Array

For this section of the build, the parts from both acrylic cut sheet 1 and cut sheet 2 will be required. Additionally, the motor mounts, magnet holders, wire routing hooks, and the short and long mounting arms will need to be 3D printed. Almost all of the acrylic pieces are good to assemble right after they have been cut, with the exception that the stir array arm braces need to be tapped with ¼-20 threads to be compatible with the bolts that will secure the mounting arms for the array.

I. Acrylic Stir Array Housing

The acrylic housing for the stir plate array is comprised of 1 stir array bottom, 2 stir array sides, 2 stir array fronts, 2 stir array braces, and 4 stir array arm mounts. To begin, place the stir array bottom on a flat working surface, with some spare cardboard or other material underneath that won't be harmed by excess acrylic adhesive. Using some strips of masking tape, attach the stir array front pieces along the edges of the bottom piece that are nearest to the large holes, as pictured in Image 1. Tape the stir array sides in place on the remaining two edges as in Image 2. Note that these front and side pieces are symmetrical and it does not matter which face points inward.

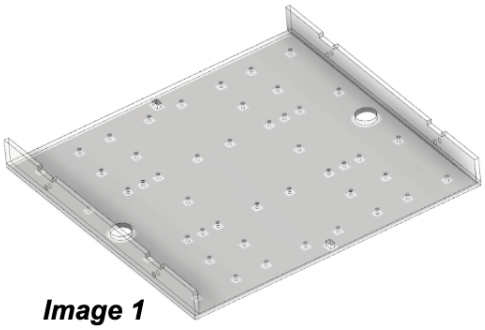


Image 1

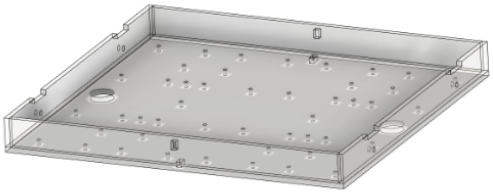


Image 2

When the sides and fronts are taped in place, place some extra pieces of tape along the corners where the sides and fronts meet, to ensure good contact for gluing. Finally, place the braces into their slots along the sides, as seen in Image 3. Using a 30 gauge syringe to draw up some acrylic adhesive from its container, apply the adhesive along the edges wherever two pieces of acrylic meet. Work one connection at a time, applying pressure for 60-90 seconds whenever a joint has been glued. The acrylic adhesive takes around 60 seconds for the initial bonding to take place, with full strength being reached 7 days later.

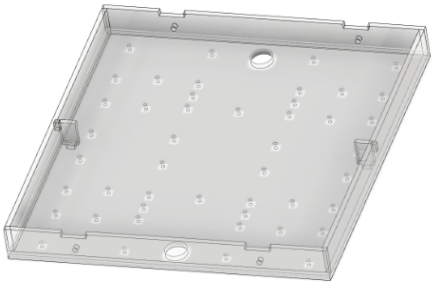


Image 3

After a couple of hours of the adhesive curing, place the tapped stir array arm braces into their place at the laser-cut holes as in Image 4. Screw the ¼-20 mounting bolts into place to hold the threaded arm mount in place while it is glued. Apply the acrylic to all joints, and allow to cure.

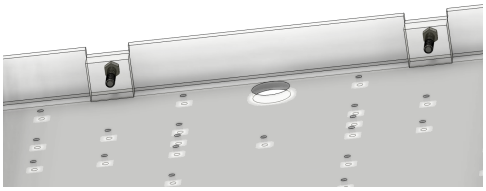


Image 4

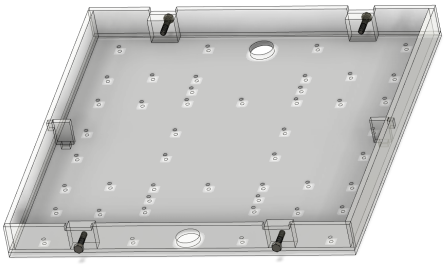


Image 5

Once the acrylic frame has cured, the cable glands can be put into place in the large holes on either end of the array bottom, with the gland facing downward so it can be loosened or tightened while the array is still installed. The mounting arms can be attached, with the shorter arms on one side and the longer arms on the other. The wire guides can also be installed at this point, in the positions indicated in Image 6 using 4-40 screws, nuts, and washers.

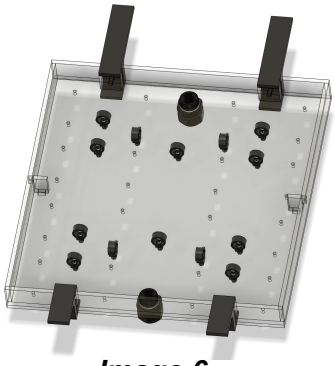


Image 6

Note: Regarding the mounting arms, these were designed specifically for the Experimental Reef Lab (displayed in Figure 1&2 of the manuscript). Depending on the use case of the stir system, these mounting arms may need to be modified, or may not be necessary at all.

