Pin Transfer Robot for Chemical Screening

Group H

Meet the team!

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Computer Engineering

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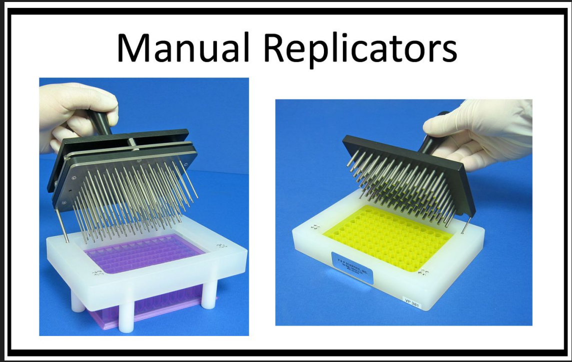
Project Overview

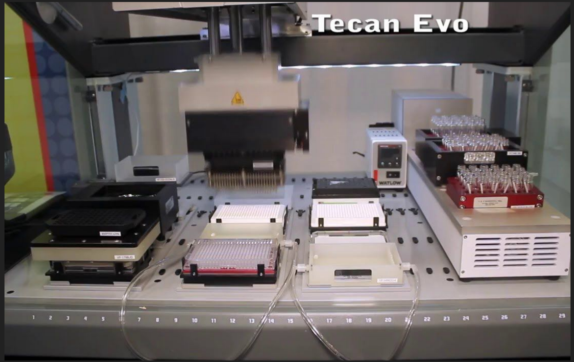
Christopher Clifford - Electrical Engineering

Motivation

The motivation of our project is to make an autonomous pin transfer solution that is accessible to smaller labs enabling exploratory drug or small molecule testing that will not be cost prohibitive.

Available pin transfer robotic solutions today





Manual

~$3000

Time consuming

Inaccurate

Small number of samples

Liquid Handling Conversion Kits

~$10,000+

Not purpose built

Requires additional robotics to fully automate many plates

Quickly gets more expensive

Commercial Robotics

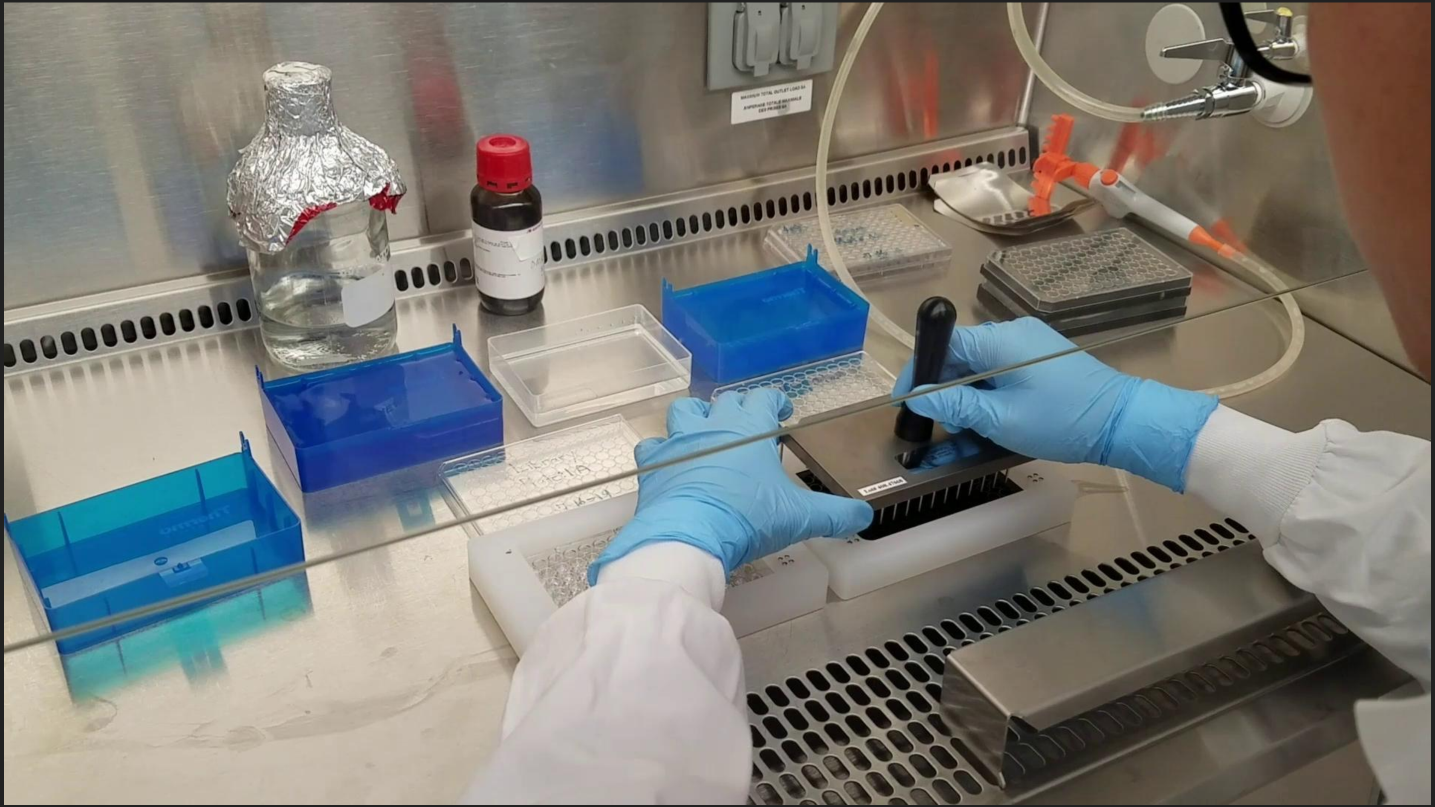
~$1,000,000+

Purpose built for drug discovery

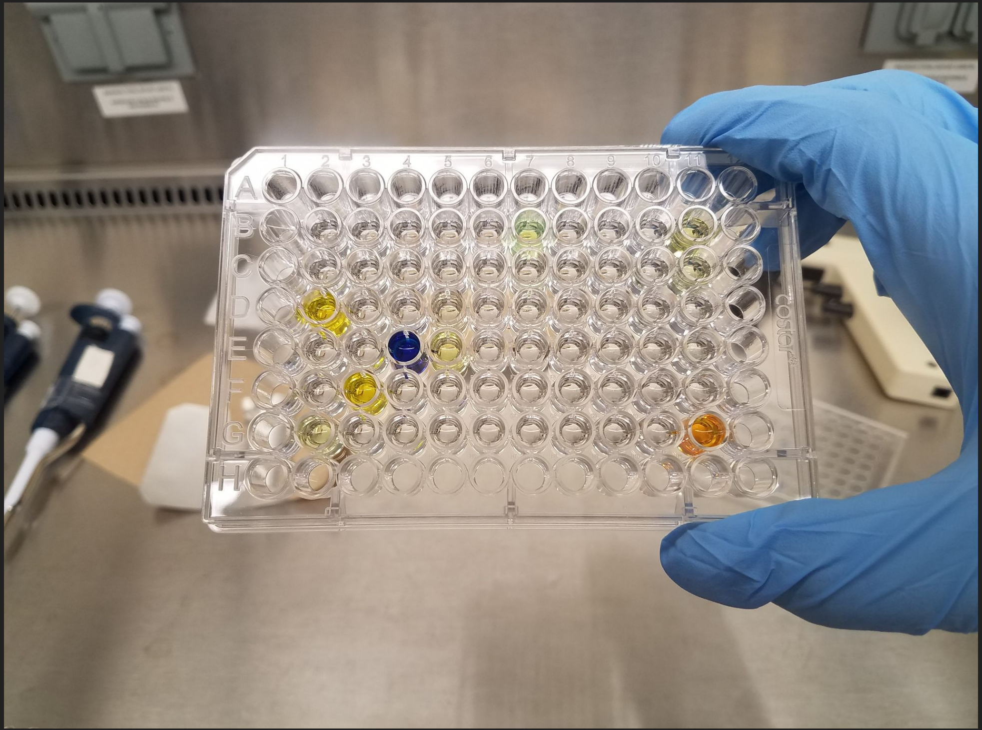
Huge (entire rooms)

