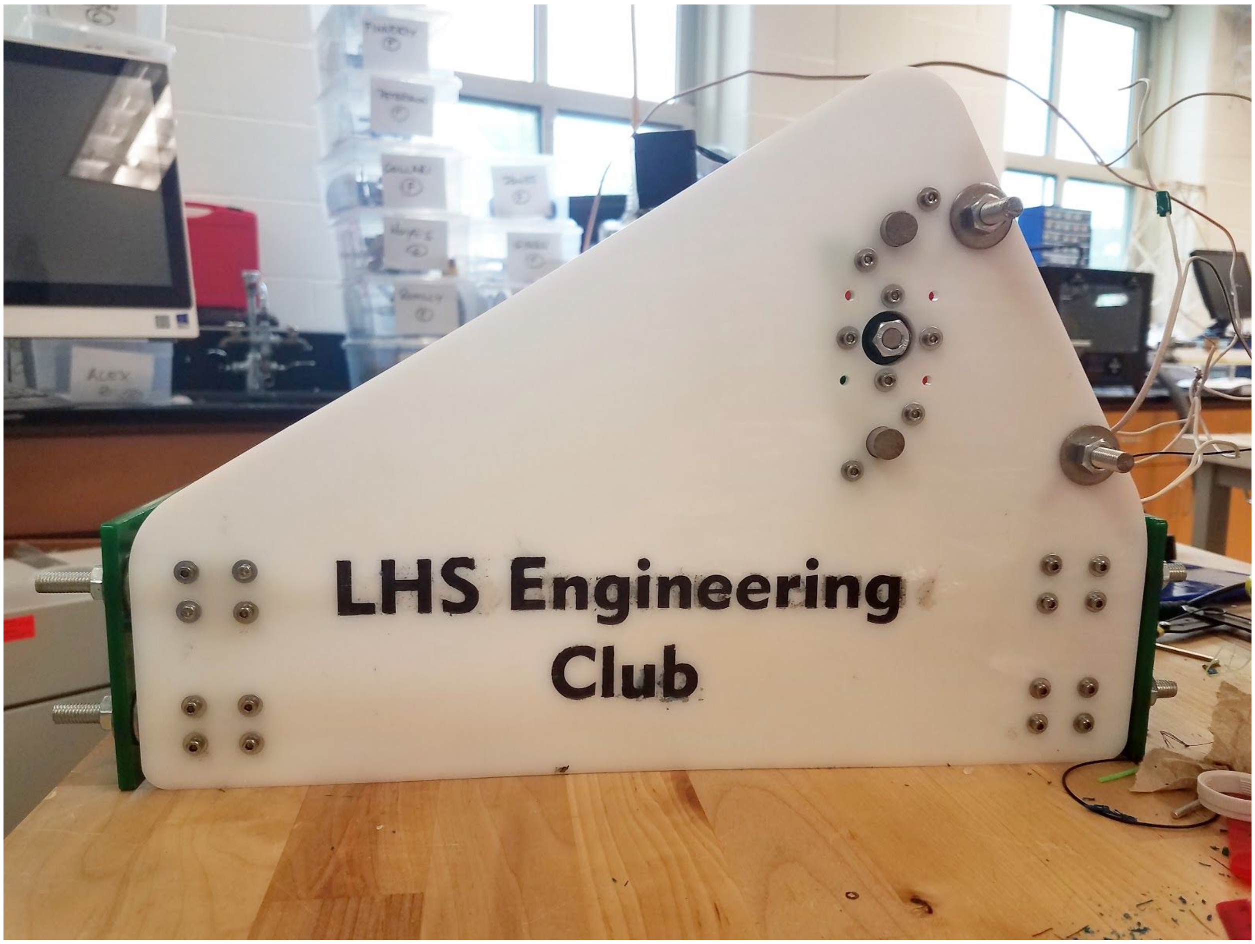
CNC Machine Report



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Introduction

The purpose of this project is to create a CNC machine from primarily 3D printed and laser cut parts. The design for this machine was found on Instructables.com. This machine is being built for the Littleton High School Engineering Lab. As of now, the lab has a few 3D printers and one laser cutter. Adding this CNC machine to the engineering lab will allow future Littleton High School Engineering students and Engineering Club members to machine parts for their classwork and projects.

3D printing the parts for the CNC machine took a couple of weeks to complete because of the 3D printer breakdowns and print malfunctions. So, the first stage of the project involved repairing the 3D printers. Next, parts were laser cut using the engineering lab's Rayjet 50 laser cutter. Then, the frame for the CNC machine was assembled using the 3D printed parts, laser cut parts, fasteners, and accessories that were purchased online. The electronics for this project were also wired, configured, and connected to the CNC machine to make it fully functional.

The CAD files for this project were prepared for 3D printing using MakerWare and FlashPrint. The laser cutter part files were modified and rescaled using CorelDraw. The G code for this project was generated using Easel, and the machine was controlled using Grbl Controller 3.5.

Step One: Repairs

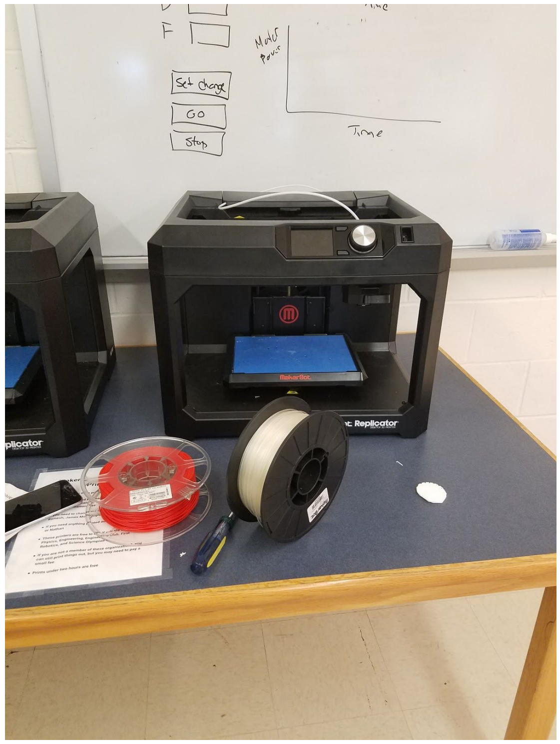

Figure 1: Makerbot Replicator Fifth Generation Printer

Figure 1 shows a Makerbot Replicator Fifth Generation Printer. The Littleton High School Makerspace has two of these printers, and they are the newest and most reliable 3D printers in the makerspace. However, filament for the newer Makerbots cost fifty dollars per roll, so printing all the parts for the CNC on these Makerbots was determined to be outside the budget of this project. Consequently, the older Makerbot 2 printer had to be repaired and used for a lot of the printing.