II. Stirrer Construction

The fan motors which act as the stirrers for this device need to be trimmed until they are just the central cylinder of the fan. First, cut away the cage around the outside of the fan with a pair of flush cutters, being careful not to clip the wires for the fan (Image 7A). Once the outside cage is off, there will likely be some small nubs of plastic coming from where the cage supports were clipped off . These will need to be trimmed back in order for the fan motor to fit into its 3D printed motor mount (Image 7B). Once the base has been trimmed, cut the fan blades off as well (Image 7C, 7D). Repeat this process for the remaining fan motors until there are 16 fully trimmed.

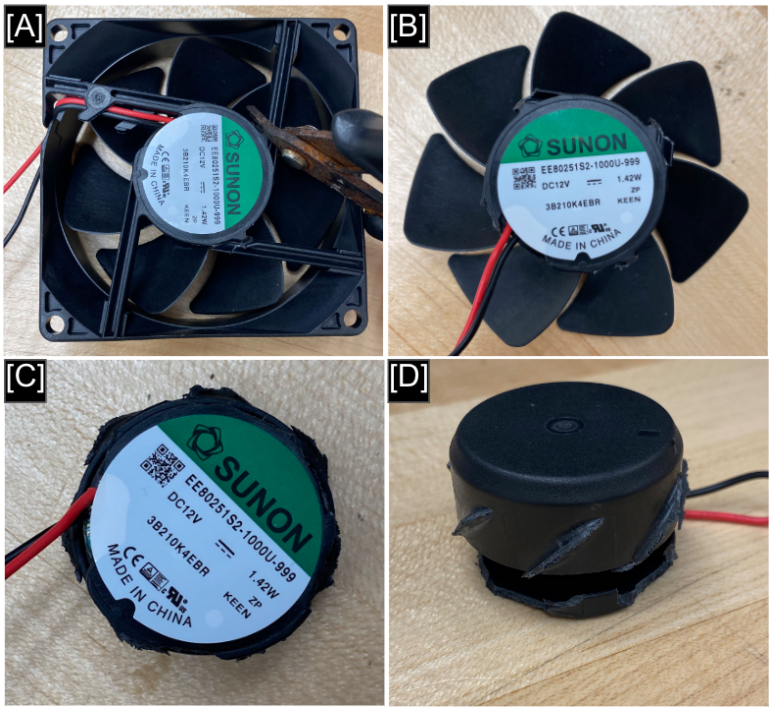


Image 7

[A] Fan motor before trimming. [B] Fan motor with outside cage removed. [C] Fan motor with blades removed. [D] Top down view of trimmed fan motor

The wires for the fan motors need to be extended to be able to reach the stir plate controller. For every motor, cut 2 wires of 3 feet in length. Solder the 3 foot lengths of wire to the positive and ground wires of the motor. If a power source is available, testing the motors for functionality here is advised by applying 12V of DC power to the wires. Apply heat shrink or electrical tape to the connection point of the wires where they were soldered together.

Put some spare cardboard or other protective material on a flat work surface, and line up the 16 motor mounts. Mix together some two-part epoxy in a small disposable container, and apply a small approximately 5 mm dot of epoxy to the center of the motor mounts. Take the fan motors that have been prepared, and fit them inside the center of the motor mounts on top of the epoxy. The wires should nestle into the groove on the motor mount to prevent strain on the wires' connection points. Allow the epoxy to cure overnight. While the motors are curing to their mounts, add another small 5mm dot of epoxy to the top. Place the magnet holder on top of the fan motor as close to the center as possible. Spinning the motor helps to visualize if the magnet holder is properly centered. Tape this in place to ensure the magnet holder does not move while curing.

After the motors have cured to their mounts overnight and the magnet holders have cured to the tops of the motors (Image 8), apply a small 2-3 mm dot of epoxy in the indentations of the magnet holders. Place the neodymium magnets into the epoxied indentations of the magnet holders, making sure that opposite poles are facing upward for each indentation. It is extremely important that opposite poles face upward in order for the magnets to interact correctly with the

stir bar. Once the magnets are in place, apply a piece of tape over them while the epoxy cures. These magnets are very strong, and over time they will pull towards each other and may even pull themselves free of the indentations if they are not secured. Allow the epoxy to cure overnight.