Expensive and therefore inaccessible for small labs with little funding

Manual process used by small biology labs

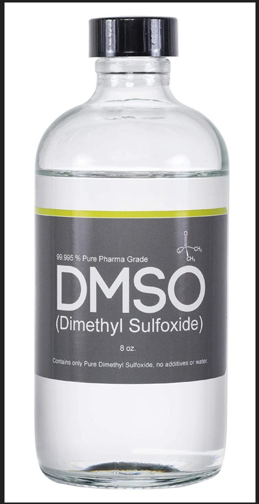


96 Perkin Elmer® Well plate

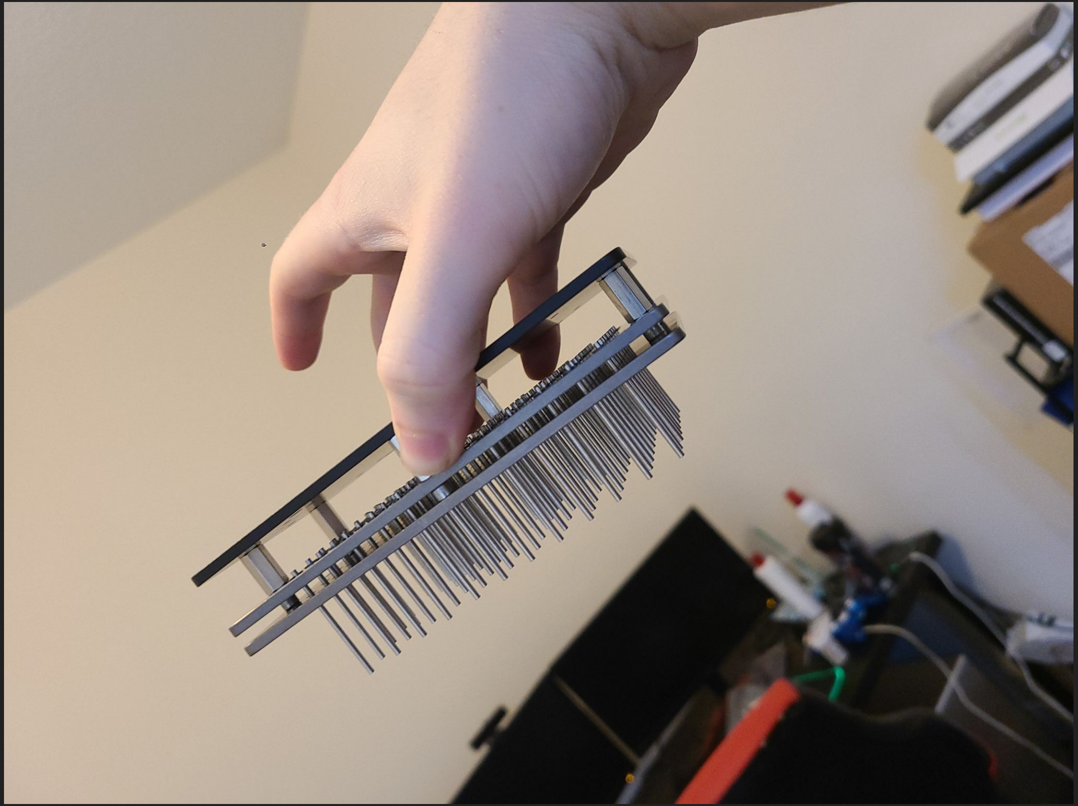


Washing and Drying the pin tool

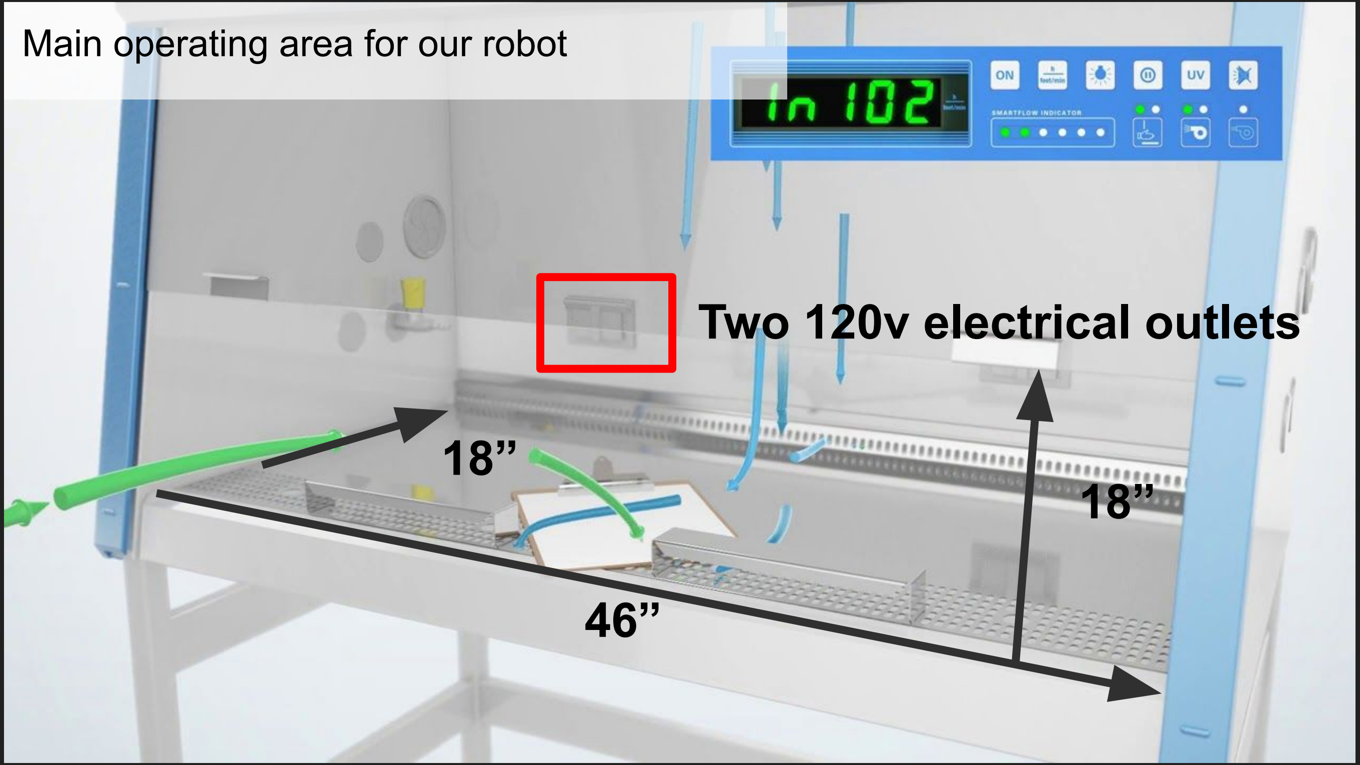
- *Varies:* Typical procedure is dipping the pin tool into DMSO, deionized water, then ethanol 3-4 times each.
- Once the pin tool has been removed from the cleaning solution, it'd have to dry before it can be used again
- Drying fan mount made from aluminum, raised with spacers, and milled to permit airflow into the fan.



