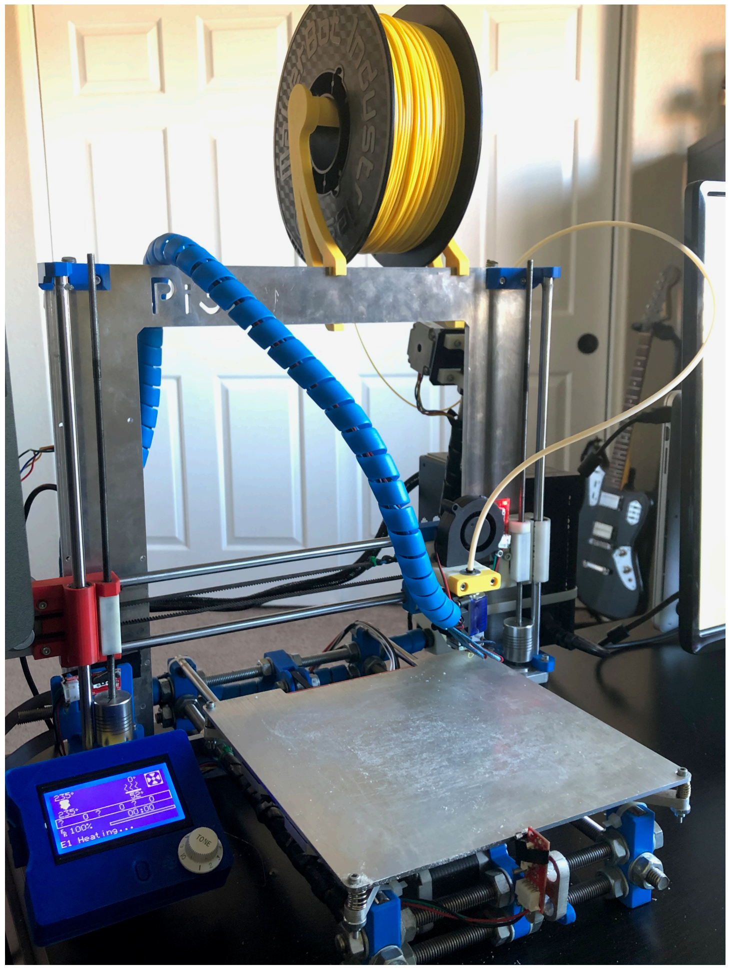
RepRap i3 Rework



DIY 3D Printer Build

Austin Stockwell
2017

Acknowledgments

I had help from many friends and online resources in the creation of this 3D printer. The end result was a 3D printer that prints quality parts and serves as a platform for other projects and rapid prototyping needs. This printer has evolved throughout multiple stages and will probably continue to do so. I would like to thank all of those who helped create this wonderful machine! [1] [2] [3] [4] [?]

Contents

List of Figures

1 Introduction

This project started as a desire to create a 3D printer with a larger build volume than my previous 3D printer (Printrbot 1405). I also had a desire to build the machine from the ground up by sourcing all of the parts myself and putting together a customized version of the popular Prusa i3. I had access to a 3D printer at my job so I could print all the parts necessary, and I knew enough about 3D printers after my first build that I didn't see a necessity to purchase a "kit". I therefore had the freedom to mix and match features of various RepRaps into a machine that I wanted most and the end result was a unique design that works great!

2 Features

The following features are integrated into the 3D printer:

- Aluminum Print Bed (200mm X 200mm)
- Bowden Extruder
- LCD Display
- SD Card Printing
- Custom Frame Support Bracing
- Kysan Stepper Motors
- ATX Power Supply