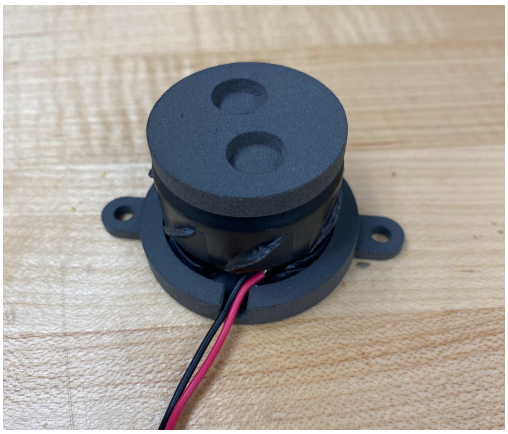


Image 8

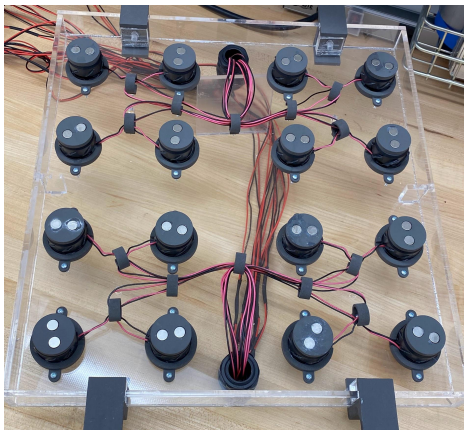


Image 9

Once the individual stirrer units have been fully epoxied together, they can be fastened to the acrylic housing using the 4-40 screws, nuts, and washers. While securing stirrers, orient the wire grooves as seen in Image 9 and route the wires through the routing hooks and out the appropriate cable gland.

3. Stir Plate Controller Construction

The controllers of the stir array are composed of two units in a single housing, each unit being responsible for one half of the stir plate array. Each unit has a custom circuit board, an LCD screen for menu display, an IR sensor to communicate with the controller, and a pushbutton to interrupt the stir plate program while it is running. The 3D printed parts required for this part of the build are a controller box, a controller lid, two controller port screws, and two controller tank mounts. The two controller windows should be cut out of quarter inch acrylic and are included on cut sheet 1. Two of the custom circuit boards will also be needed.

I. Circuit Board Assembly

For placement of components on the circuit board, reference Image 10.

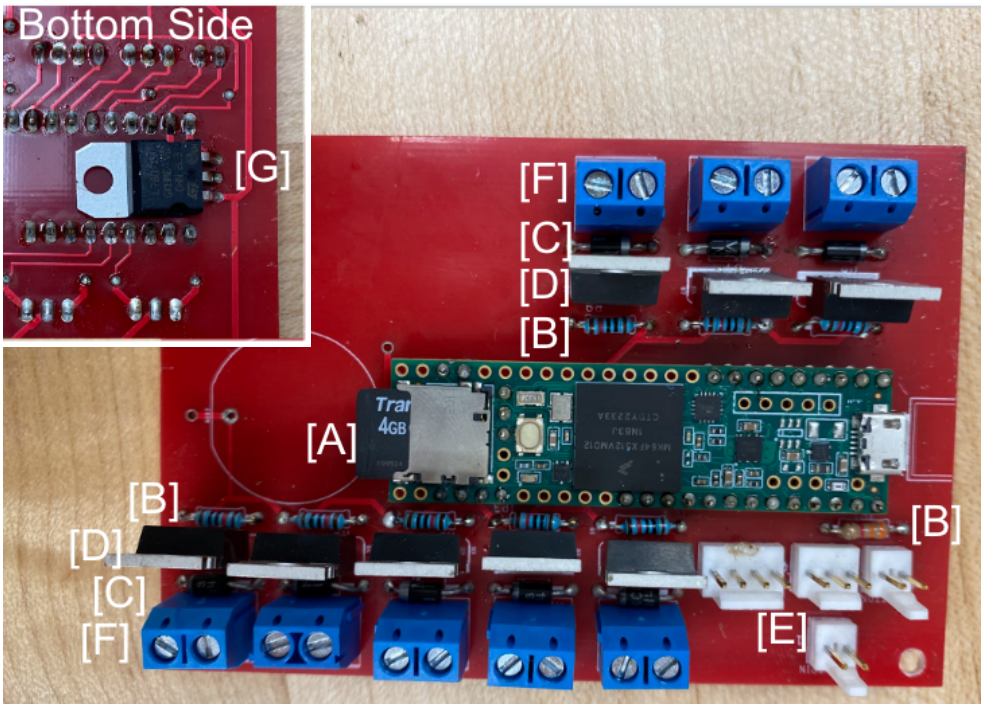
To start, solder the headers for the Teensy onto the board. It is advantageous to rest the Teensy on the top side of the headers while they are being soldered into place from the bottom. This helps to ensure the headers remain perpendicular to the board and the Teensy will fit onto the headers correctly.

Solder on all resistors and diodes (Image 10B-C). Resistors are not directionally sensitive, however diodes need to be placed in the correct orientation to regulate current correctly. The line on the diode body should go to the same end as the line on the board silkscreen if it was purchased online, but if the circuit board was milled by the builder, follow the orientation of the diodes in Image 10.
The male KK connectors should go on next (Image 10E), along with the screw terminals (Image 10F).