Robotic Pin Transfer Tool

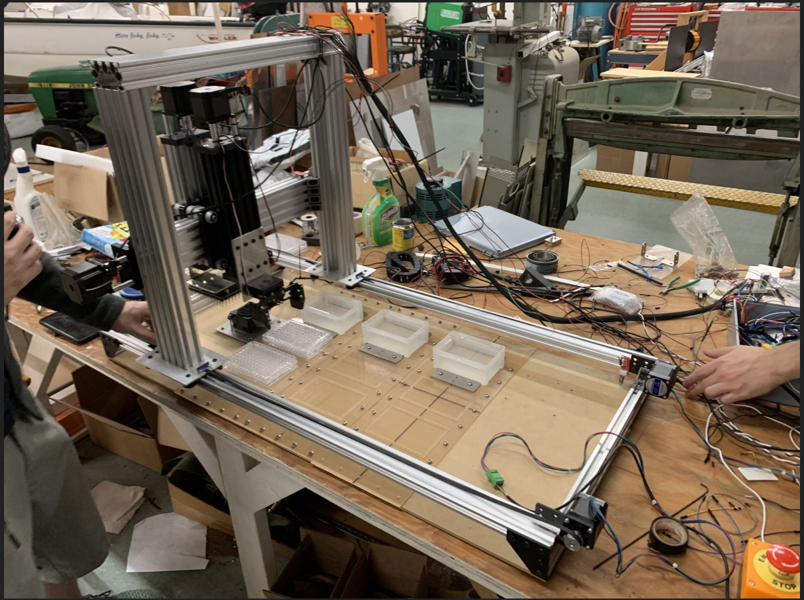


Biosafety Cabinet



Robotic design

- 3 Axis CNC
- 2 input and 2 output microplate stacks and a staging area for operation
- The pin tool is attached to one z-axis and a parallel gripper to another
- Mounts were designed and milled for the pin tool and parallel gripper so that they are fastened firmly on their respective z-axes



Stacking Design

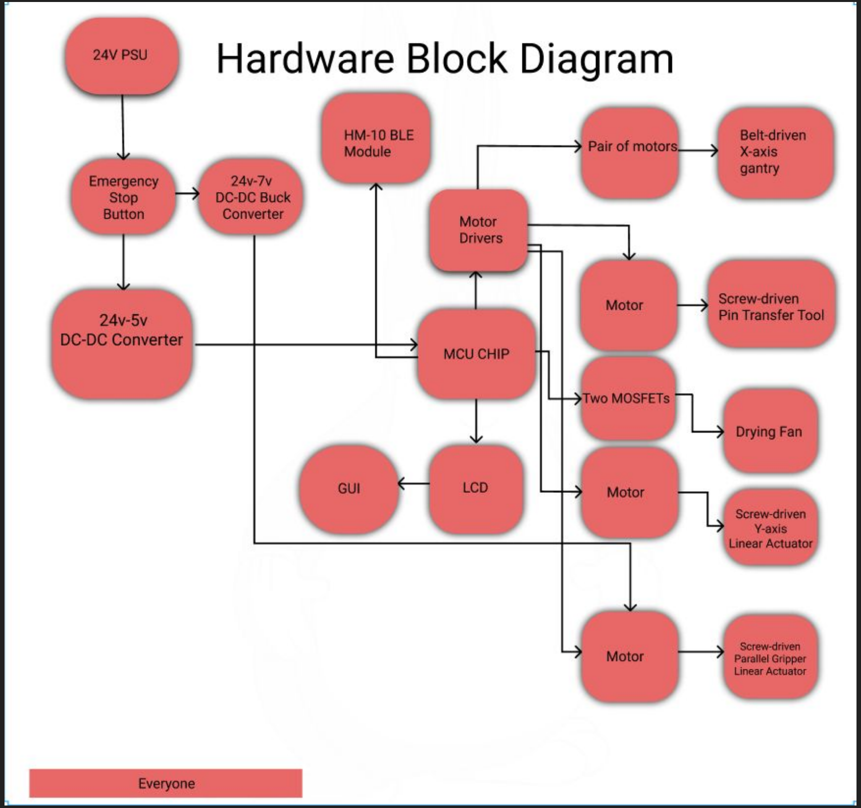
- A baseplate was designed to firmly seat microplates onto the robot workspace. A lip was milled .04” deep into acrylic which prevents the microplates from sliding in the X or Y axis and improves the accuracy of the gripper and pin tool. Three 7”x20” acrylic sheets are screwed into a base of MDF for the first prototype. Later iterations will be milled entirely from aluminum.

- The parallel gripper will move the microplates from the input stack to the staging area and from the staging area to the output stack after a pin transfer is successfully completed.

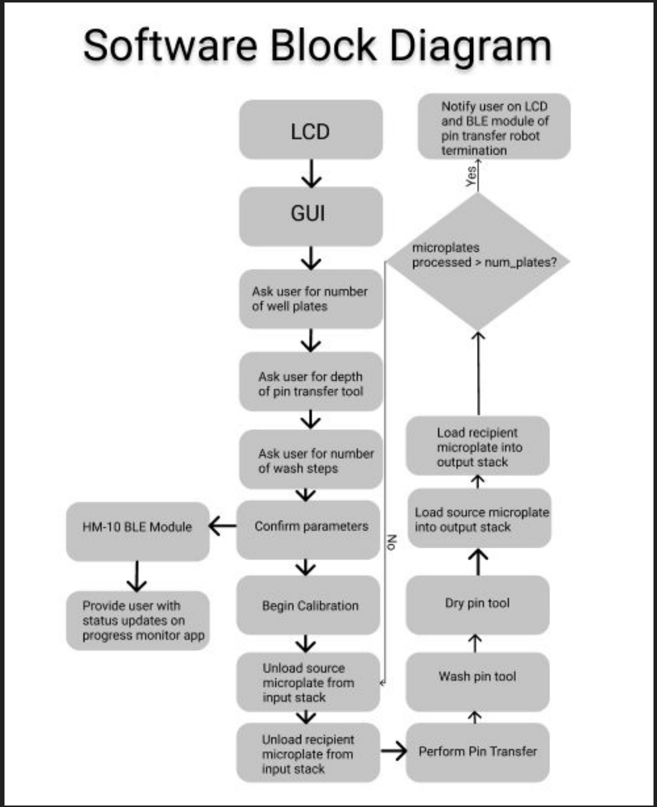
Technical Specifications

- Should be within 18” x 46” x 18” to fit within a biosafety cabinet
- Should be less than 50 lbs
- Should be sanitizable with 70% isopropyl alcohol
- Should have a failure rate of <1%
    - Any error that results in a failed pin transfer constitutes a failure.
- Robot work status can be sent to phones or PCs wirelessly
- Emergency shut off button
- Input stacks can take 8 microplates at a time

Hardware Block Diagram



Software Block Diagram



Budget Analysis

1	Item name	Supplier	Quantity	Total Price	Price per part	ETA
2	Xtreme Solid V Wheel Kit	OpenBuilds	8	$55.92	$6.99	Arrived
3	Drop in Tee Nuts	OpenBuilds	4	$3.96	$0.99	Arrived
4	2 x 1/4" x 8mm Flexible Coupling	OpenBuilds	2	$13.98	$6.99	Arrived
5	Lock Collar	OpenBuilds	4	$4.76	$1.19	Arrived
6	Nema 23 Stepper	OpenBuilds	2	$55.98	$27.99	Arrived
7	Ball Bearing 688Z 8x16x5	OpenBuilds	4	$3.96	$0.99	Arrived
8	Shim - 12 x 8 x 1mm	OpenBuilds	4	$1.16	$0.29	Arrived
9	540mm 8mm Metric Acme Lead Screw	OpenBuilds	1	$21.99	$21.99	Arrived
10	290mm 8mm Metric Acme Lead Screw	OpenBuilds	1	$10.99	$10.99	Arrived
11	Cast Corner Bracket	OpenBuilds	24	$35.76	$1.49	Arrived
12	C-Beam End Mount	OpenBuilds	4	$35.96	$8.99	Arrived
13	Anti-Backlash Nut Block for 8mm Metric Acme Lead Screw	OpenBuilds	2	$19.98	$9.99	Arrived
14	XLarge C-Beam Gantry Plate	OpenBuilds	2	$29.98	$14.99	Arrived
15	1000mm V-slot 20 x 40mm Linear Rail	OpenBuilds	2	$27.98	$13.99	Arrived
16	500mm V-slot 20 x 40mm Linear Rail	OpenBuilds	2	$13.98	$6.99	Arrived
17	Low Profile Screws M5(10 Pack) (Length: 1000mm)	OpenBuilds	11	$11.99	$1.09	Arrived
18	Allen Wrench(2mm)	OpenBuilds	1	$0.39	$0.39	Arrived
19	Allen Wrench(2.5mm)	OpenBuilds	1	$0.39	$0.39	Arrived
20	Allen Wrench(3mm)	OpenBuilds	1	$0.39	$0.39	Arrived
21	Aluminum Spacers(10 Pack)(Size: 6mm)	OpenBuilds	8	$27.12	$3.39	Arrived
22	Aluminum Spacers(10 Pack)(Size: 40mm)	OpenBuilds	4	$31.56	$7.89	Arrived
23	Aluminum Spacers(10 Pack)(Size: 3mm)	OpenBuilds	6	$14.94	$2.49	Arrived
24	Precision Shim - 10 x 5 x 1mm	OpenBuilds	4	$1.24	$0.31	Arrived
25	Eccentric Spacer	OpenBuilds	4	$7.96	$1.99	Arrived
26	Allen Wrench(1.5mm)	OpenBuilds	1	$0.39	$0.39	Arrived
27	Low Profile Screws M5(10 Pack)(Length: 8mm)	OpenBuilds	4	$3.96	$0.99	Arrived
28	Low Profile Screws M5(10 Pack)(Length: 12mm)	OpenBuilds	1	$1.09	$1.09	Arrived
29	Low Profile Screws M5(10 Pack)(Length: 20mm)	OpenBuilds	2	$2.58	$1.29	Arrived
30	Low Profile Screws M5(10 Pack)(Length: 50mm)	OpenBuilds	1	$1.89	$1.89	Arrived