3 Bill of Materials

3.1 3D Printed Parts

3.1.1 RepRap i3 Rework

Figure 1: RepRap i3 Rework

3.1.2 Extruder / Bowden Mounts

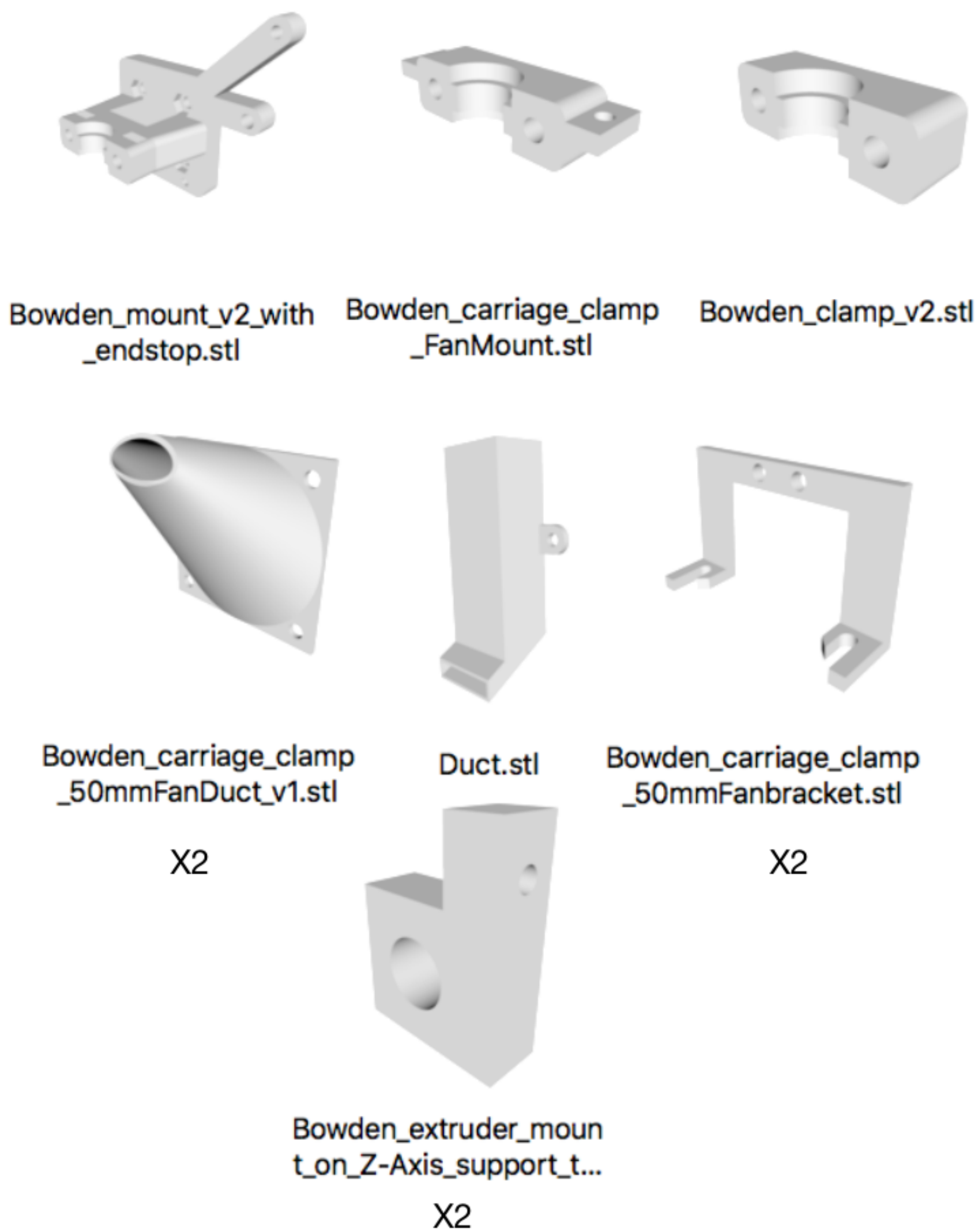


Figure 2: Extruder / Bowden Mounts

3.1.3 Frame / Z-Axis Support

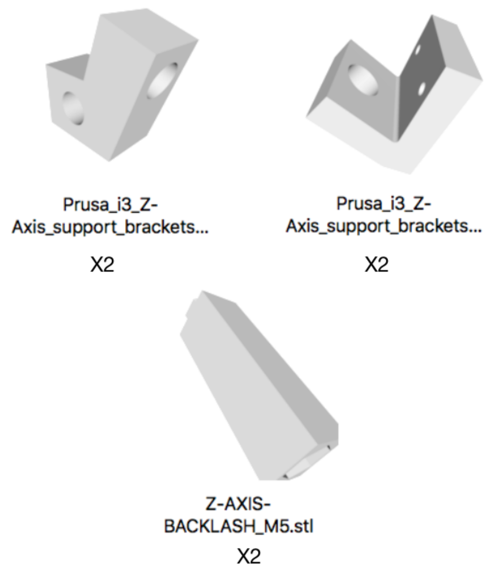


Figure 3: Frame / Z-Axis Support

3.1.4 LCD Case

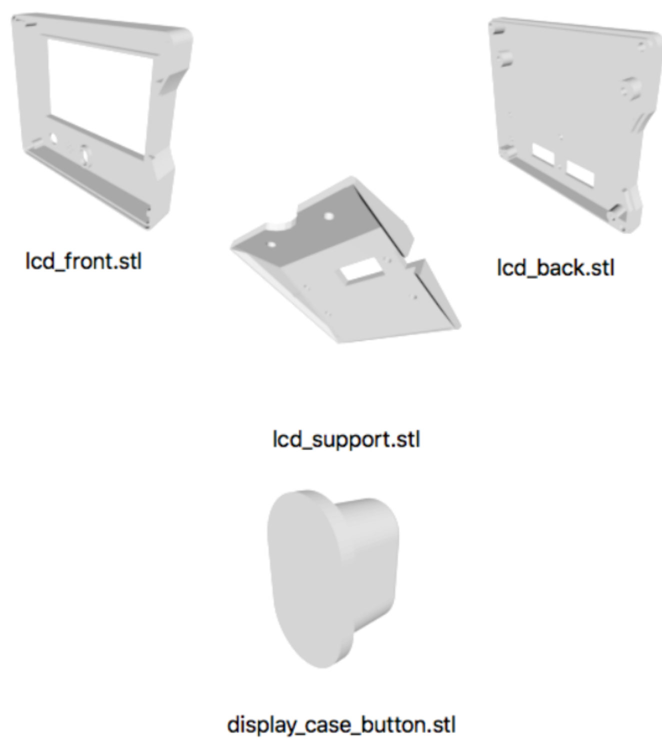


Figure 4: LCD Case

3.2 Hardware

3.2.1 Belts, Pulleys, Bearings, Couplers

Figure 5: Belts, Pulleys, Bearings, Couplers

NOTE: The current configuration requires 16 LM8UU bearings!

3.2.2 Nuts, Bolts, Screws, Washers

Figure 6: Nuts, Bolts, Screws, Washers

3.2.3 Rods

Smooth and threaded rods

- 2x Smooth rod Ø8x320 mm (for the Z-axis)
- 2x Smooth rod Ø8x350 mm (for the Y-axis)
- 2x Smooth rod Ø8x370 mm (for the X-axis)
- 2x Threaded rod M5x300 mm (these are replaced by lead screws / ACME rods in the new revision)
- 4x Threaded rod M10x210 mm
- 2x Threaded rod M10x380 mm

Figure 7: Smooth and Threaded Rods

3.2.4 Frame / Bed Holder

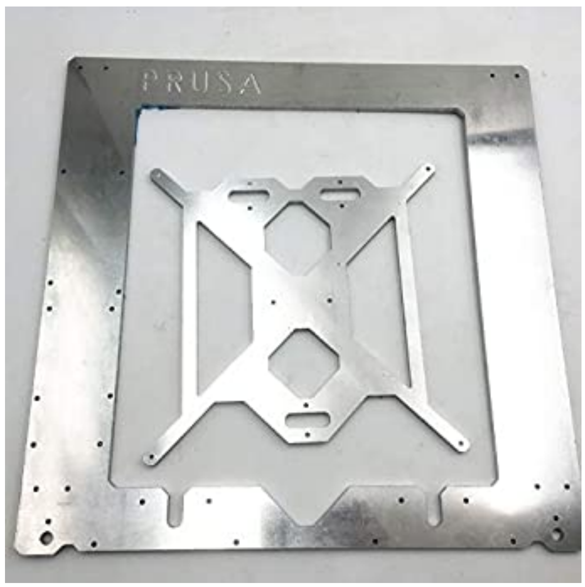


Figure 8: Aluminum Frame and Bed Holder

NOTE: The printer frame was later modified from the original RepRap i3 Rework design by installing the printed 'Z-Axis Support Brackets' that helped further stabilize the Z-Axis. This modification also required:

- (12) M10 Hex Nut
- (2) 350mm M10 Threaded Rod
- (1) 410mm M10 Threaded Rod
- (2) 25mm M10 Screw
- (2) 15mm M3 Screw

NOTE: The aluminum frame also came with a metal Y-axis end-stop holder that mounted to the 3D printed Prusa i3 Rework 'Y-Motor' (end-stop holder) part.

3.2.5 Print Bed

The print bed installation also required the following parts to ensure the bed could be leveled appropriately:

- (4) 20mm X 7mm Spring
- (4) M3 Bed Nut

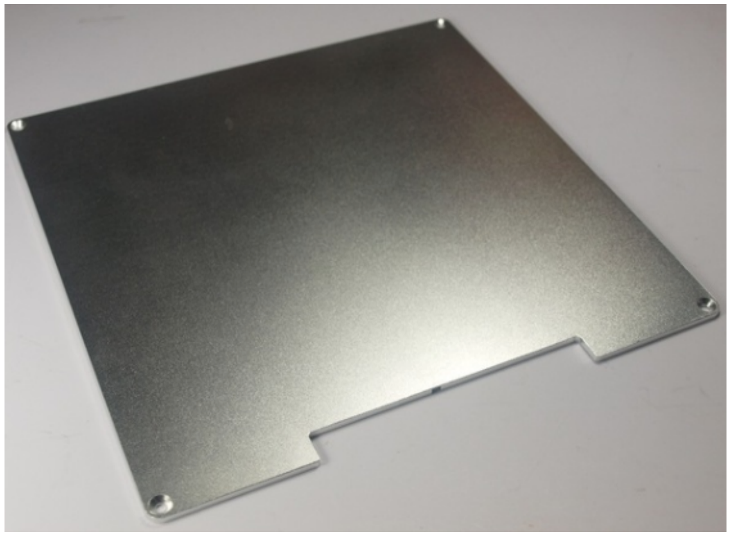


Figure 9: Aluminum Bed

Some data about the springs

Height 20mm

Outer diameter 7.5mm

Inner diameter 5mm

Figure 10: Bed Springs

Figure 11: Bed Nuts

3.3 Electronics

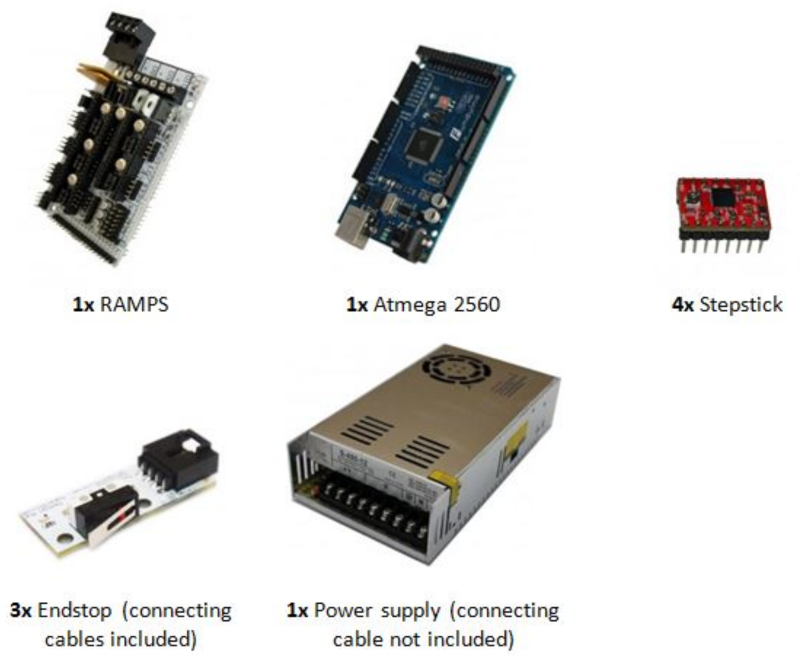


Figure 12: PSU, Controller, Stepper Drivers, Endstops

Figure 13: LCD Controller

Figure 14: Cooling Fans

3.4 Extruder

Figure 15: Bowden Extruder

Figure 16: Bowden Tube

Figure 17: E3Dv6 Hot End

3.5 Extra Materials

- Electrical Tape
- Zip Ties
- Spiral Wire Wrapping
- Synthetic Bearing Grease

FINAL BUILD CONFIGURATION

Category	Quantity	Type	Name	Size
Printed parts	32	Frame/Support/Extruder/LCD		
Nozzle	1	Bowden Extension, Thermistor, Fan	E3DV6	1.75mm
Extruder	1	Extruder Body Assembly & Mount	Redrex	
	1	PTFE Tube	M2	40-50 mm
	1	MK7 Drive-Gear		
Rods	2	Smooth Rod	Ø8	320 mm
	2	Smooth rod	Ø8	350 mm
	2	Smooth rod	Ø8	370 mm
	2	Threaded rod	M5	300 mm
	4	Threaded rod	M10	210 mm
	2	Threaded rod	M10	380 mm
Mechanical Parts	16	Linear Bearing	LM8UU	
	2	Z-Axis Couplers		5mm to 5mm
	2	Pulley (X/Y-Axis)	GT2 (20 Teeth)	2mm pitch
	1	Belt (X-Axis)	GT2	760 mm
	1	Belt (Y-Axis)	GT2	900 mm
	1	Bearing	624	
	1	Bearing	608	
Print Bed	1	Aluminum Print Bed		200mm X 200mm