The N-channel mosfets and voltage regulator are soldered on next. The metallic back of the mosfet should face the thick white line of the silkscreen on the board if it was printed (Image 10D). The voltage regulator should be installed on the bottom side of the board, with the pins bent at a 90 degree angle so the back of the voltage regulator rests along the circuit board (Image 10G).

Finally, the Teensy should be installed last. Place the Teensy on the headers that were soldered in at the beginning of board construction (Image 10A) and solder along the top of all the header pins, being careful not to burn components on the Teensy board.

Image 10
[A] Teensy
[B] resistors
[C] diodes
[D] mosfets
[E] KK connector
[F] screw terminals
[G] voltage regulator



II. Controller Box Construction

The power source for the circuit boards are routed through the bottom of the controller box (Image 11). This one power source needs to be split into two different power cords, one for each board. Do so by soldering an additional length of wire to both the red and black wires of the

waterproof barrel jack (Image 11). Crimp the ends of all four wires with KK crimps. Slip the waterproof barrel jack into the appropriate place on the controller housing, so the wires that were soldered and crimped are on the interior of the box, and the barrel jack is on the exterior.

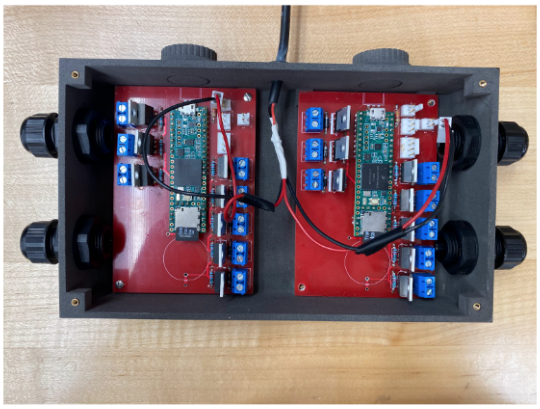


Image 11

Turn the controller box upside down. There should be a “cup” where the barrel jack enters the controller housing. Mix some two part epoxy and deposit in this “cup”. When the epoxy cures, this will keep the barrel jack in place as well as water-proof this part of the box.

After the epoxy has cured, the threaded inserts for the controller box and controller lid should be pushed into place, in the places shown in Images 12 and 13. Using a hard flat object such as a scrap piece of acrylic to push these in is recommended.

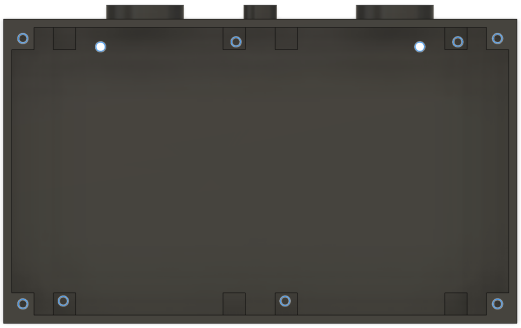


Image 12

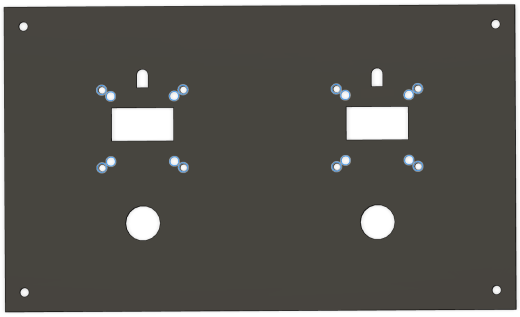


Image 13

Finally, the IR sensor, pushbutton, and OLED screen should be affixed to the controller lid. Solder the headers onto the OLED, and then bend the headers at a roughly 30 degree angle to the board. Solder wires to the pins of the pushbutton. The OLED can be screwed into place using the appropriate threaded inserts. The pushbutton can be screwed into place and affixed with the nut the button comes packaged with. The IR sensor will need to be epoxied into place. Place the lid on a flat surface. Bend the pins of the IR receiver at a 90 degree angle as close to the body of the IR receiver as possible, as seen in Image 14. Place the receiver in the appropriate position on the lid and epoxy it into place. Let it cure overnight.

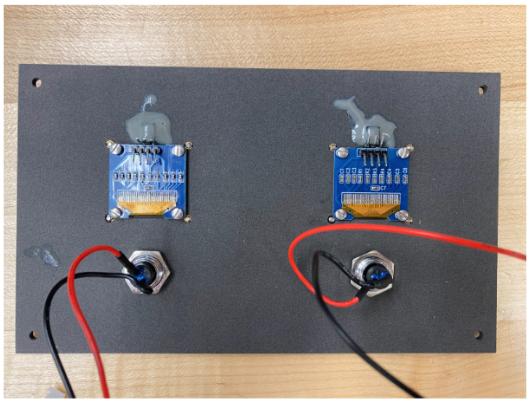


Image 14

For the wiring to the IR receiver and OLED, make cables with dupont style connectors at one end and KK style connectors at the other. See images 15 and 16 for examples of the OLED and IR cables, respectively.