Budget Analysis

1	Item name	Supplier	Quantity	Total Price	Price per part	ETA
31	Low Profile Screws M5(10 Pack)(Length: 27mm)	OpenBuilds	1	$1.39	$1.39	Arrived
32	Tee Nuts - M5(10 Pack)	OpenBuilds	10	$29.90	$2.99	Arrived
33	Shipping	OpenBuilds	1	$19.28	$19.28	Arrived
34	Sales Tax	OpenBuilds	1	$43.74	$43.74	Arrived
35	V-Slot Nema 17 Linear Actuator Bundle(Length: 1000mm)	OpenBuilds	2	$243.98	$121.99	Arrived
36	24V Mean Well Power Supply Bundle	OpenBuilds	1	$69.99	$69.99	Arrived
37	Shipping	OpenBuilds	1	$13.45	$13.45	Arrived
38	Adafruit PiTFT 2.2" LCD	Amazon	1	$23.02	$23.02	Arrived
39	DSD Tech HM-10 Bluetooth Module	Amazon	1	$10.99	$9.99	Arrived
40	URBEST AC 250v 5A SPDT 1NO 1NC Momentary Hinge Ro	Amazon	1	$6.99	$6.99	Arrived
41	STEPPERONLINE CNC Stepper Motor Driver	Amazon	5	$129.95	$25.99	Arrived
42	PCB	JLC PCB	1	$39.08	$39.08	Arrived
43	Bourns CAY16-102J4LF Resistor Networks & Arrays 1K 5%	Mouser	8	$0.80	$0.10	Arrived
44	Bourns CR0603-FC-1004ELF Thick Film Resistors - SMD 1M	Mouser	5	$0.50	$0.10	Arrived
45	KEMET C0603C105K3RACTU Multilayer Ceramic Capacitor	Mouser	5	$1.45	$0.29	Arrived
46	Bourns CR0603-JW-202ELF Thick Film Resistors - SMD 2K	Mouser	20	$0.30	$0.02	Arrived
47	Vishay CRCW060310K0JNEBC Thick Film Resistors - SMD	Mouser	5	$0.50	$0.10	Arrived
48	Elegoo Mega R3 ATmega2560	Amazon	1	$15.99	$15.99	Arrived
49	C-Beam(250mm)	MakerStore	1	$8.90	$8.90	Arrived
50	C-Beam(500mm)	MakerStore	3	$161.91	$53.97	Arrived
51	USPS Shipping	MakerStore	1	$28.39	$28.39	Arrived
52	100 M5x0.8x10mm Screws	Amazon	1	$8.99	$8.99	Arrived
53	35ft Wire Primary BLK and 35ft Wire Primary WHT	Ace Hardware	1	$21.72	$21.72	Arrived
54	ATMega2560-16AU	Not sure	1	$45.68	$45.68	Arrived
55	M3 10mm Screws	Lowe's	3	$5.94	$1.98	Arrived
56	1/8" Acrylic Sheet	Lowe's	1	$40.00	$40.00	Arrived
57	Vapker 100PCs 10 value DIP Quartz Crystal Oscillator	Amazon	1	$10.99	$10.99	Arrived
58	E-outstanding Nema 17 Stepper Motor Mount Flat Bracket Bl	Amazon	1	$8.99	$8.99	Arrived
59	ACTOBOTICS Parallel Gripper Kit A	Amazon	0	$0.00	$15.99	Arrived
60	Hilitchi 165-Pcs SMD Aluminum Electrolytic Capacitors Asso	Amazon	1	$9.99	$9.99	Arrived

Budget Analysis

1	Item name	Supplier	Quantity	Total Price	Price per part	ETA
61	Hulless Sliding T Nuts 2020 Series M3 T Slot Nut Fastener fo	Amazon	1	$4.99	$4.99	Arrived
62	Liberty, AC660V 10A Plastic Shell Red Sign Emergency Stop	Amazon	1	$9.68	$9.68	Arrived
63	2020 Corner Bracket 40PCS Aluminum Extrusion Corner Bra	Amazon	1	$12.99	$12.99	Arrived
64	Chanzon SMD Fast Switching/Schottky/Rectifier Diode Asso	Amazon	1	$6.99	$6.99	Arrived
65	SMT Removal Alloy 4.5ft	Amazon	1	$19.99	$19.99	Arrived
66	eoocvt DC Converter Buck Module 12V Convert to 5V USB (	Amazon	1	$12.12	$12.12	Arrived
67	KOOTANS 100pcs 2020 Series M5 Sliding T Nuts Metric M5	Amazon	1	$14.50	$14.50	Arrived
68	Mechanical Robot Arm Claw/Gripper Robot Gripper	Amazon	1	$17.99	$17.99	Arrived
69	No Clean SnPb Leaded Solder Paste	Amazon	1	$10.99	$10.99	Arrived
70	Binzzo T Nuts Tee Sliding Slot Nuts 20 Series M3 Threaded	Amazon	1	$7.99	$7.99	Arrived
71	Quick Charge QC3.0 USB Step Down Converter DC-DC Buc	Amazon	1	$11.77	$11.77	Arrived
72	DGZZI 2PCS 5-36V 400W MOS Field Effect Transistor Trigg	Amazon	1	$7.99	$7.99	Arrived
73	ReliaBot 2PCs Aluminum 2GT Timing Pulley 30 Teeth Bore 8	Amazon	1	$9.99	$9.99	Arrived
74	LC LICTOP 2pcs GT2 30 Teeth 8mm/0.31" Bore 6mm/0.24"	Amazon	1	$7.99	$7.99	Arrived
75	3D Printing GT2 Timing Belt, Zeelo 5 Meters (16.4ft) GT2 Op	Amazon	1	$10.99	$10.99	Arrived
76	Aluminum Spacers(10 Pack)(Size: 3mm)	OpenBuilds	1	$2.49	$2.49	Arrived
77	Aluminum Spacers(10 Pack)(Size: 20mm)	OpenBuilds	1	$4.99	$4.99	Arrived
78	Aluminum Spacers(10 Pack)(Size: 9mm)	OpenBuilds	1	$3.89	$3.89	Arrived
79	Aluminum Spacers(10 Pack)(Size: 6mm)	OpenBuilds	1	$3.39	$3.39	Arrived
80	Nylon Insert Hex Locknut - M5(10 Pack)	OpenBuilds	1	$0.99	$0.99	Arrived
81	Precision Shim - 10 x 5 x 1mm	OpenBuilds	12	$3.72	$0.31	Arrived
82	Eccentric Spacer(Length: 6mm)	OpenBuilds	4	$7.96	$1.99	Arrived
83	Low Profile Screws M5(10 Pack)(Length: 65mm)	OpenBuilds	1	$2.19	$2.19	Arrived
84	Low Profile Screws M5(10 Pack)(Length: 60mm)	OpenBuilds	1	$2.09	$2.09	Arrived
85	Low Profile Screws M5(10 Pack)(Length: 20 mm)	OpenBuilds	1	$1.29	$1.29	Arrived
86	Low Profile Screws M5(10 Pack)(Length: 10mm)	OpenBuilds	1	$1.09	$1.09	Arrived
87	Slot Washer - 15x5x2mm	OpenBuilds	1	$0.19	$0.19	Arrived
88	Nut Block for 8mm Metric Acme Lead Screw	OpenBuilds	2	$14.98	$7.49	Arrived
89	Xtreme Solid V Wheel Kit	OpenBuilds	8	$55.92	$6.99	Arrived
90	XLarge C-Beam Gantry Plate	OpenBuilds	1	$14.99	$14.99	Arrived