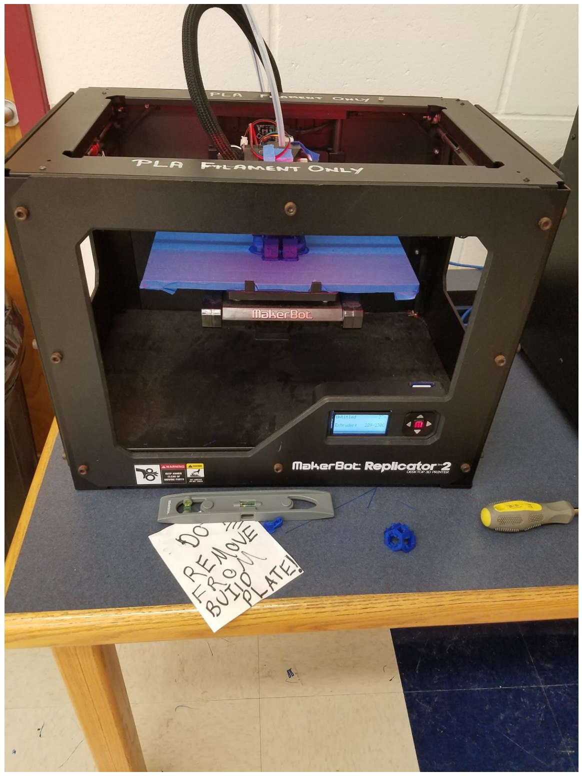

Figure 2: Makerbot Replicator 2

Figure 2 shows a Makerbot Replicator 2. This Makerbot is the oldest 3D printer in the makerspace, and has almost 600 hours of print time. Repairing this printer was quite time consuming. The Makerbot's extruder was clogged, and as it was being disassembled, the carriage snapped. To fix the carriage, a piece of acrylic, which was laser cut to the exact size of the hole in the carriage, was glued to the remaining parts. Once the carriage was repaired, the nozzle was replaced and refitted.

However, the refitting was not airtight, so plastic began seeping through the extruder during prints. As a result, the nozzle and extruder head were removed and soaked in acetone for close to a week. Once the nozzle and extruder head were cleaned, they were fitted onto the carriage again; however, plastic still started seeping through the extruder.

The extruder head and nozzle were removed and cleaned again by heating the printer up to 230 degrees Celsius. The printer was heated up to melt the remaining plastic on the nozzle before fastening the nozzle to the carriage. The final refitting worked perfectly and plastic does not leak through the extruder anymore. After printing out all the parts for the project out using PLA plastic, it was discovered that printing with ABS plastic provides a much finer print. As a result, a Flashforge Creator Pro printer was used to reprint all the parts. The parts printed out using PLA were used as spares.

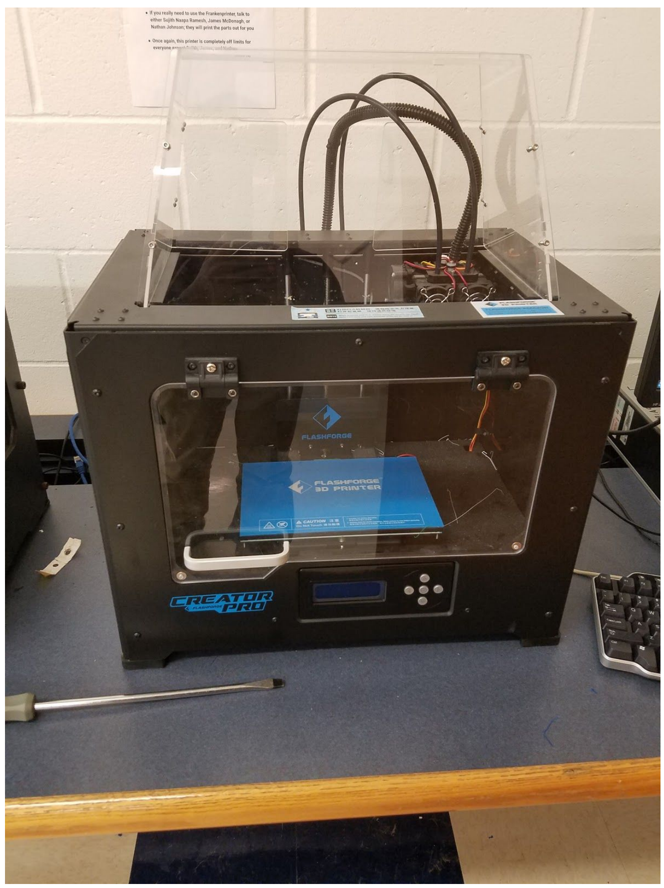

Figure 3: Flashforge Creator Pro

Figure 3 shows a Flashforge Creator Pro. This printer prints out parts in ABS plastic. As a result, the parts printed from this printer are much finer print..

Step Two: 3D Printing

Extruder Temperature	230°C
Base Plate Temperature	110°C
Rafts	Yes
Raft Margin	10 mm
Supports	Yes
Extruder Speed While Printing	90 mm/s
Infill	75% - 100% (Note: Higher infill does not make much of a difference after 75% because the hexagons become insignificantly smaller with each increment.

Table 1: Table 1 shows the settings at which all the parts were printed out on the Flashforge Creator Pro printer.

Figure 4: Z Axis Carriage

Figure 4 shows the Z Axis Carriage and this is the most difficult part to print. Print time was a total of thirty-seven hours and the part was printed with supports. The 12mm linear bearings did not fit into the Z Axis Carriage because of ABS's extreme dimensional shrinking. As a result, the Z Axis Carriage was reprinted using PLA, which has better dimensional stability.

Figure 5: Tool Slide

Figure 5 shows the Tool Slide. Total print time for this part is about eight hours.

Figure 6: Spindle Motor Mount

Figure 6 shows a Spindle Motor Mount. This part houses the motor. Total print time for this part is about four hours.

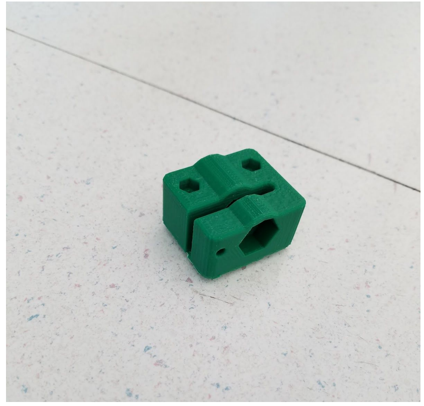

Figure 7: Backlash Nut

Figure 7 shows a Backlash Nut. There is one backlash nut for each axis, and there are three backlash nuts in total. Each backlash nut is fitted with an M8 brass nut, and print time for each backlash nut is about two and half hours.