	4	Thumb Nuts		M3
	4	Springs		20mm X 7mm
Electronics	1	Extension Board (RAMPS 1.4)	HESAI	
	1	Atmega 2560 Microcontroller	Arduino Mega	
	5	DC Motor	Nema 17	
	4	Stepper Motor Driver	Pololu A4983	
	3	Mechanical Endstop Switch		
	1	ATX Power Supply		
	2	12V PC Cooling Fans		50mm X 10mm
	1	LCD 12864 LCD Display Controller & Breakout Board	Ramps 1.4	
Screws, Nuts, Washers	41	Screw	M3	14mm
	3	Screw	M3	24mm
	4	Screw	M3	30mm
	2	Screw	M3	60mm
	6	Screw	M4	20mm
	1	Screw	M8	30mm
	53	Washer	Ø3 mm	
	6	Washer	Ø8 mm	
	34	Washer	Ø10 mm	
	1	Grub Screw	M8	20mm
	5	Grub Screw	M3	8mm
	33	Nut	M3	
	6	Nut	M4	
	2	Nut	M5	
	1	Nut	M8	
	34	Nut	M10	
Bowden /Z-Axis Support	2	Threaded Rod	M10	350 mm
	1	Threaded rod	M10	410 mm
	16-20	Hex Nuts	M10	
	2	Screws	M3	25 mm
	2	Screws	M3	15 mm
Plastic Extruder Assembly	1	Plastic-Threading Screw	M5	10 mm
	1	PTFE Push Fitting	M5	1.75 mm tube
	2	Screws	M3	10 mm
	1	Bearing	608	

4 Electronics

The following schematic shows how the peripherals were connected to the RAMPS 1.4 breakout board. This board was then connected to the Arduino MEGA.

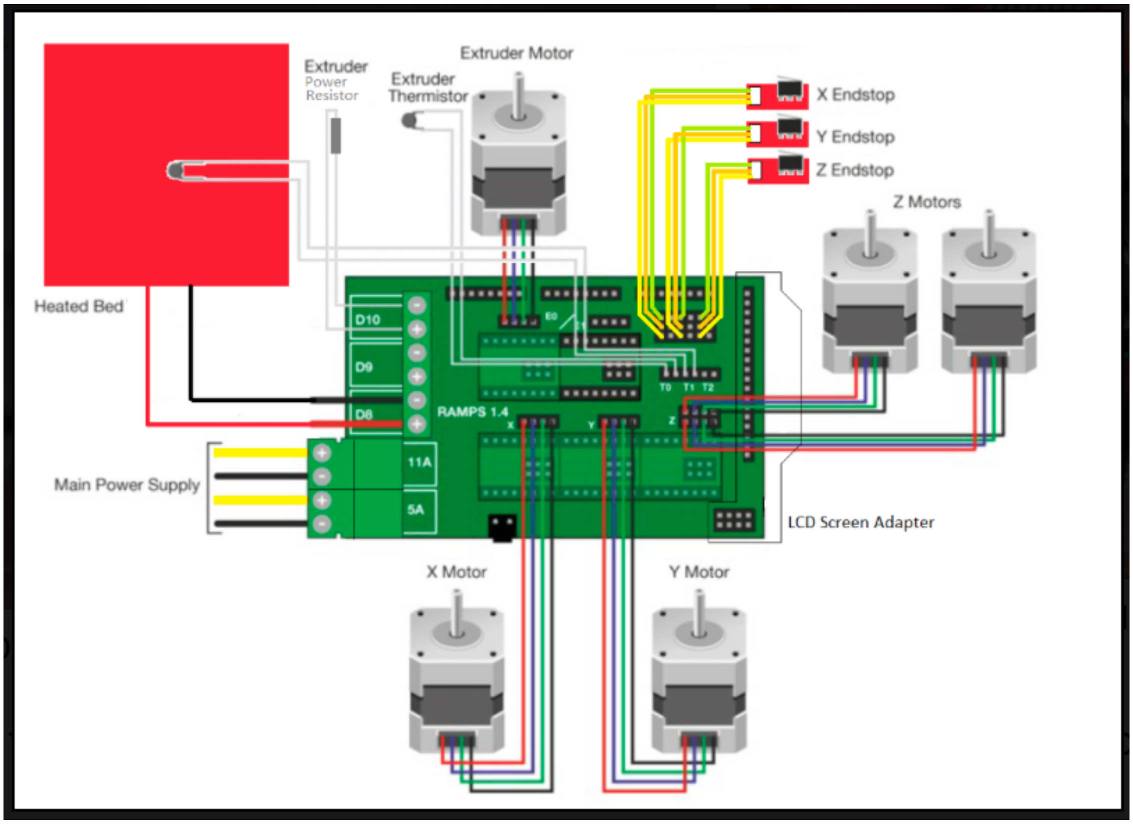


Figure 18: Wiring Schematic

NOTE: This printer DID NOT utilize the Heated Bed. Instead, two 50mmX10mm 12V cooling fans were wired into terminals D8 and D9 of the ramps board!

NOTE: The LCD display was connected to the RAMPS 1.4 board on the right-most vertical pin-section (as shown).

The Pololu A4983 stepper driver for the extruder motor is shown mounted on the RAMPS 1.4 board in the picture below. The X/Y/Z stepper drivers are mounted above the X/Y/Z capacitors in the sections labeled X, Y, and Z on the RAMPS 1.4 board (second picture).