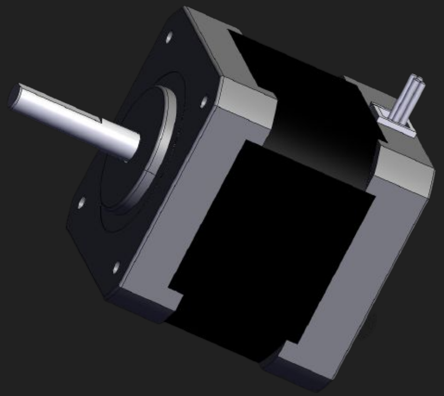
Budget Analysis

1	Item name	Supplier	Quantity	Total Price	Price per part	ETA
91	Tee-Nuts - M3(10 Pack)	OpenBuilds	1	$2.79	$2.79	Arrived
92	C-Beam XLarge Linear Actuator Bundle(Length: 250mm)	OpenBuilds	1	$155.99	$155.99	Arrived
93	Shipping	OpenBuilds	1	$17.87	$17.87	Arrived
94	Sales Tax	OpenBuilds	1	$16.79	$16.79	Arrived
95	Black Plastic Drag Chain Cable Carrierw 10 x 15 for CNC Ro	Amazon	3	$30.87	$10.29	Arrived
96	DSD TECH HM-10 Master and Slave Bluetooth 4.0 LE iBeac	Amazon	1	$11.49	$11.49	Arrived
97	Songhe HM-10 Bluetooth 4.0 BLE iBeacon UART Module wi	Aamzon	1	$11.64	$11.64	Arrived
98	Total			$1,979.60		

Hardware

Motors

NEMA 17 and NEMA 23 stepper motors



Stepper motors

- Used in similar applications
    - CNC machines
    - 3D printers

- Inexpensive (~$15)

- Compatible with many different motor drivers

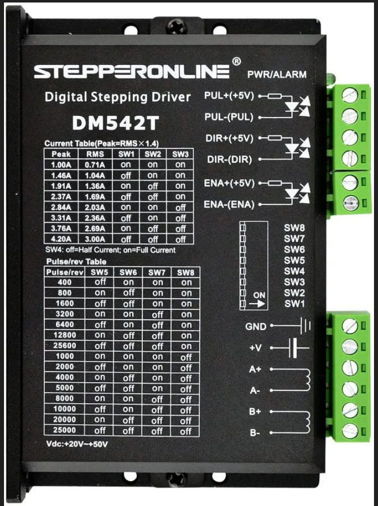
- Accuracy
    - Configurable steps

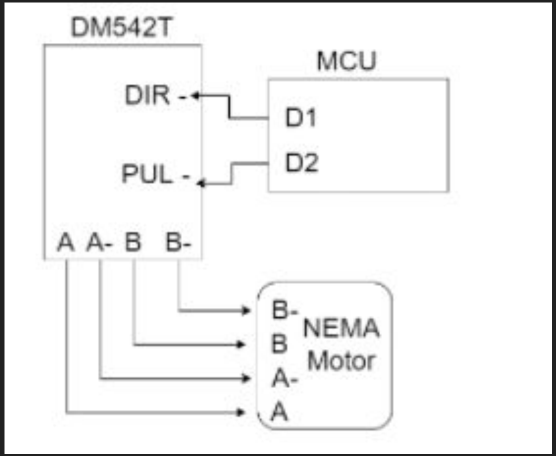
	NEMA 17	NEMA 23
Face plate area	(1.7 x 1.7) in^2	(2.3 x 2.3) in^2
Holding Torque	3.2 kg-cm	19 kg-cm
Phase draw	1.2A @ 4V	2.8A @ 3.2 V

Motor Drivers

DM542T Driver

- Compatible with NEMA-17 and NEMA-23 stepper motors
- Configurable steps
    - Dip-switches for changing steps and current draw
- Works well with the AccelStepper library which is used for interfacing the motor drivers through C++ software
- Simple wiring and set-up

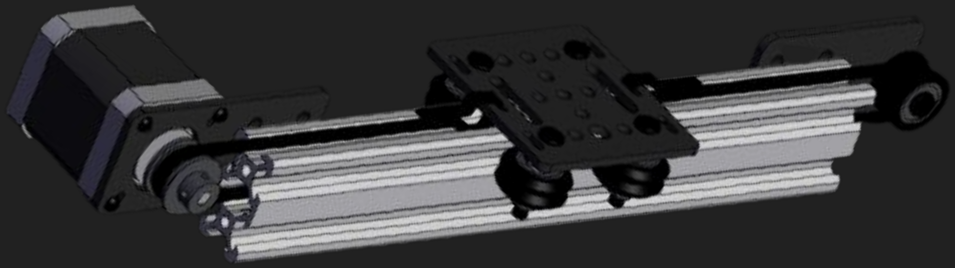


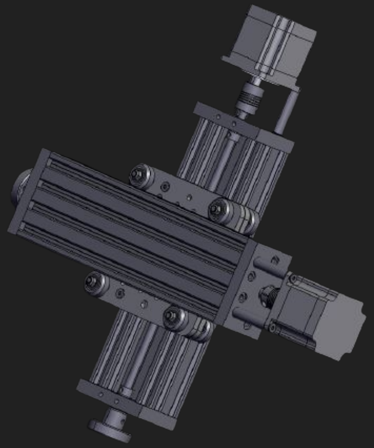


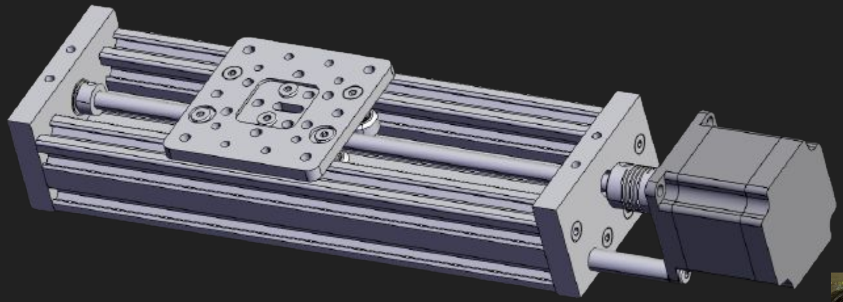
Linear Actuators

- V-slot belt-driven linear actuators
  - Used for X-axis linear actuators

- C-beam
  - Used for Z/Y configuration



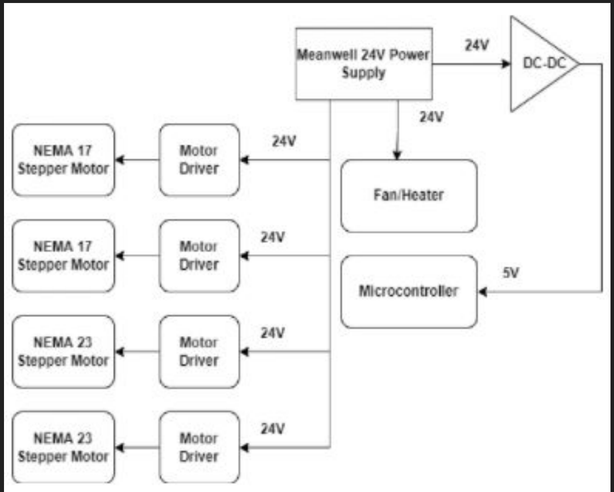




Limit Switches

- On the ends of each linear actuator
- Used for determining the bounds
    - As gantry card activates the switch, interrupt service routine (ISR) is executed to stop motor
- Safety precaution for motors, motor drivers, belts, etc.