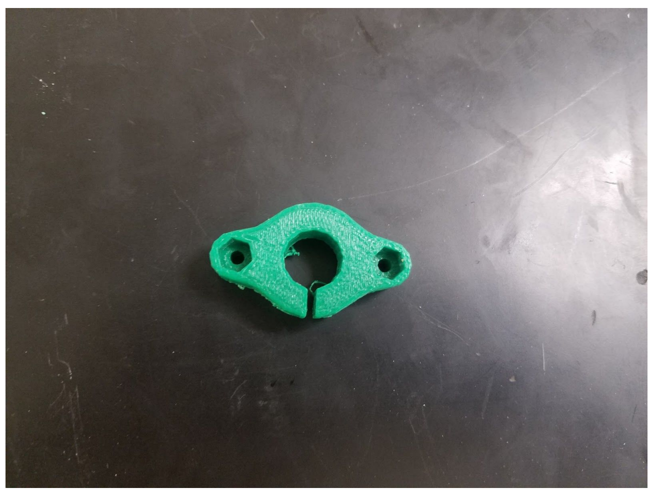

Figure 8: Rod Clamp

Figure 8 shows a Rod Clamp. There are eight rod clamps in total. Print time for each rod clamp is about one hour and fifteen minutes.

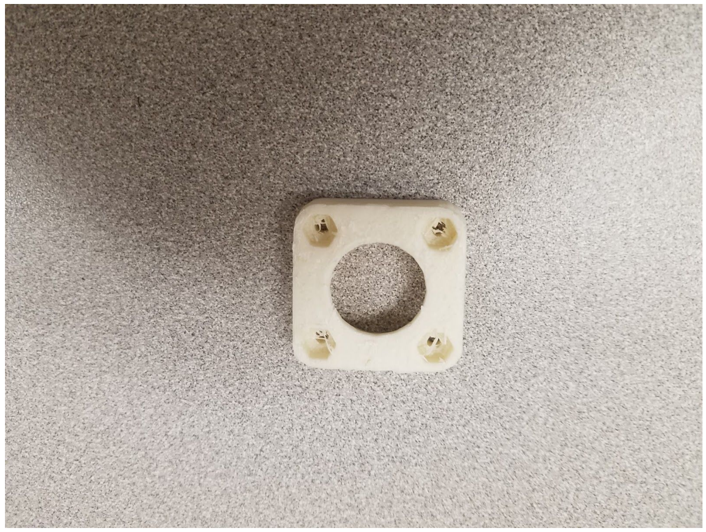

Figure 9: Bearing Holder

Figure 9 shows a Bearing Holder. Each bearing holder will house a skateboard bearing. There are four bearing holders in total, and each bearing holder takes about an hour to print.

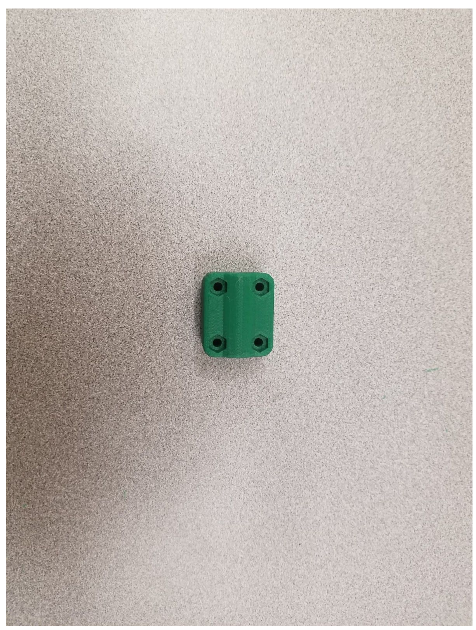

Figure 10: Rod Holder

Figure 10 shows a Rod Holder. Two rod holders hold one threaded rod. There are eight rod holders in total, and each rod holder takes about one hour to print.

Figure 11: Linear Bearing Mount

Figure 11 shows a Linear Bearing Mount. The linear bearing mounts will help the work deck move along the y axis. Each linear bearing mount is fitted with a 12mm linear bearing, and each linear bearing mount took about two and half hours to print.

Step Three: Laser Cutting

The laser cutter part files came from Instructables.com. This CNC machine was designed to be modular, so the size of the machine can be altered by scaling the individual parts. For this project, all the laser cut parts were scaled so that the width of the machine would be 400mm long. These parts were laser cut on a Rayjet 50 laser cutter.

Figure 12: Front and Back Plate

Figure 12 shows a Front and Back Plate. These pieces were laser cut on 3mm acrylic. Two of the plates will be screwed together on the front and two of the plates will be screwed together on the back. Therefore, there are four of these pieces in total.

Figure 13: Side Plate

Figure 13 shows a Side Plate. There is a side plate on each side of the CNC Machine. These pieces were laser cut on 6mm acrylic.