Image 15

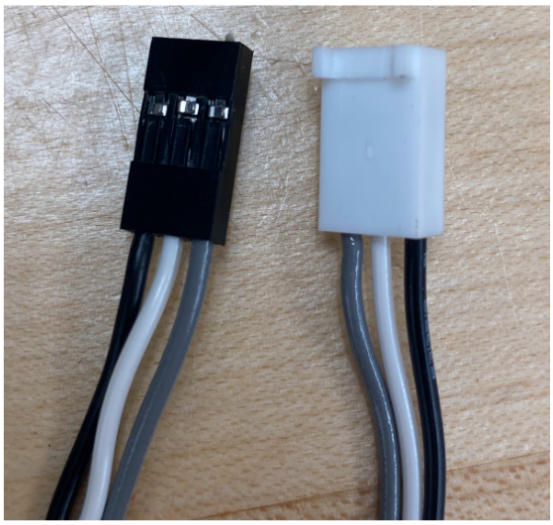


Image 16

III. Software Download and Initial Setup

Follow the step-by-step instructions on the Teensy website to download and install the Arduino and Teensyduino softwares onto a computer. Ensure that the version of Arduino that is installed is compatible with the Teensy software, the Teensyduino install wizard states compatible Arduino versions on the first page of the install setup.

Once the software is installed, download the stir plate code from the STAR System github repository. Move the code into a folder titled the same as the code file. For example, if the code file is called “starStirCode.ino”, it should be inside a folder called “starStirCode”. Move this folder to the documents tab > “Arduino” > “Arduino libraries”.

IV. Arduino Libraries

This code requires the use of several libraries to run properly, which are listed in Table 3:

Table 3: Arduino Libraries for Stir System Controller		
Library	Purpose	Author
Wire.h	Data communication	A
Adafruit_GFX.h	Adafruit OLED display	Fried, L; Adafruit
Adafruit_SSD1306.h	Adafruit OLED display	Fried, L; Adafruit
IRremote.h	IR communication	Kahn, R; Shirriff, K; et al.
SdFat.h	Read and write to SD card	Greiman, B;
SPI.h	Serial communication	Maglie, C; Stoffregen, P; Kooijman, M

To include these libraries, click the sketch tab, go to “Include Libraries” and select “Manage Libraries”. When the library manager pops up, search for each library and download the most recent version of each. This will download the library to the “starStirCode” folder the code was placed inside.

The Adafruit_SSD1306 library is responsible for the output to the OLED screen, and the resolution for the OLED being used needs to be modified inside the code of the library. To do this, find the folder for the library. On a PC, the file path should be Arduino > hardware > teensy > avr > libraries > Adafruit_SSD1306. On Mac, right click the Teensyduino icon and select “Show Package Contents” > Contents > Java > hardware, at which point the directions should be the same. Open the file titled “Adafruit_SSD1306.h” with the text editing program of the builder’s choice. Scroll down to the following section:

```
// ONE of the following three lines must be #defined:
//#define SSD1306_128_64 ///< DEPRECATED: old way to specify 128x64 screen
#define SSD1306_128_32 ///< DEPRECATED: old way to specify 128x32 screen
//#define SSD1306_96_16  ///< DEPRECATED: old way to specify 96x16 screen
```

The default resolution of this library is for a screen resolution of 128 x 32, but the screen resolution used in this code is for 128 x 64. To remedy this, the comments should be removed from the 128_64 line, and new comments should be added before the 128_32 line, like so:

```
// ONE of the following three lines must be #defined:
#define SSD1306_128_64 ///< DEPRECATED: old way to specify 128x64 screen
//#define SSD1306_128_32 ///< DEPRECATED: old way to specify 128x32 screen
//#define SSD1306_96_16  ///< DEPRECATED: old way to specify 96x16 screen
```

Once this is taken care of and saved, the libraries are good to go, and the code may be uploaded to the Teensy

V. Code Upload

To begin, open the Teensyduino software. Under Tools > Board, choose Teensy 3.5, this step should only be necessary the first time the program is opened. From the File tab, open the starStirCode file that was saved in the library folder that was created in part II. Once the code has been opened, click the verify button in the upper right corner of the screen to compile the code.

Image 17

Once the code has been successfully compiled, a new window that looks like Image 17 should pop up. This window is how the code is sent to the Teensy. Connect the computer being used to the Teensy via a USB to micro-USB cable. Once connected, press the beige button next to the SD card slot. This should trigger the Teensyduino program to send the compiled code to the Teensy. The OLED screen should power on at this point and say “MicroSD Card Not Detected”.