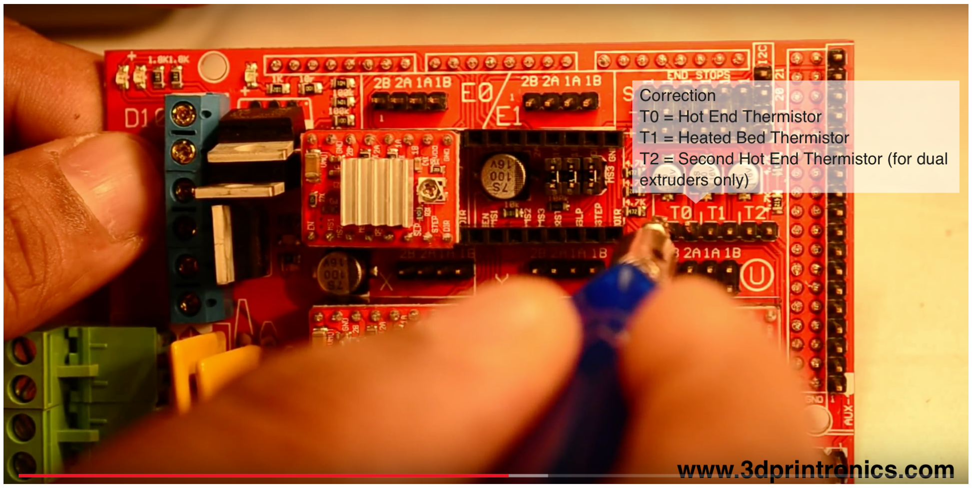


Figure 19: RAMPS 1.4 Detail 1/2

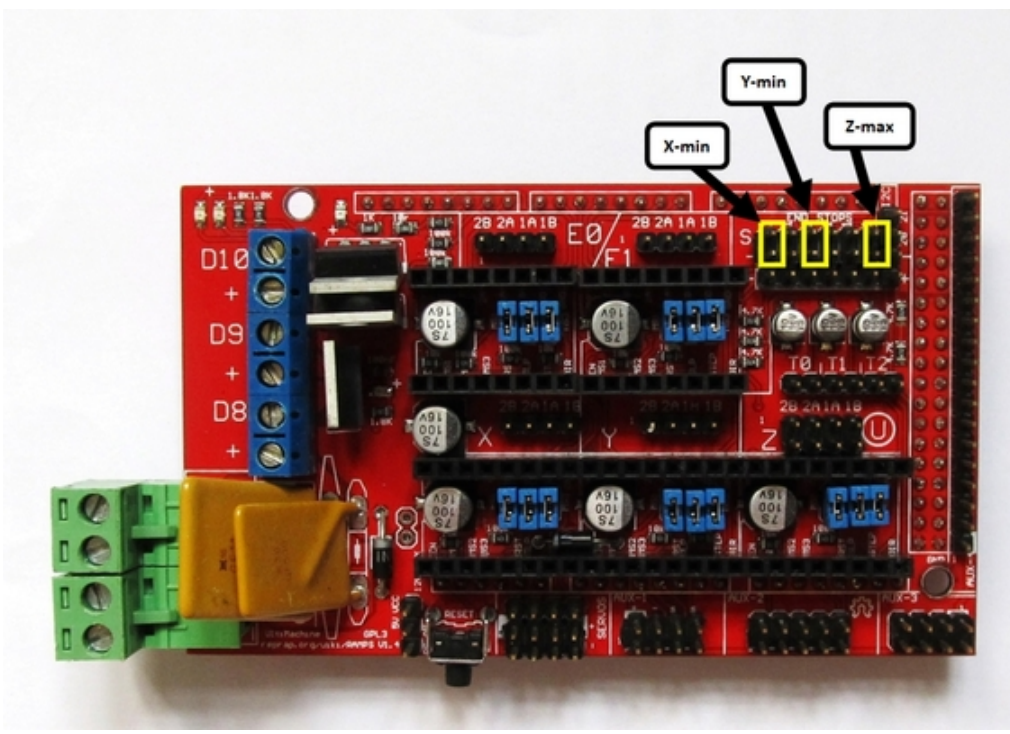


Figure 20: RAMPS 1.4 Detail 2/2

NOTE: The endstops must be placed in the positions indicated on the board or they will not function according to the calibration steps taken in the next section!

5 Firmware Calibration

The printer uses the Marlin Firmware that runs on an Arduino MEGA (Atmel 2560) micro-controller and a RAMPS 1.4 breakout board. Prior to printing, the machine's firmware was calibrated to ensure the code corresponded to the appropriate machine behavior. All calibration takes place in the Arduino IDE and Marlin firmware files named 'Configuration.h' and 'Configurationadv.h' files. There are many different ways to configure the firmware and it depends upon the architecture of the machine and the components used.

- Controller Board Selection
- Extruder Count
- Power Supply Selection
- Extruder Thermistor Selection
- Thermal Runaway Protection
- Endstop Positions
- Stepper Direction
- Stepper Motor Current Calibration
- Steps per Unit Calibration
- Acceleration
- Extruder Calibration
- Bed Size
- LCD

5.1 Controller Board Selection

The appropriate electronics controller board must be selected out of the variety of supported boards available in Marlin. Because the Arduino Mega/Ramps 1.4 boards were used in this printer, 'MOTHERBOARD 35' was chosen (RAMPS 1.4/Arduino).

```
// The following define selects which electronics board you have.
// Please choose the name from boards.h that matches your setup
#ifndef MOTHERBOARD
  #define MOTHERBOARD 35  // WAS ORIGINALLY 33
#endif
```

Figure 21: Controller Board Selection

5.2 Extruder Count

Next, the number of extruders was set. This printer has a single extruder so EXTRUDERS was set to '1'.

```
// This defines the number of extruders
// :[1, 2, 3, 4, 5]
#define EXTRUDERS 1
```

Figure 22: Extruder Count

5.3 Power Supply Selection

The appropriate power supply must be selected. This printer uses an ATX power supply, so '1' was chosen (as it has an ON/OFF switch).

```
/**
 * Select your power supply here. Use 0 if you haven't connected the PS_ON_PIN
 *
 * 0 = No Power Switch
 * 1 = ATX
 * 2 = X-Box 360 203Watts (the blue wire connected to PS_ON and the red wire to VCC)
 *
 * :{ 0:'No power switch', 1:'ATX', 2:'X-Box 360' }
 */
#define POWER_SUPPLY 1
```