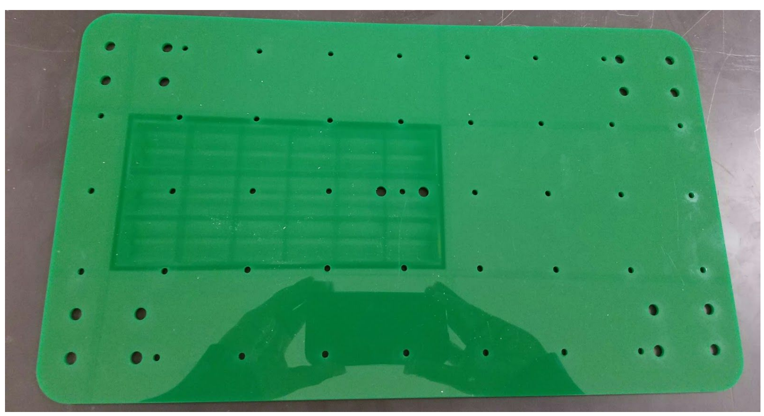

Figure 14: Bottom Piece of the Work Deck

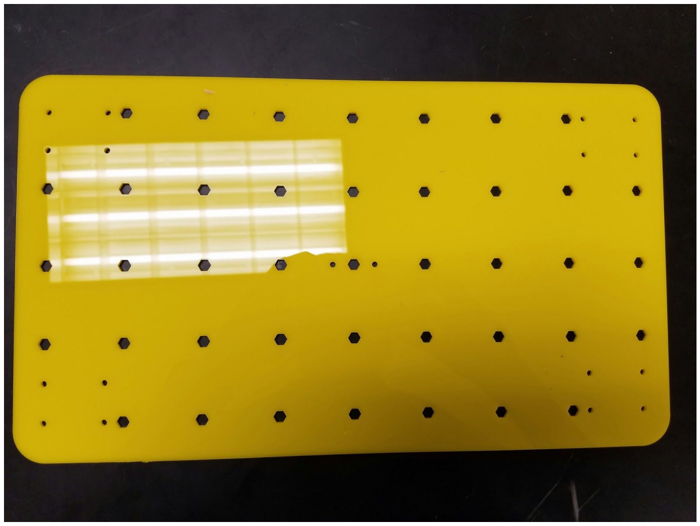

Figure 15: Middle Piece of the Work Deck

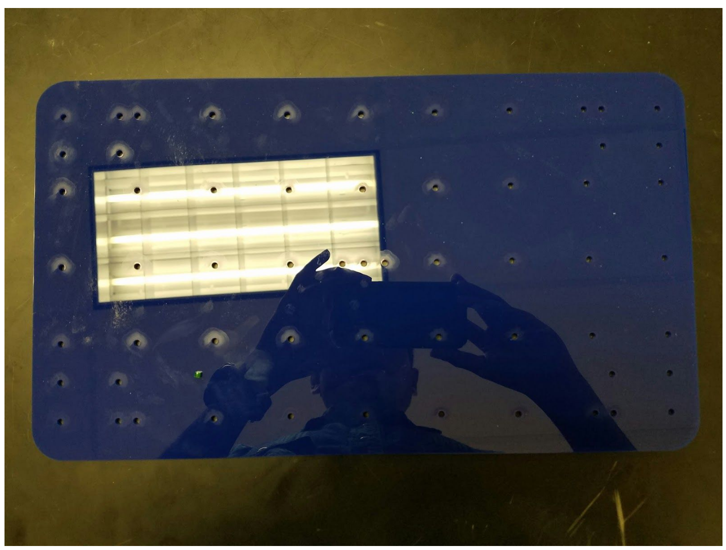

Figure 16: Top Piece of the Work Deck

Figure 14, 15, and 16 show the three parts of the work deck. These three pieces were laser cut on 6mm acrylic and they were glued together. Before the gluing process, the middle plate was fitted with M3 nuts. The CNC machine will do all cutting and processing on this work deck; therefore, it is an important piece.

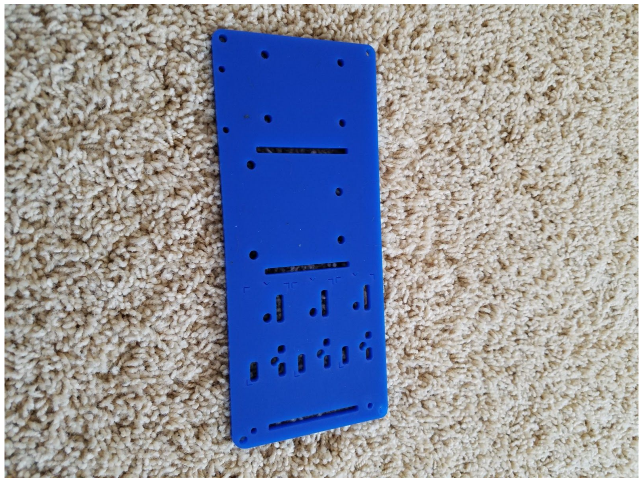

Figure 17: Piece One of the Electronics Box

Figure 18: Piece Two of the Electronics Box

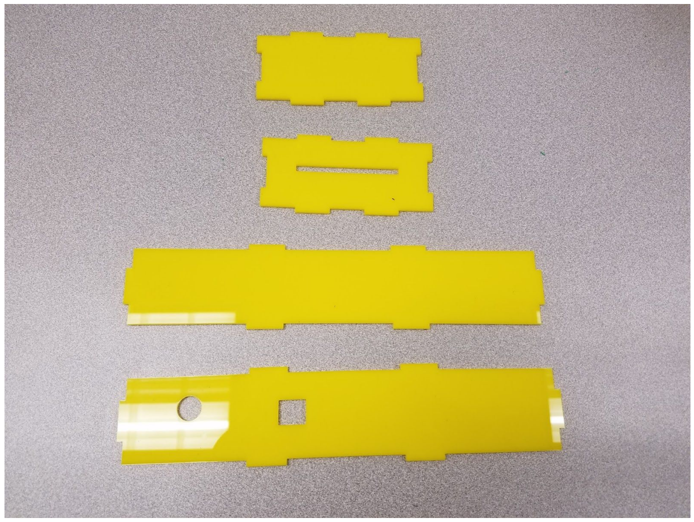

Figure 19: Side Pieces of the Electronics Box

Figure 17, 18, and 19 show the parts of the electronics box. Piece one and piece two were laser cut on 6mm acrylic, while the side pieces were laser cut on 3mm acrylic.

Figure 20: Top Plate

Figure 20 shows a Top Plate. The top plate is also a piece in the electronics box. This piece was laser cut on 6mm acrylic.

Step Four: Gathering Materials

SUNKEE 40 Pin Break Away Male Header- Long Straight 19mm -10 Pcs
40 Pin Break Away Male Header- Right Angle-10 Pcs
Breadboard-friendly 2.1mm DC barrel jack
Arduino Uno R3 Microcontroller A000066
SUNKEE 100pcs 1p to 1p female to female jumper wire Dupont cable 20cm
Stepper motor - NEMA-17 size - 200 steps/rev, 12V 350mA
Stepper motor - NEMA-17 size - 200 steps/rev, 12V 350mA
Stepper motor - NEMA-17 size - 200 steps/rev, 12V 350mA
ST2 (Two-Pack) StripBoard, Uncut Strips, 1 Sided PCB, Size 2 = 100 x 80mm (3.94 x 3.15in)
10pcs LM12UU 12mm Linear Ball Bearing Bush Bushing 12*21*30mm for DIA. 12mm Linear Shaft Rod DIY CNC
10pcs 8mm LM12UU Linear Ball Bear Bearing Bush Bushing Linear Motion Machinery
Mini Chuck Set for 1/8" motor shaft
5mm x8mm CNC Stepper Motor Flexible Jaw Shaft Coupling Coupler Ecodeer Connector
EasyDriver Stepper Motor Driver
EasyDriver Stepper Motor Driver
EasyDriver Stepper Motor Driver
608-2RS Skateboard Bearing, 8x22x7, Sealed (Pack of 8)
2ch Relay Shield Module
Spindle Motor
6pcs Limit Switches
DC Motor Controller
Emergency Stop Button

Table 2: Table 2 shows all the hardware that was ordered. These parts were ordered from Amazon.

M3x30mm Alloy Steel Hex Bolt Head Cap Screws - 50 Pcs
0.5 mm Pitch M3x25mm Stainless Steel Hex Socket Head Cap Screws - 60 Pcs
M3 Brass and Stainless Steel Hex Spacers Set - 120 Pcs
0.5 inch Braided Cable Sleeve
M3 Stainless Steel Hex Socket Screws and Nuts Set - 2 Sets
M8x1.25 Stainless Threaded rod 1m - 7pcs
M8 Brass Hex Nuts - 10 Pcs
M8 Stainless Steel Fender Washer - 25 Pcs
M3 Stainless Steel Hex Nuts - 100 Pcs
M3 Zinc Finish Steel Washers - 100 Pcs
M8 Zinc Finish Steel Hex Nuts - 80 Pcs
12mm x 1m Precision Chromed Rod - 2 Pcs
8mm x 500mm Precision Chromed Rod

Table 3: Table 3 shows all the fasteners that were ordered. These parts were ordered from Amazon, Fastenal, and Folger Technologies.