Power Supply



Meanwell 24V PSU

- 24V / 14.6 A power delivery
  - ~350 W Output
- Built-in fan for cooling
- 3 DC outputs
  - Sufficient for 5 motor drivers
- Suitable PSU for driving an array of NEMA-23 and NEMA-17 motors

Component	Power produced	Total
Power Supply	Power Supply	+350W
NEMA 17	-(2 motors x 4.8W/motor)	+340W
NEMA 23	-(3 motors x 8.96W/motor)	+313.5W
Fan/Heater	-250W	+63.5W
Parallel Gripper	-2W	+61.5W

ATMega 2560 Microcontroller

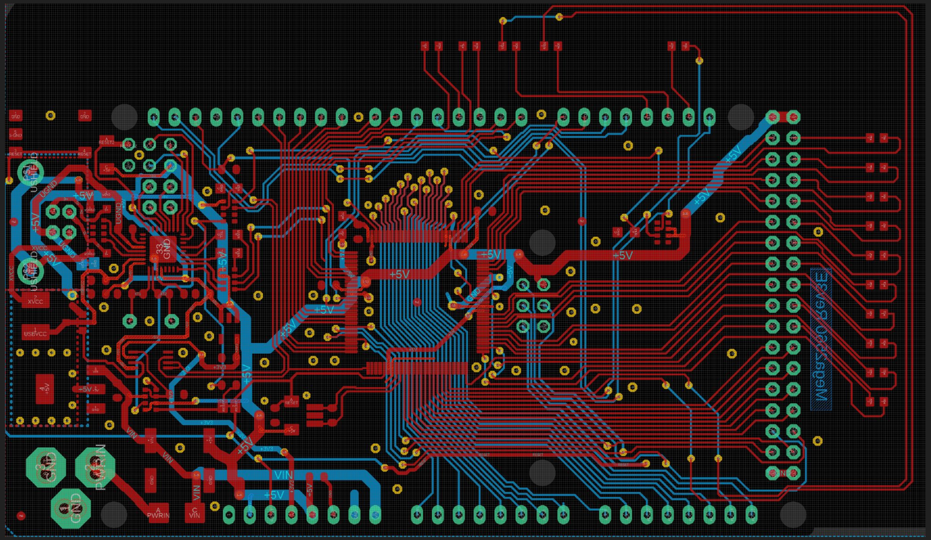
Specification	Value
Pin Operating Voltage	5V
Input Voltage	7-12V
Digital I/O Pins	54
Program Memory	256 kB

- Number of GPIOs
- Pins to be configured as interrupts
- Memory size
- Pin operating voltage
- Additional components needed for operation

Schematic and PCB

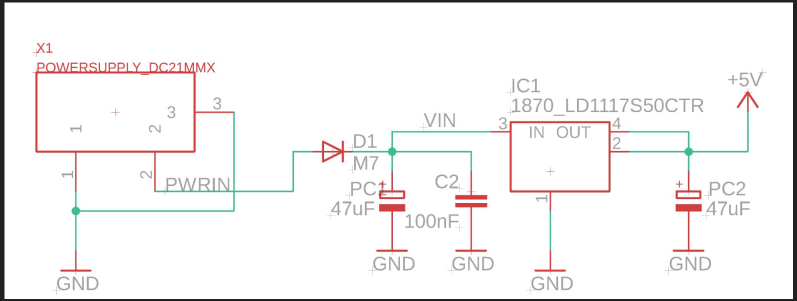
- References:
  - Open-source designs
    - Routing
    - Component selection
  - Forums
    - Component selection
  - ATmel Datasheets
    - Peripheral circuitry
    - Typical applications

- 2-Layer board
  - Majority SMD components
  - Some through-hole

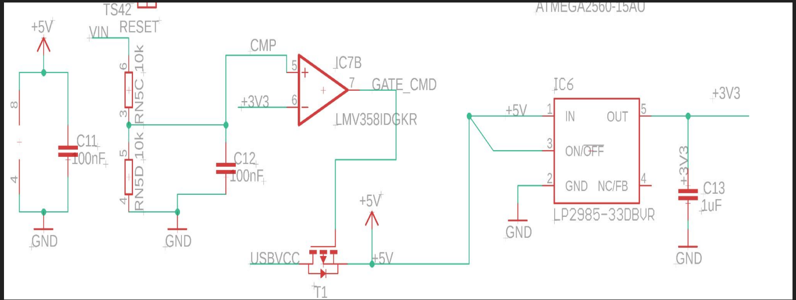


Power

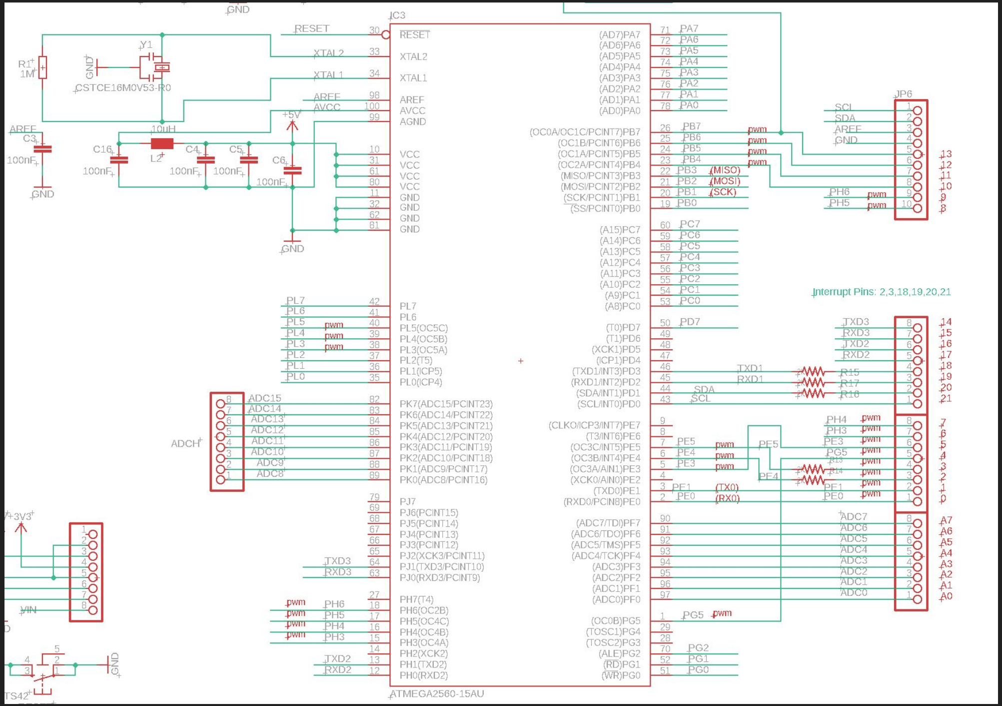
5 V


X1
POWERSUPPLY_DC21MMX
PWRIN
D1
M7
VIN
IC1
1870_LD1117S50CTR
IN
OUT
PC1
47uF
C2
100nF
PC2
47uF
+5V
GND
GND
GND
GND
GND

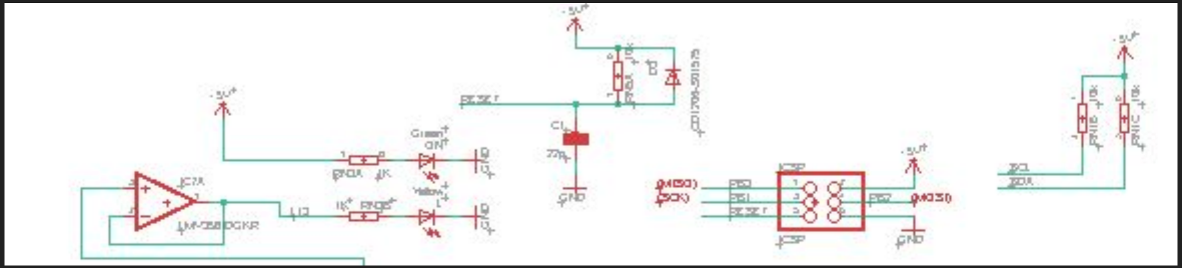
3.3 V


TS42
RESET
VIN
+5V
C11
100nF
RN5C 10k
RN5D 10k
CMP
C12
100nF
IC7B
LMV358IDGKR
+3V3
GATE_CMD
USBVCC
T1
+5V
ATMEGA2560-15AU
IC6
IN
OUT
ON/OFF
GND
NC/FB
LP2985-33DBVR
+3V3
C13
1uF
GND
GND
GND
GND