VI. MicroSD Installation

The controller is designed to retain power settings in case of power interruption. Upon changing the voltage settings on the controller and selecting “ENTER SET”, a microSD card inserted into the Teensy will save and retain the settings the user has selected. In the case of a temporary power interruption, once the controller is reconnected to power it will automatically read the user input settings from the microSD and start up with them. In order for the controller to work as intended, a microSD card that has been formatted correctly is necessary.

Using a text editor (TextEdit on Mac, Notepad on PC), create a file that has 8 0’s separated by commas on a single line (Image 18). Save this file as .TXT file, with the file name of “sampleParam.TXT”. Once saved, move this file onto the Micro SD for the controller. When this SD card is slotted into the Teensy and power is applied to the controller, the text saying “MicroSD Card Not Detected” should no longer be displayed.

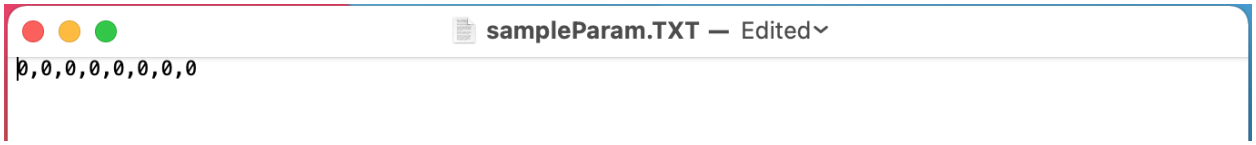


Image 18

VII. Software Usage

The controller is programmed to start applying voltage when power is connected to the device. This is so the motors can start back up without user intervention in the case of power interruption. To wake the controller, the button must be pushed to get the main menu screen to pop up. Here, there should be an array of 8 numbers, 0's if this is the first time the software is being used. Use the IR remote to navigate to each number, and use the up or down buttons on the remote to raise or lower the voltage of that particular motor, where higher voltage increases spinning speed and lower voltage decreases speed. Once the settings are at the desired voltages, navigate to the bottom of the screen and select "Enter Set". This should write the settings to the sampleParam file on the SD card, the OLED screen should go blank, and the motors should start spinning at the user-programmed speeds.

4. Doser Box Construction

The STAR system doser box contains two calibrated peristaltic pumps (Image 19I) for bulk dosing liquids at a higher volume, as well as a Kloehn syringe pump (Image 19H) for high precision and accuracy dosing. The peristaltic pumps are turned by brushless DC motors for continuous use application, which require motor drivers (Image 19A). The drivers are mounted on the interior of the box on standoffs (Image 19K). A female panel mount barrel jack for 24V DC power (Image 19E), two SP13 connectors for pump communication (Image 19C), and an LED push button to toggle power on and off (Image 19D) are located on the back of the box. A 24V fan mounted on the inside of the box cools the system (Image 19B). Power for the system is distributed from the push button using a power distribution board (PDB, Image 19F). There are three 3D printed parts needed for the construction of this device: the doser box, doser box vent, and pump mount panel. Only one of each is needed.