Step Five: Assembly

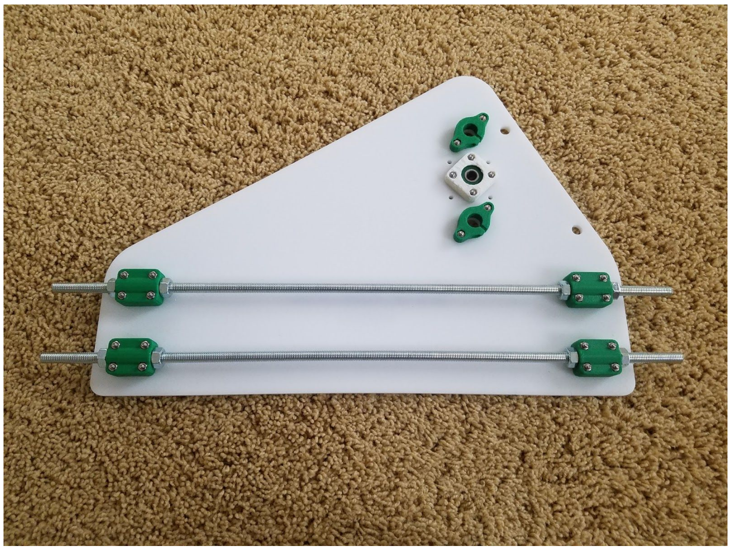

Figure 21: Side Plate Assembly

Figure 21 shows a Side Plate Assembly. First two threaded rods were cut to 450 mm and attached to the side plate using rod holders, M3 x 25mm bolts, M3 nuts, and M3 washers. The rod holders were fastened to the rod using two M8 steel nuts. Then. the rod clamps and bearing holders were attached to the side plate using M3 x 15mm bolts, M3 nuts, and M3 washers.

Figure 22: Front and Back Plate Assembly

Figure 22 shows a Front and Back Plate Assembly. Two of the 3mm plates were fastened together using rod clamps, bearing holders, M3 x 15mm bolts, M3 nuts, and M3 washers to create the front plate and the back plate.

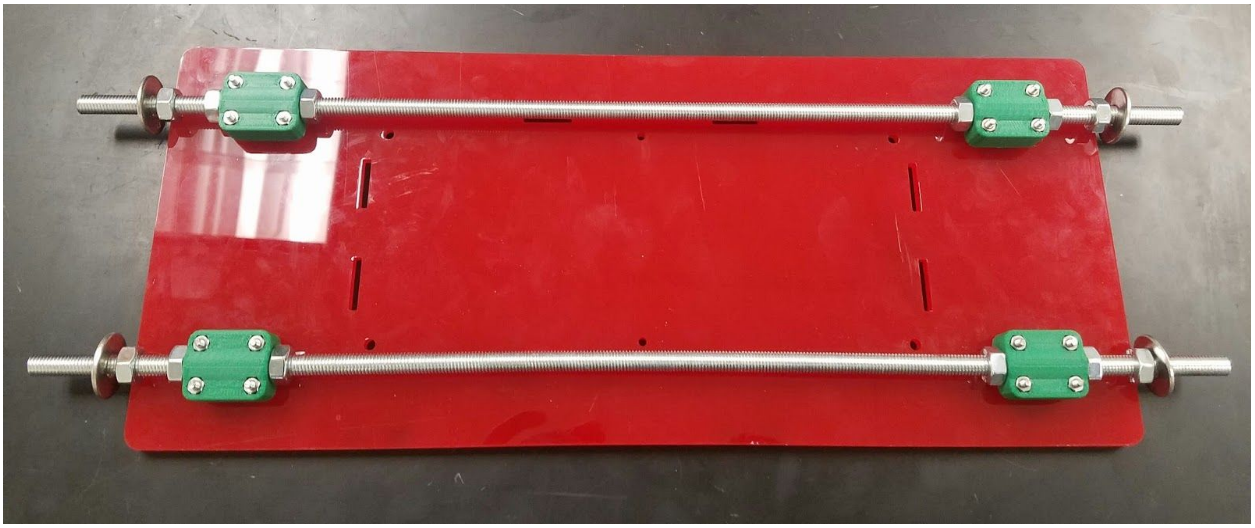

Figure 23: Top Plate Assembly

Figure 23 shows a Top Plate Assembly. Two threaded rods were cut to 450 mm and attached to the side plate using rod holders, M3 x 25mm bolts, M3 nuts, and M3 washers. The rod holders were fastened to the rod using two M8 steel nuts.

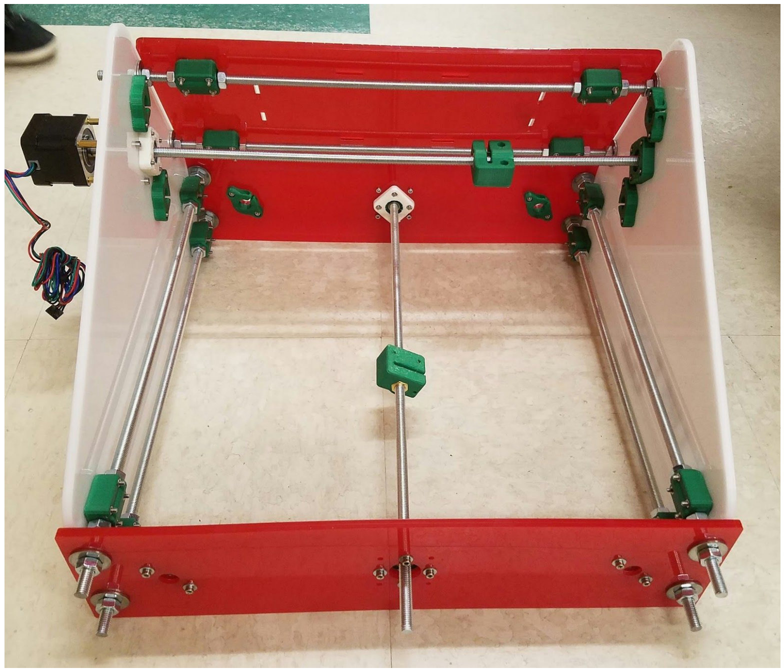

Figure 24: Main Body Assembly

Figure 24 shows the Main Body Assembly. The side, front, back, and top plates were attached together by connecting the plates to the threaded rods. The threaded rods and plates were connected using steel M8 nuts. Two additional 450mm threaded rods were also also placed through the side plates, and the front and black plates. Each of these rods has a backlash nut travelling along the rod.