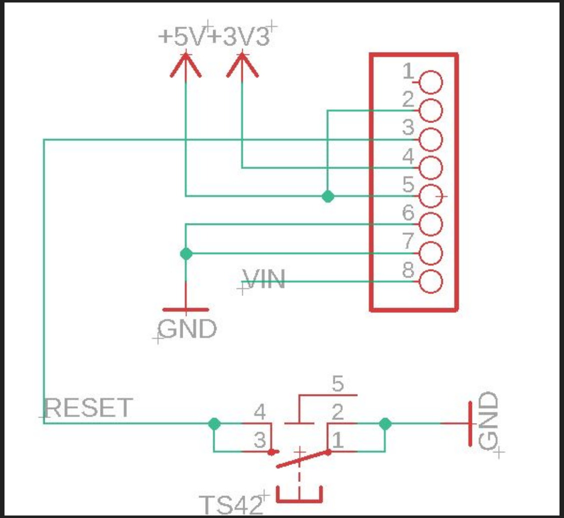
ATmega2560 Schematic



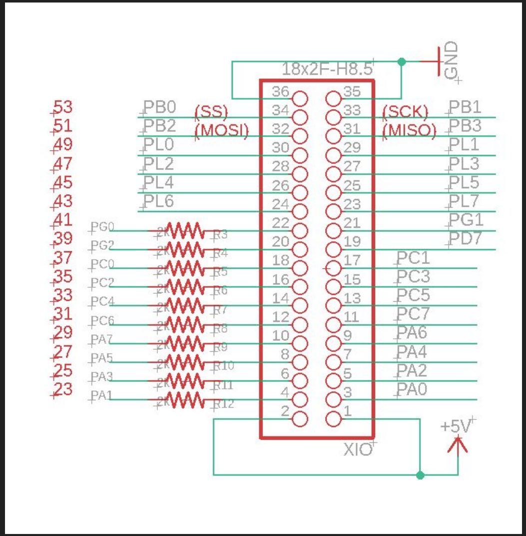
Schematic



Indicator LEDs

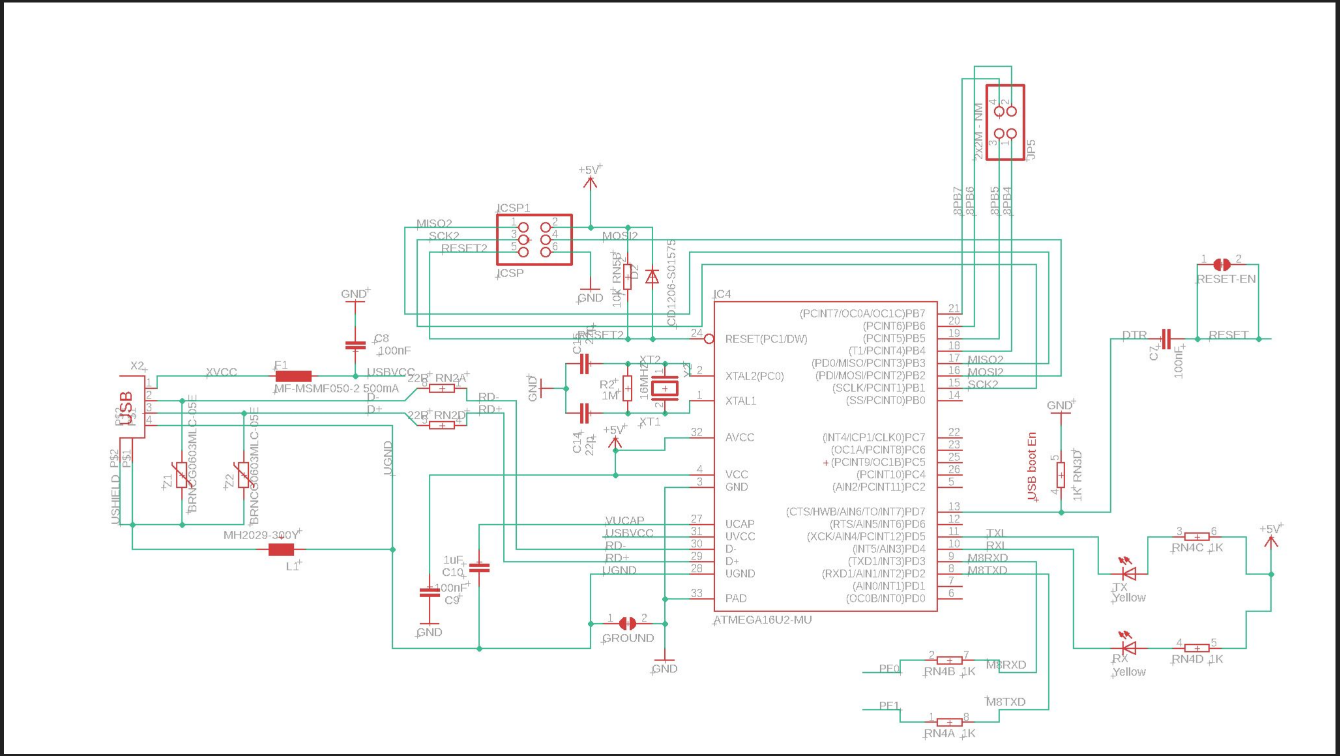


Voltage lines and RESET logic for ATMega2560



Solder pads

ATmega16U2-MU Schematic



User Interface

Dominic Simon - Computer Engineering

Initial User Interface - LCD and Keypad

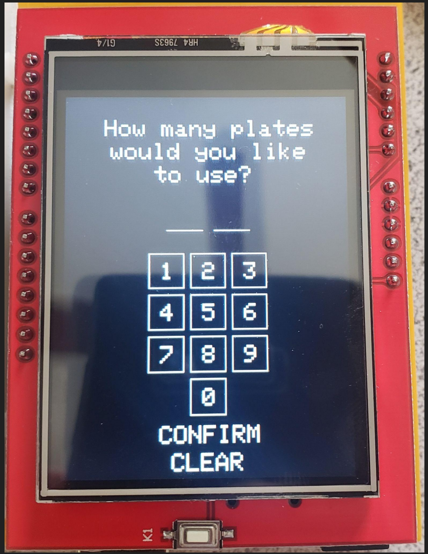
Keypad vs Touchscreen

Keypad

+ Low user error due to large keys
- Not aesthetically pleasing

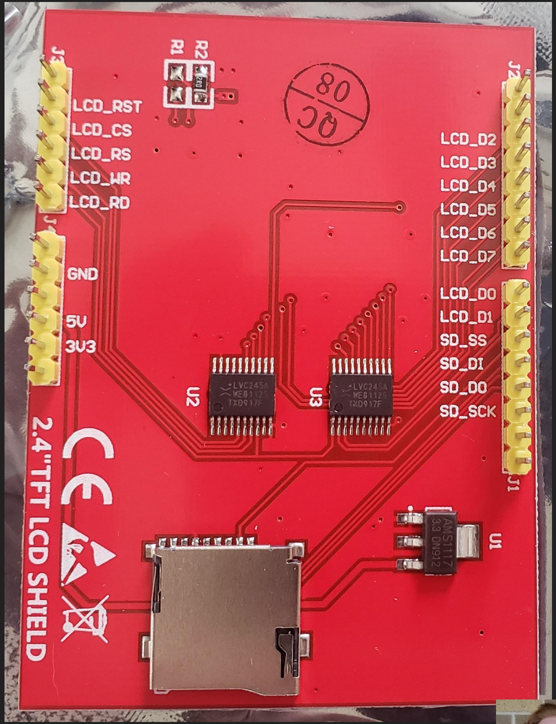
Touch Screen

+ Looks sleek
+ Compact
- Smaller keys require users to be more precise



Current User Interface - Touchscreen

- 2.4” display
- 3.3V and 5V compatible
- 18 bits for color
- 9 digital pins
- 5 analog pins