Figure 23: PSU Selection

5.4 Extruder Thermistor Selection

The extruder used (E3Dv6) has a single 100K Thermistor in the hot-end. Therefore, TEMP SENSOR was set to 5 (corresponding to 100k thermistor in the provided list).

```
 * Temperature sensors available:
 *
 *    -3 : thermocouple with MAX31855 (only for sensor 0)
 *    -2 : thermocouple with MAX6675 (only for sensor 0)
 *    -1 : thermocouple with AD595
 *     0 : not used
 *     1 : 100k thermistor - best choice for EPCOS 100k (4.7k pullup)
 *     2 : 200k thermistor - ATC Semitec 204GT-2 (4.7k pullup)
 *     3 : Mendel-parts thermistor (4.7k pullup)
 *     4 : 10k thermistor !! do not use it for a hotend. It gives bad resolution at high temp. !!
 *     5 : 100K thermistor - ATC Semitec 104GT-2 (Used in ParCan & J-Head) (4.7k pullup)
```

Figure 24: Available Extruder Thermistors

```
#define TEMP_SENSOR_0 5
```

Figure 25: Extruder Thermistor Selection

5.5 Thermal Runaway Protection

Thermal Runaway Protection provides additional protection to the printer from damage and fire. Marlin includes a safe minimum and safe maximum temperature range that protect against broken and disconnected thermistor wire.

```
//===========================================================================
//======================== Thermal Runaway Protection =======================
//===========================================================================

/**
 * Thermal Protection provides additional protection to your printer from damage
 * and fire. Marlin always includes safe min and max temperature ranges which
 * protect against a broken or disconnected thermistor wire.
 *
 * The issue: If a thermistor falls out, it will report the much lower
 * temperature of the air in the room, and the the firmware will keep
 * the heater on.
 *
 * If you get "Thermal Runaway" or "Heating failed" errors the
 * details can be tuned in Configuration_adv.h
 */

#define THERMAL_PROTECTION_HOTENDS // Enable thermal protection for all extruders
#define THERMAL_PROTECTION_BED     // Enable thermal protection for the heated bed
```

Figure 26: Thermal Runaway Protection

It is possible to get false "Thermal Runaway" messages that cause the printer to halt even in normal operation due to the firmware falsely identifying that the heater end is continuing to heat up when it is not. To prevent this, the **'Configurationadv.h'** file was used.

```
#if ENABLED(THERMAL_PROTECTION_HOTENDS)
  #define THERMAL_PROTECTION_PERIOD 60        // Seconds -default 58
  #define THERMAL_PROTECTION_HYSTERESIS 20     // Degrees Celsius -default 10
```

Figure 27: Thermal Runaway Range

It is also possible to get false "Heating Failed" messages that cause the printer to halt even in normal operation due to the firmware falsely identifying that the heater end is no longer powered. To prevent this, the **'Configurationadv.h'** file was also used.

```
   * If you get false positives for "Heating failed", increase WATCH_TEMP_PERIOD
   * and/or decrease WATCH_TEMP_INCREASE. WATCH_TEMP_INCREASE should not be set
   * below 2.
   */
  #define WATCH_TEMP_PERIOD 30                // Seconds -- default 25
  #define WATCH_TEMP_INCREASE 5               // Degrees Celsius - default 2
#endif
```

Figure 28: Extruder Heating Duration

5.6 Enstop Positions

It is critical to define where the end-stops are located (which side of each axis they are mounted). The figure below shows how Marlin views the print-bed in terms of a coordinate system. The bottom left is considered the "origin". As the bed moves towards the **FRONT of the PRINTER** , the Y value increases because the nozzle will be near the back of the bed like in the picture. As the extruder nozzle moves right, the X value increases. This is important as it determines which setting in Marlin you set the end-stop limit switches to.

```
  +-- BACK ---+
  |           |
L |    (+) P  | R
E |           | I
F | (-) N (+) | G
T |           | H
  |    (-)    | T
  |           |
  O-- FRONT --+
(0,0)
```

Figure 29: Coordinate System of Print-bed in Marlin

The limit switch on the X-axis of the Prusa i3 Rework is on the right-most side. The limit switch of the Y-axis on the Prusa i3 is on the front of the printer. The limit switch for the Z-axis is on the bottom of the Z-axis (near the print bed rather than the top of the printer).

```
//===========================================================================
//============================== Endstop Settings ===========================
//===========================================================================

// @section homing

// Specify here all the endstop connectors that are connected to any endstop or probe.
// Almost all printers will be using one per axis. Probes will use one or more of the
// extra connectors. Leave undefined any used for non-endstop and non-probe purposes.
//#define USE_XMIN_PLUG
//#define USE_YMIN_PLUG
#define USE_ZMIN_PLUG
#define USE_XMAX_PLUG
#define USE_YMAX_PLUG
//#define USE_ZMAX_PLUG
```

Figure 30: Endstop Positions

NOTE: Although it may seem counter-intuitive, for the reasons stated above, the Y-axis endstop is set to 'USEYMAXPLUG' because the nozzle is located on the MAX coordinate (back of print-bed) when the limit switch on the front of the bed is triggered.

```
// Direction of endstops when homing; 1=MAX, -1=MIN
// :[-1,1]
#define X_HOME_DIR 1
#define Y_HOME_DIR 1
#define Z_HOME_DIR -1
```

Figure 31: Homing Direction

IMPORTANT: Ensure the end-stop position and homing direction settings are correct because if they are not, the limit switch will not stop the motor even if it is triggered as the firmware is looking for a value on the opposite side of the bed!

Finally, the end-stop position offsets must be set to ensure the whole volume of the bed is used. The values for this particular printer are shown below.

```
// Set the boundaries for probing (where the probe can reach).
#define LEFT_PROBE_BED_POSITION 15
#define RIGHT_PROBE_BED_POSITION 170
#define FRONT_PROBE_BED_POSITION 20
#define BACK_PROBE_BED_POSITION 170

// The Z probe minimum outer margin (to validate G29 parameters).
#define MIN_PROBE_EDGE 10
```

Figure 32: Endstop Offsets

5.7 Stepper Direction

The Y motor direction had to be inverted. This was because of the the Y-axis end-stop being mounted on the front of the printer.

```
// Invert the stepper direction. Change (or reverse the motor connector) if an axis goes the wrong way.
#define INVERT_X_DIR false
#define INVERT_Y_DIR true
#define INVERT_Z_DIR false
```

Figure 33: Stepper Motor Direction

NOTE: If the motor was not inverted, the printer will print parts 'mirrored'!