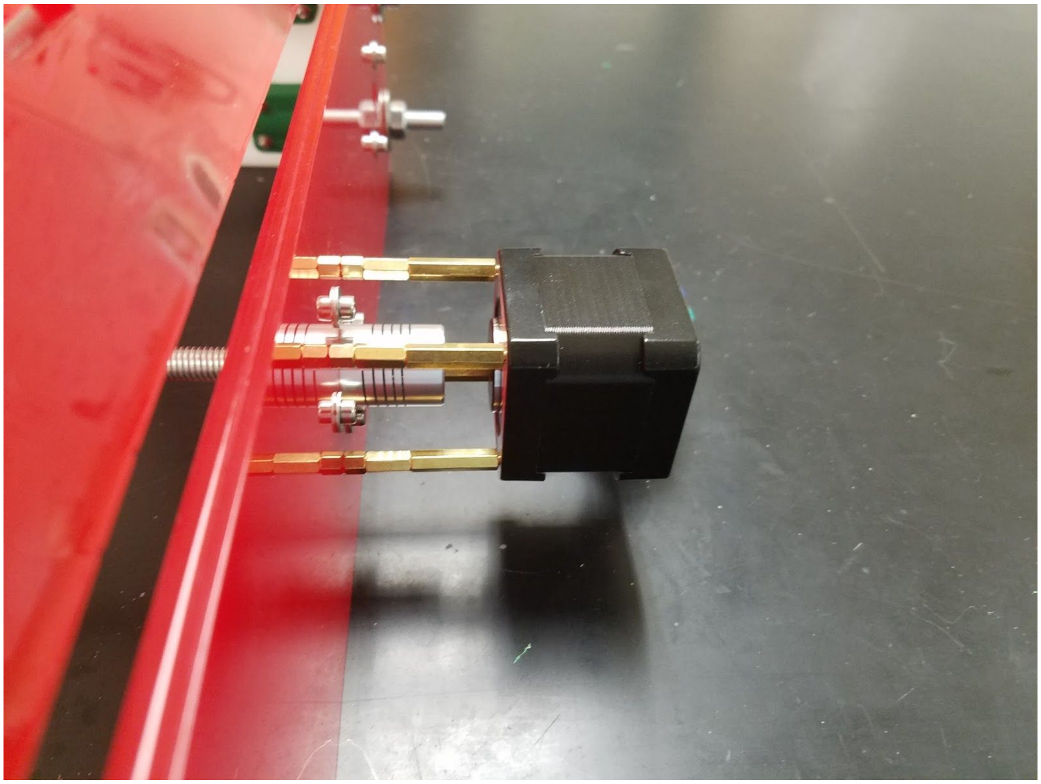

Figure 25: Stepper Motor Assembly

Figure 25 shows a Stepper Motor Assembly. A jaw shaft coupler was attached to the stepper motor, and then the stepper motor was attached to the threaded rod coming out of the back plate with the use of M3 x 30mm spacers and M3 x 30mm nuts. A similar assembly was built onto a side plate and z axis carriage assembly as well.

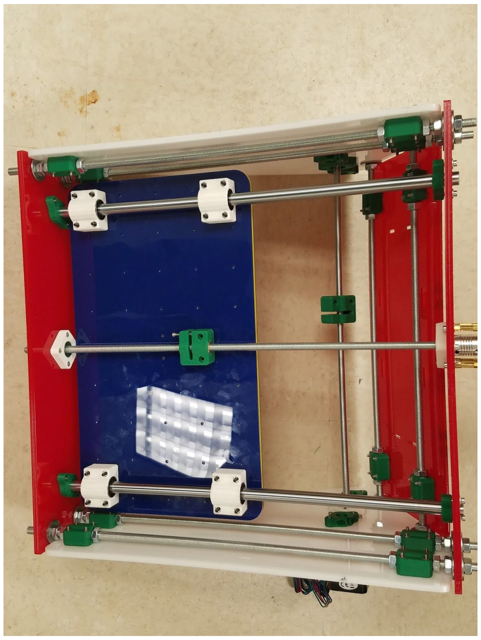

Figure 26: Work Deck Assembly

Figure 26 shows the underside of the Work Deck Assembly. The three pieces of the work deck were glued together, and the middle piece was fitted with M3 nuts before the pieces were glued together. Four linear bearing mounts were screwed into the build plate using M3 x 30mm bolts, M3 washers, and M3 nuts. One of the linear bearing mounts kept snapping when the 12mm linear bearing because the linear bearing mount shrunk due to ABS' extreme dimensional shrinking. As a result, one of the linear bearing mounts was replaced with a linear bearing mount printed using PLA. An M3 x 20mm bolt and M3 nut were used to tighten the backlash nut. The work deck assembly moves along two 420mm chromed rods.

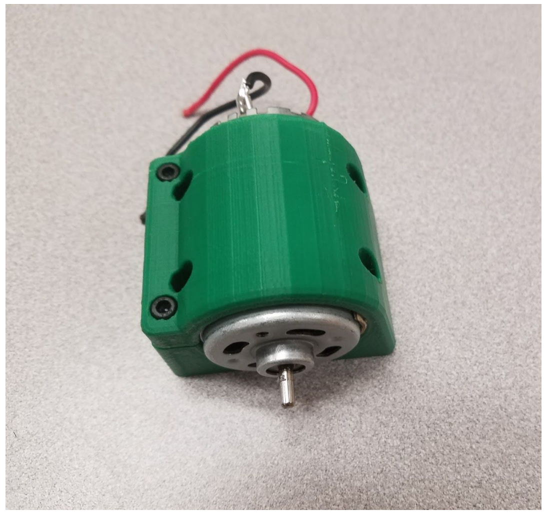

Figure 27: Spindle Motor Assembly

Figure 27 shows the Spindle Motor Assembly. The spindle motor was covered with a layer of cardboard and inserted into the spindle motor mount. The spindle motor mount was then tightened using M3 x 30mm bolts, M3 nuts, and M3 washers. M3 x 25mm bolts, M3 nuts, and M3 washers will be used to fasten the spindle motor assembly to the tool slide. Chucks will be fastened to the spindle motor shaft so that CNC drill bits can be attached to the spindle motor.

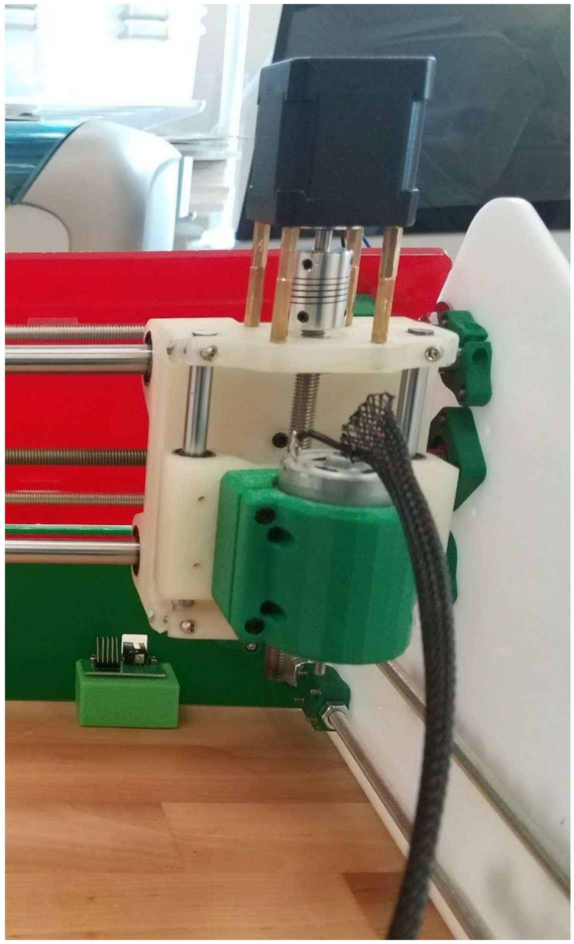

Figure 28: Z Axis Carriage Assembly

Figure 28 shows the Z Axis Carriage Assembly. The spindle motor assembly was attached to the tool slide using using M3 x 30mm bolts, M3 nuts, and M3 washers. The tool slide was attached to the z axis carriage using two 150mm chromed rods which it slides along. The Spindle Motor assembly was attached to the back of the tool slide using a backlash nut and M3 x 25mm bolts, M3 nuts, and M3 washers. A skateboard bearing was placed fitted into the z axis carriage and place on the threaded rod to facilitate accurate z axis motion without the loss of steps.