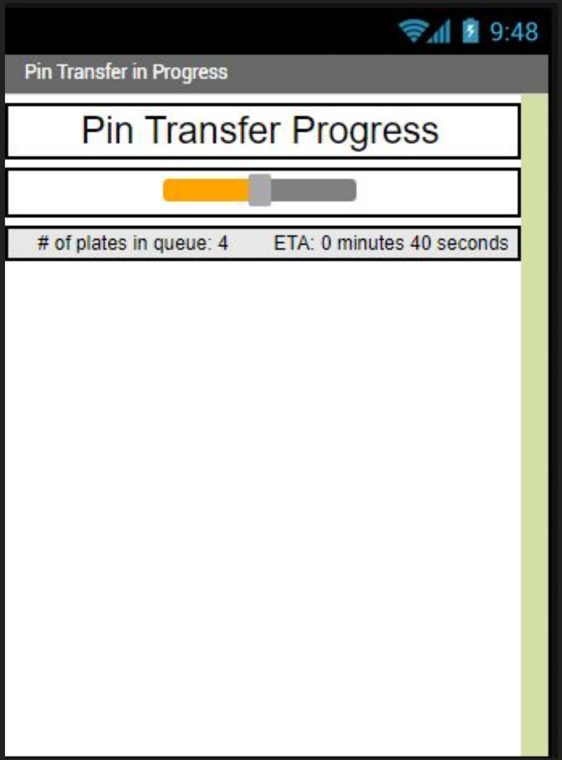
HiLetgo 2.4" ILI9341 240X320 TFT LCD Display

User Interface Functionality

- Take input for:
  - Number of well plates
  - Pin tool depth in well plates
  - Washing steps
- Confirm user’s selection
- Show batch progress
- Prompt user to restart when a batch is completed

Progress Monitor App

- Notifies the user on the current microplate number under processing as well as the current stage that the Pin Transfer Robot is in, whether it is under calibration, unloading the input stack, performing a pin transfer, loading the output stack, washing, or drying
- Tells the user when the Pin Transfer Operation has concluded for all the microplates.



Bluetooth Module

- 5V VCC for TX, 3.3V for RX
- Configurable via AT commands that allow for setting the baud rate, # of stop bits, etc...
- Half duplex communication via master slave communication model
- Up to 2 Kbps rate of data transfer
- Range of up to 100m in open air

HM-10 Bluetooth Low Energy(BLE) module

Software

Display Software

```
#include <Adafruit_GFX.h>
#include <MCUFRIEND_kbv.h>
#include <TouchScreen.h>
```

Touchscreen Software

Adafruit_GFX.h

- Move to different points on the screen
- Write characters
- Create virtual keypad keys
- Reset screen on screen change

```
// Area where the inputted numbers will show up
tft.drawLine(85, 115, 115, 115, WHITE);
tft.drawLine(125, 115, 155, 115, WHITE);

// Buttons
tft.drawRect(70, 135, 30, 30, WHITE);
tft.setCursor(80,143);
tft.println("1");
```

Touchscreen.h

- Determine if the screen is being touched
- Determine where the screen is being touched

```
TSPoint point = ts.getPoint();
if (point.z  >= 200 && point.z <= 1500)
{
  int x = map(point.x, 78, 951, 0, 320);
  int y = map(point.y, 96, 921, 0, 240);
  Serial.println(x);
```

Touchscreen Software

MCUFRIEND_kbv.h

- Use in place of ADAFRUIT_TFTLCD.h
- Does all the port switching to make the LCD compatible with the ATMEGA 2560 architecture
- Extends the Adafruit_GFX library, allowing for the LCD screen to be written to

```
MCUFRIEND_kbv tft;
```

```
tft.setCursor(33,20);
tft.println("How many plates");
tft.setCursor(38,40);
tft.println("would you like");
tft.setCursor(75,60);
tft.println("to use?");
```

AccelStepper

- An object-oriented C++ library for interfacing with 2,3 and 4 pin stepper motors and stepper motor drivers.
- Supports both manual control of acceleration and deceleration
- Blocking and non-blocking function calls for motor movement
- Precision control of speed and position tracking

Motor Software Pseudo Code

```
// Calibrates a single motor
long calibrate_motor(AccelStepper *motor, int limit_switch){
    long steps;
    motor->setSpeed(100);
    while (digitalRead(limit_switch) != LOW){
        motor->runSpeed();
    }
    steps = -1*motor->currentPosition();
    // Stop the motor and store the current position
    motor->stop();
    motor->setCurrentPosition(0);
    return steps;
}
```

Position Data from calibrate_motors()

Positions

	Name	X	Y	Z1	Z2
Gripper	Cell Input Stack	2063	3423	0	-1772
	Cell Output Stack	873	3351	0	-1755
	Chemical Input Stack	2063	6091	0	-1748
	Chemical Output Stack	885	6006	0	-1854
Pin tool	Solution 1	1451	486	-1680	0
	Solution 2	855	417	-1656	0
	Solution 3	249	334	-1657	0
	Fan/Heater	1908	3318	-154	0
	Cell Transfer Area Gripper	1463	3358	0	-1892
	Chemical Transfer Area Gripper	1467	6051	0	-1748
	Good Height value for base	-1881			
	Offset	319			
	Wellplate Height				
	Pins just above well plate entrance			-1897	
	Pins at bottom of well plate but not pushed			-2128	
	Cell Transfer Area Pintool X_LEFT	846	3323		
	Cell Transfer Area Pintool X_RIGHT	841	3267		
	Cell Transfer Area Pintool Y_LEFT	845	3339		
	Cell Transfer Area Pintool Y_RIGHT	845	3223		
	Cell Transfer Area X_MIDPOINT	843.5			
	Cell Transfer Area Y_MIDPOINT	3281			
	Chemical Transfer Area Pintool Y_RIGHT	837	5875		
	Chemical Transfer Area Pintool Y_LEFT	838	6023		
	Chemical Transfer Area Pintool X_LEFT	838	5991		
	Chemical Transfer Area Pintool X_RIGHT	834	5951		
	Chemical Transfer Area Pintool X_MIDPO	836			
	Chemical Transfer Area Pintool Y_MIDPOI	5949			
	Chemical Transfer Area Pintool Center	841	5950		

Motor Software Pseudo Code

```
// Moves each motor to a given position
starting with the x-axis
void move_to_coordinate_x_first (long x,
long y, long z1, long z2){

  motor_z1.setSpeed(SPEED_Z);
  motor_z2.setSpeed(SPEED_Z);
  gantry.setSpeed(SPEED_GANTRY);
  motor_y.setSpeed(SPEED_Y);

  gantry.runToNewPosition(x);
  motor_y.runToNewPosition(y);
  motor_z1.runToNewPosition(z1);
  motor_z2.runToNewPosition(z2);

}
```

```
// Moves each motor to a given
position starting with the z-axis
void move_to_coordinate_z_first(long
x, long y, long z1, long z2){

  motor_z1.setSpeed(SPEED_Z);
  motor_z2.setSpeed(SPEED_Z);
  gantry.setSpeed(SPEED_GANTRY);
  motor_y.setSpeed(SPEED_Y);

  motor_z1.runToNewPosition(z1);
  motor_z2.runToNewPosition(z2);
  gantry.runToNewPosition(x);
  motor_y.runToNewPosition(y);
}
```

Motor Software Pseudo Code

```
void run_all_cycles(){
  for(int i = 0; i < num_cycles; i++){
    do_cycle();
  }
}

void do_cycle(){
  take_from_stack()
  do_pin_transfer()
  push_onto_stack()
  do_wash()
  do_dry()
}
```

Testing

Useful test functions:

1) `void test_limit_switches()`
2) `void test_different_heights()`
3) `long calibrate_motor()`