I. Component Placement

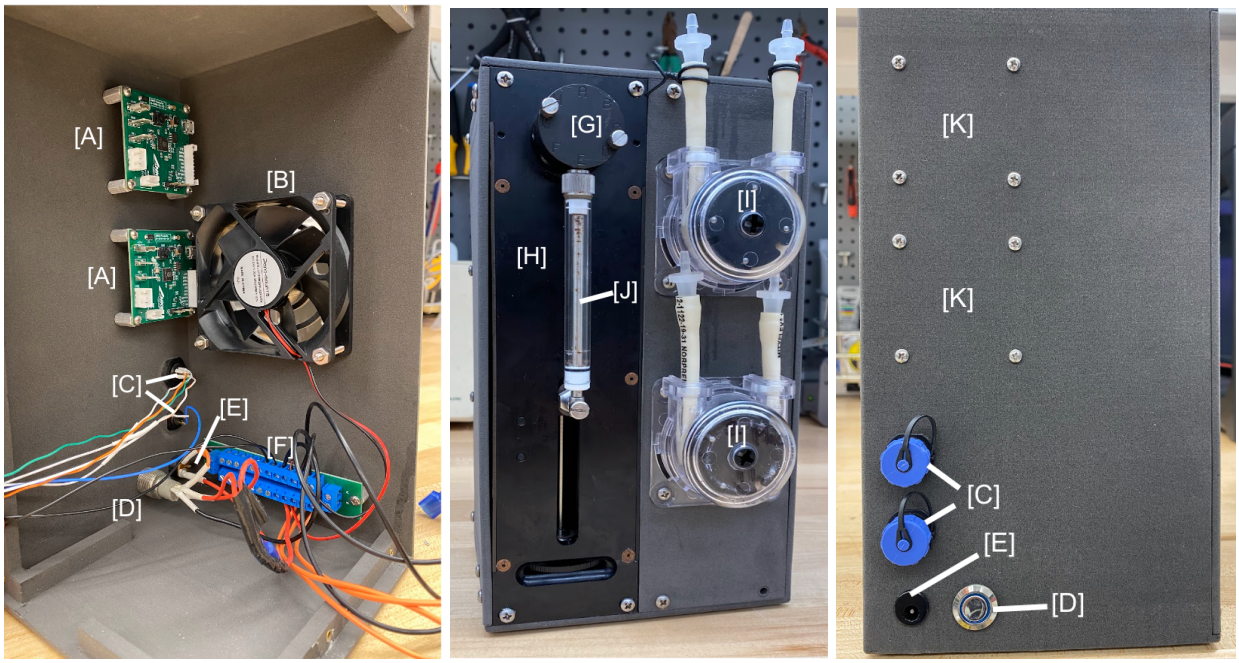


Image 19

[A] motor drivers
[B] 24V fan
[C] SP13 bulkhead
[D] LED push button
[E] panel mount barrel jack
[F] power distribution board (PDB)
[G] Kloehn 8 channel valve
[H] Kloehn syringe pump
[I] peristaltic pump
[J] Kloehn 2.5 mL syringe
[K] motor driver mounting points

II. Wiring Guide

24V Power

The doser box requires 24V DC power input into the panel mount barrel jack. The negative/ground (black) wire is hooked straight into the negative side of the PDB, where the positive is soldered to the 24V in pin on the LED push button. A negative wire from the power distribution board is soldered to the ground pin on the push button. The 24V out pin of the push button is then wired to the positive terminal of the PDB. One last wire from the positive side of the PDB to power the light on the push button has to be soldered onto the LED power pin along with a 470 Ω resistor.

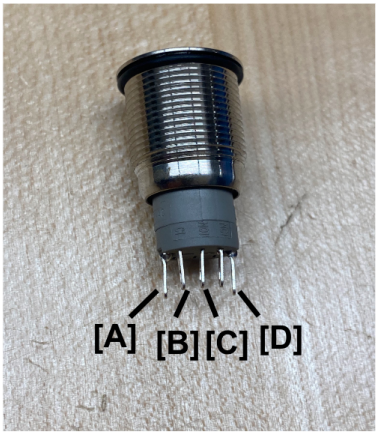


Image 20

[A] Ground
[B] 24V in
[C] 24V out
[D] LED power

Peristaltic Pumps

Communication between the doser box and the computer is handled with two SP13 connectors, one for the peristaltic pumps and one for the Kloehn Syringe Pump. Two communication wires from this SP13 connector are required for each peristaltic pump driver: one that delivers signal voltage which determines the speed of the motor (Image 21E), and another wire which will determine the direction the motor turns (Image 21C). The motor driver also requires access to 24V power from the PDB (Image 21G) and grounding as well (Image 21F, Image 21H). The remaining three wires on Image 21 ([A], [B], [D]) will lead to a 3-pin connector at the indicated place of the motor driver on Image 21. Image 22 is an illustration of a fully connected peristaltic pump and driver, and Image 23 shows pictures of the peristaltic pumps fully hooked up into the system.

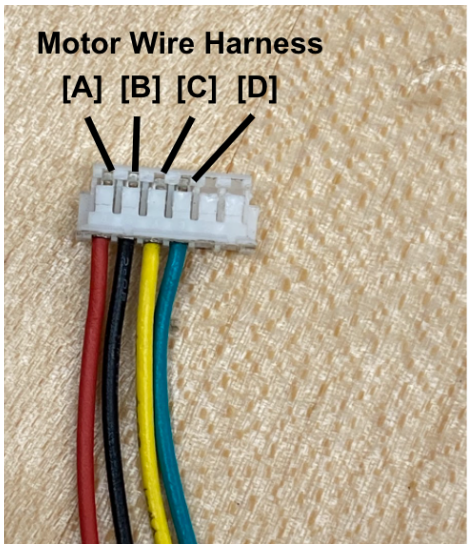
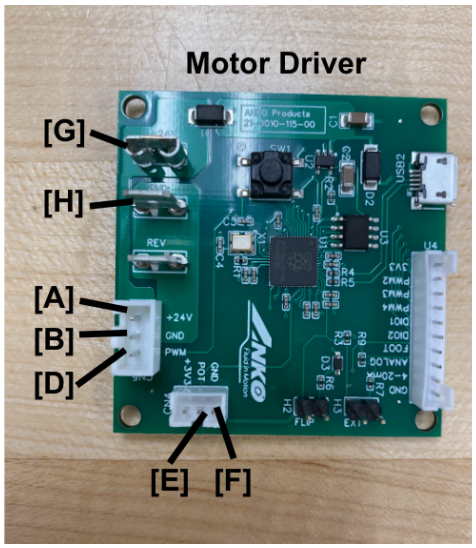


Image 21
[A] +24V
[B] Ground
[C] Direction (SP13)
[D] PWM
[E] Motor speed (SP13)
[F] Ground (PDB)
[G] +24V (PDB)
[H] Ground (PDB)