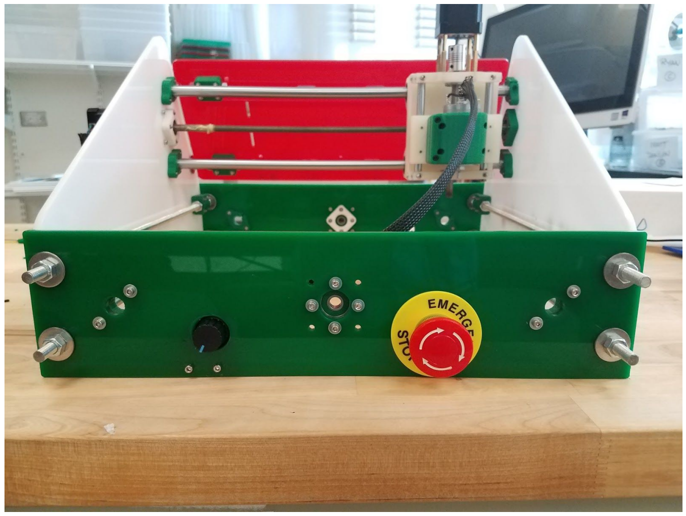

Figure 29: Front/Back Plate Modification One

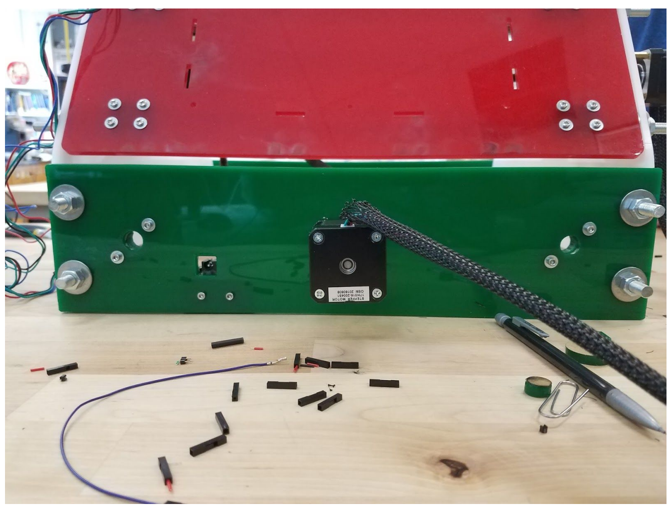

Figure 30: Front/Back Plate Modification Two

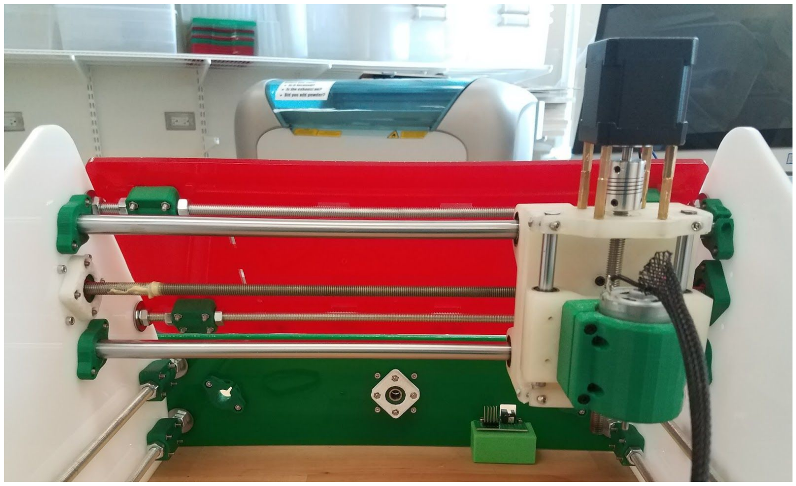

Figure 31: Front/Back Plate Modification Three

Figures 29, 30, 31 show the modifications done to the front and back plates. Holes were laser cut out of the front plates to enable fitting in a DC motor controller and emergency stop button. These parts were fastened to custom made 3D printed adapters using M3 x 30mm bolts, and the adapters were attached to the front plate using M3 x 30mm bolts. The DC motor controller and emergency stop button greatly increased the safety rating of the machine. A hole was also cut out of the back plate to place a barrel jack and straight pin assembly to the back of the machine. The barrel jack and straight pin assembly was also attached to a custom made 3D printed adapter using M3 x 30mm bolts, and the adapter was connected to the back plate using M3 x 30mm bolts. Figure 31 shows the back of the adapter used to hold the barrel jack and straight pin assembly. The barrel jack receives power which is then dissipated to other various components using the straight pins. The back plate modification allows for a cleaner more organized approach to wiring. Print times for the adapters were about one hour each.

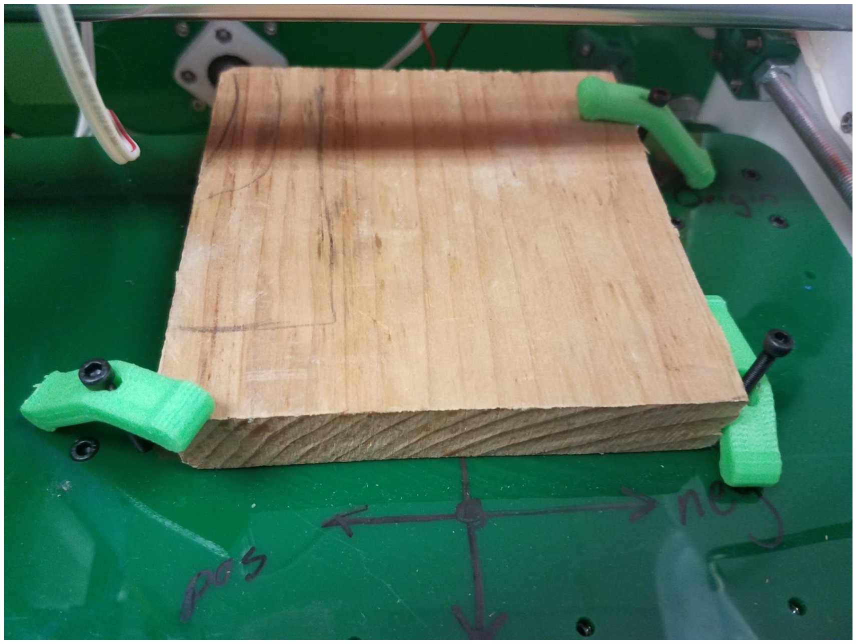

Figure 32: 3D Printed Clamps

Figure 32 shows 3D printed clamps which were used to hold down the work material during run time.