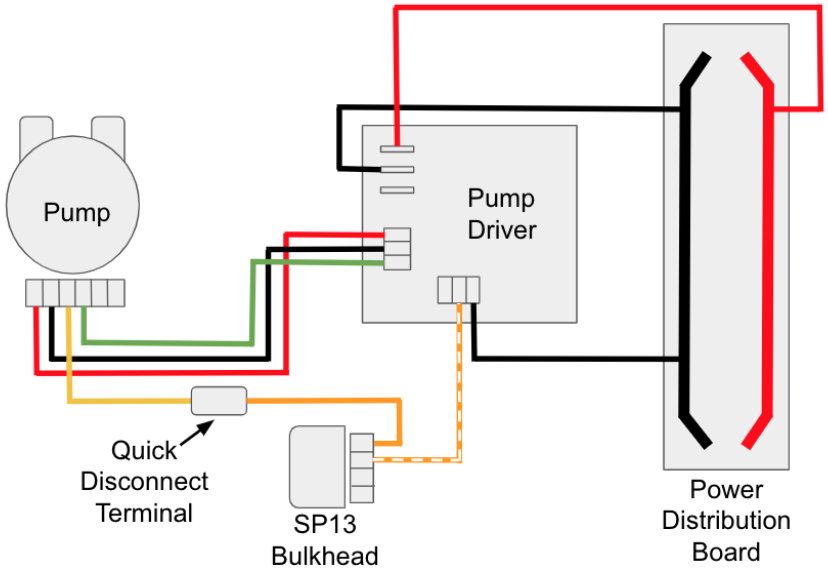


Image 22

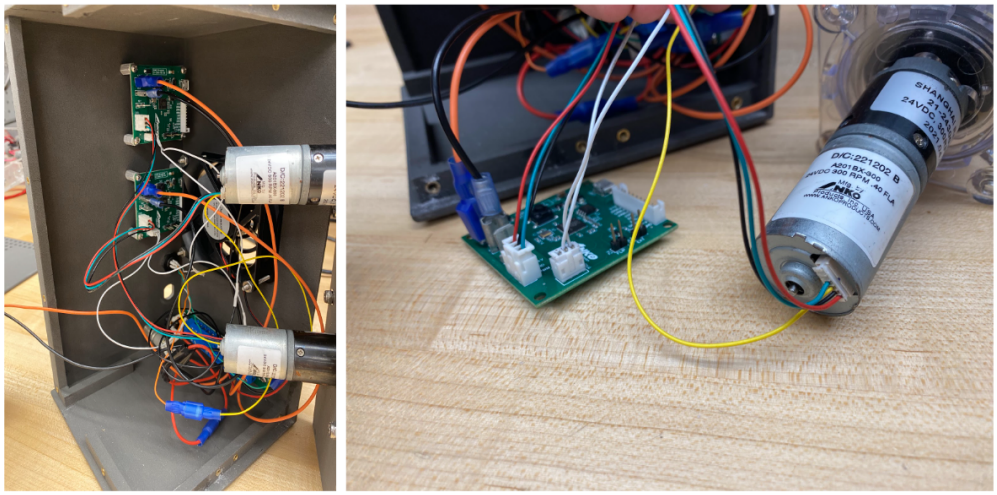


Image 23

Kloehn Pump

The Kloehn syringe pump requires 24V power (Image 24B). The computer communicates with the Kloehn pump through RS232 communication. This is done through a USB to serial DB9 connector, which is wired to a SP13 connector into the doser box. On the Kloehn SP13 connector three wires are needed: RXD for receiving data from the computer, TXD for transmitting data to the computer, and a system ground. On the doser box side of the SP13 connector, these three wires should be hooked up into a 3-pin female KK connector. 24V power should also be led from the power distribution board into a 4-pin KK connector, utilizing the top 2 pins for ground and positive. These connectors will be placed onto the card edge adaptor in the locations encircled in Image 24.

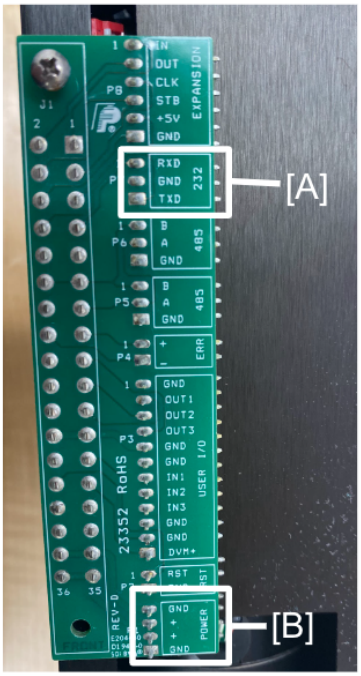


Image 24
[A] RS232 from SP13
[B] Power from PDB