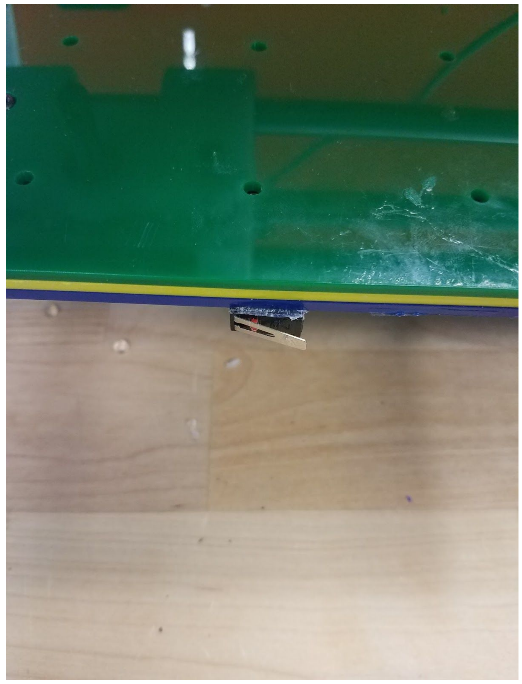

Figure 33: Limit Switches

Figure 33 shows a limit switch that is attached to the work deck assembly. Six normally open limit switches, two on each axis, to ensure that the machine would have positional awareness during run time. Also, the use of the limit switches allows for a homing cycle which enables the machine to retreat to its zero position at any time. The machine shuts down if a limit is triggered for safety purposes under the pretense that the CNC machine malfunctioned. Four limit switches were placed on the z-axis carriage for the x and z axes, and two limit switches were placed on either end of the work deck assembly for the y axis.

Step Six: Electronics

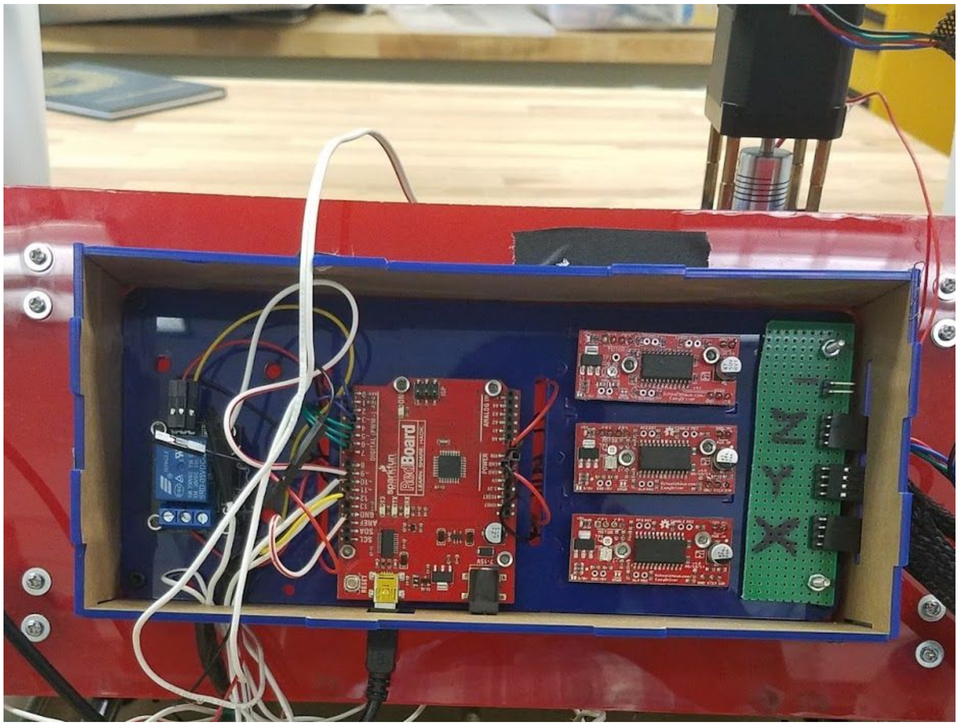

Figure 34: Electronics Board

Figure 34 shows the electronics board used by the machine. The Electronics Board was attached to the top plate using M3 x 6mm spacers, M3 x 25mm bolts, and M3 nuts. The electronics components were attached on the electronics box using M3 x 20mm bolts, M3 nuts, and M3 washers. The Uno microcontroller is the main processor for the CNC machine. It receives input from the 6 limit switches as well as a computer that sends G code. The UNO runs the G code, translates the G code into stepper motor commands, and sends the commands to the three stepper motor drivers. Each driver controls a stepper motor and consequently controls motion along an axis. Using the commands sent to the drivers, each driver sends signals to the corresponding stepper motor to enable precise motion. The drivers power the stepper motors by siphoning off the current that comes to the barrel jack. The spindle motor works quite differently than the stepper motors. The spindle motor is connected to a relay which receives commands for when to start and stop the motor from the Uno. The relay also siphons of current from the barrel jack to spin the spindle motor. The DC motor controller and emergency stop button are connected in series with the components on the electronics board. As a result, motor controller and emergency stop are able to limit current flow to the spindle motor and stepper motors when necessary.

Step Seven: Software

Homing Feed	25 mm/min
Homing Seek	250 mm/min
Homing Pull-Off	3 mm
X, Y, and Z Step Rate	1,280 steps/mm
Step Pulse	30 usec
Default Feed	250 mm/min
Default Seek	500
Acceleration	5 mm/ s^2

Table 4: Table 4 shows the machine settings that were used to configure this CNC machine. To configure these settings, the Uno microcontroller was first loaded with Grbl v1.1 hex file which enables the Uno to process G code. The hex file was loaded onto the Uno using Xloader, and once the file was loaded, the Uno lost its command line and required a Grbl Controller to receive user input. The Grbl controller was then used to set these machine settings. Note that these settings are unique for this machine and were mostly provided in the Instructables guide. For this

project, Grbl Controller 3.5 was used as the primary interface for this CNC machine. The G code for this project was generated using the Easel G Code tool.

Conclusion

The CNC Machine is now mostly functional, but still has a few bugs that need to be solved for maximum efficiency. The biggest bug encountered so far is the warping of the z axis carriage, which is primarily caused by zonal temperature differences in the 3D printer during print time. As a result, travel along the z axis is not as precise as motion along the other two axes. One was to solve this problem is to print the z axis carriage using an SLA printer to reduce warping on the part.

The machine also shuts down during run time because of interference from the stepper motors. The wires connecting the stepper motor to the electronics board run next to the wires for the limit switches. As a result, interference from the stepper motors causes the limit switches to get triggered and the machine to shut down. One possible solution is to rewire the cables in such a way that the stepper motor wires and the limit switch wires are not close together. However, this would only be a temporary fix for the problem, and hopefully in the future, the limit switches can be wired in a way that they are more tolerant to interference from the stepper motors.