5.8 Stepper Motor Current Calibration

The stepper motor drivers must be calibrated to ensure smooth operation of each stepper motor and avoid overheating. A multimeter was used to measure the voltage across each driver. Each driver should be set to output as close to 12V as possible. To alter each driver's voltage output, a screwdriver is used to turn a potentiometer that varies the voltage (as shown below).

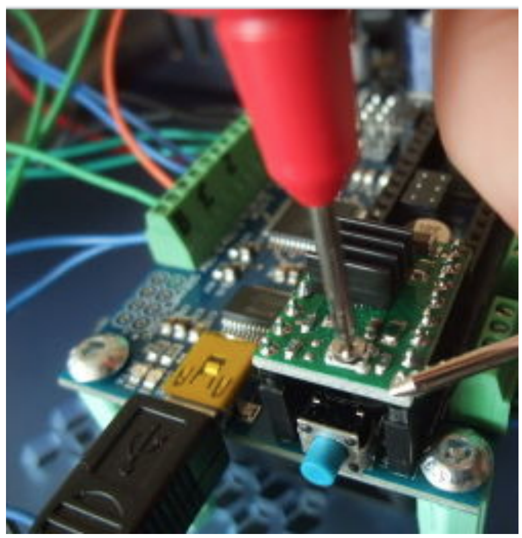


Figure 34: Stepper Motor Driver Calibration

5.9 Steps Per Unit Calibration

5.9.1 X-Axis and Y-Axis

The X-axis and Y-axis stepper motors must be calibrated to ensure that the motors are moving the appropriate length.

- Mark the starting position on each axis' rod
- Choose a length to move each axis (100mm)
- Measure the new position on each axis' rod
- Re-adjust steps-per-unit of the desired axis if the measured distance is not the exact length requested.

NOTE: If the distance traveled is less than expected, increase the associated steps-per-unit value. If the distance traveled is greater than expected, decrease the associated steps-per-unit value.

```
/**
 * Default Axis Steps Per Unit (steps/mm)
 * Override with M92
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 80, 79.75, 4000, 95.72 }
```

Figure 35: XYZ Stepper Motor Steps-per-Unit Calibration

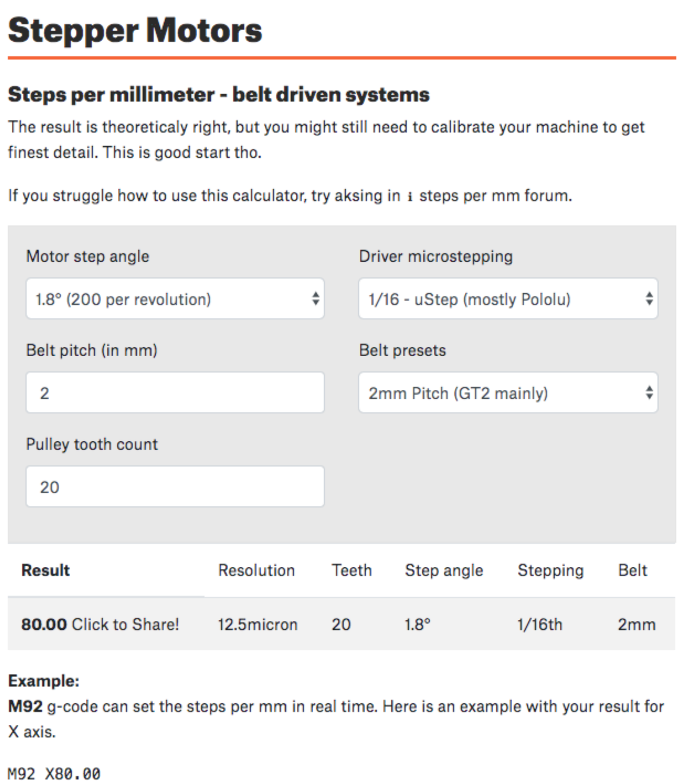


Figure 36: X-Axis and Y-Axis Steps-per-Unit Calculated Values

5.9.2 Z-Axis

The Z-axis stepper motors must be calculated using the following values:

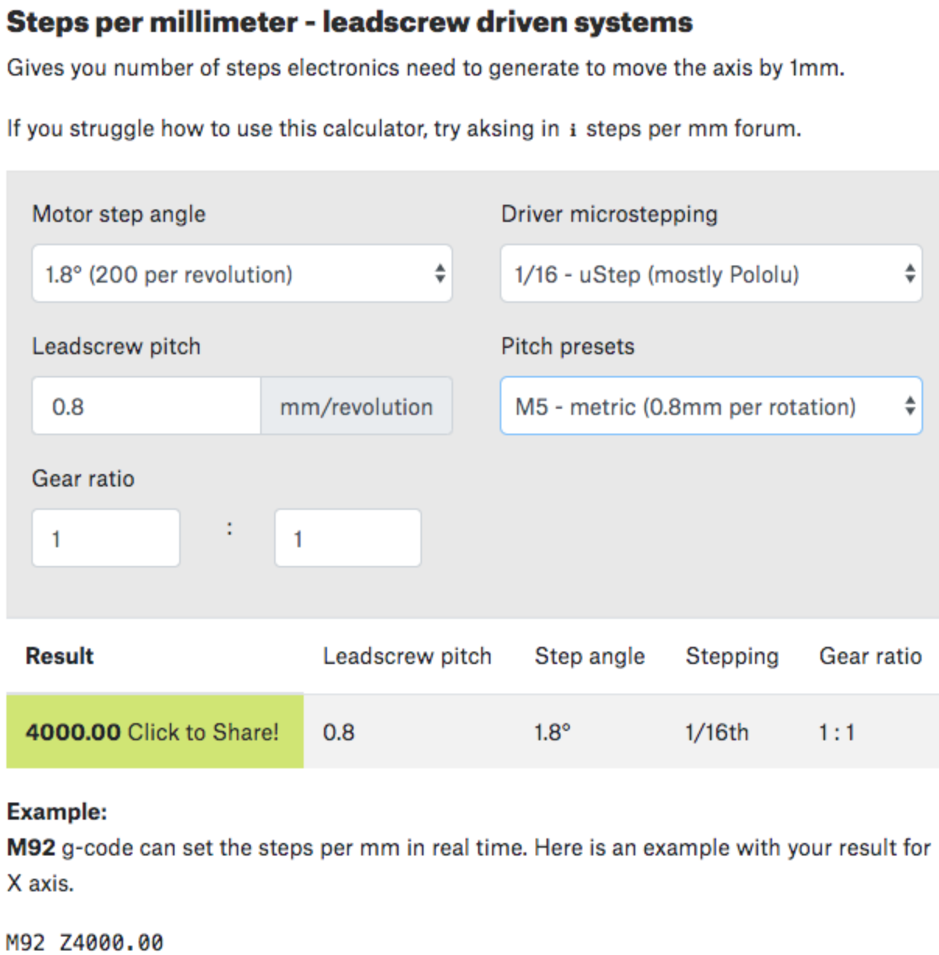


Figure 37: Z-Axis Steps-per-Unit Calculated Values

5.10 Acceleration

The acceleration settings used were based on the recommended RepRap Prusa i3 profiles. The values used were slightly lower to help increase print quality. These settings are also able to be re-written using GCode in 3D Printing / Slicer software.

```
/**
 * Default Max Acceleration (change/s) change = mm/s
 * (Maximum start speed for accelerated moves)
 * Override with M201
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_MAX_ACCELERATION      { 1800, 1800, 15, 500 }

/**
 * Default Acceleration (change/s) change = mm/s
 * Override with M204x
 *
 *   M204 P    Acceleration
 *   M204 R    Retract Acceleration
 *   M204 T    Travel Acceleration
 */
#define DEFAULT_ACCELERATION          2500    // X, Y, Z and E acceleration for printing moves
#define DEFAULT_RETRACT_ACCELERATION  200   // E acceleration for retracts
#define DEFAULT_TRAVEL_ACCELERATION   2000    // X, Y, Z acceleration for travel (non printing) moves
```

Figure 38: Acceleration Settings

5.11 Extruder Calibration

Extruder calibration is critical to get the proper amount of filament extruded. This ensure proper dimensions of parts and quality layers. The calculated value is located in DEFAULT AXIS STEPS PER UNIT (as in XYZ stepper motor calibration).

To calculate the required number of extruder steps needed:

- Choose a length to extrude (10mm)
- Measure the extruded plastic
- Use the following formula below to re-adjust step if the measured plastic is not yet the appropriate length:

$$\frac{\text{(REQUESTED EXTRUSION LENGTH)} \ \text{X} \ \text{(CURRENT AXIS STEPS PER UNIT)}}{\text{MEASURED EXTRUSION LENGTH}}$$

Figure 39: Extruder Calibration Formula

```
/**
 * Default Axis Steps Per Unit (steps/mm)
 * Override with M92
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 80, 79.75, 4000, 95.72 }
```

Figure 40: Extruder Stepper Motor Calibration

5.12 Bed Size

The bed size is set in the firmware in the following section of the code. The build volume on the Prusa i3 Rework is 200cm x 200cm.

```
// The size of the print bed
#define X_BED_SIZE 200
#define Y_BED_SIZE 200
```

Figure 41: Bed Size

5.13 LCD

The addition of the LCD requires that the LCD section of the firmware is configured. The first option is to set the language. English was selected.

```
//=============================================================================
//============================= LCD and SD support ============================
//=============================================================================

// @section lcd

/**
 * LCD LANGUAGE
 *
 * Select the language to display on the LCD. These languages are available:
 *
 *    en, an, bg, ca, cn, cz, cz_utf8, de, el, el-gr, es, eu, fi, fr, fr_utf8, g
 *    hr, it, kana, kana_utf8, nl, pl, pt, pt_utf8, pt-br, pt-br_utf8, ru, sk_ut
 *    tr, uk, zh_CN, zh_TW, test
 *
 * :{ 'en':'English', 'an':'Aragonese', 'bg':'Bulgarian', 'ca':'Catalan', 'cn':'
 */
#define LCD_LANGUAGE en
```

Figure 42: LCD Language

The next step was to enable the SD card slot of the LCD board so the printer can print using an internal SD card without being connected to an external computer.

```
/**
 * SD CARD
 *
 * SD Card support is disabled by default. If your controller has an SD slot,
 * you must uncomment the following option or it won't work.
 *
 */
#define SDSUPPORT
```

Figure 43: SD Card Support

Finally, the appropriate LCD board was selected from list of available boards supported in

Marlin. The board used on this printer was the 'REPRAP DISCOUNT FULL GRAPHIC SMART CONTROLLER', so the line was uncommented and activated.

```
//
// RepRapDiscount FULL GRAPHIC Smart Controller
// http://reprap.org/wiki/RepRapDiscount_Full_Graphic_Smart_Controller
//
#define REPRAP_DISCOUNT_FULL_GRAPHIC_SMART_CONTROLLER
```

Figure 44: LCD Board Selection

6 3D Printing / Slicing Software

Cura was used as the 3D printing/slicing software.

7 Future Improvements

Although the printer is complete and is producing very high-quality prints, there are a few additions that could be added in the future to improve the printer:

- Larger Z-axis rods to improve layer resolution
- New printed X-axis idler and motor mount to accommodate for larger Z-axis rods
- Heated bed for ABS printing
- Printed proximity sensor holder
- Installation of proximity sensor to replace mechanical Z-axis end-stop limit switch
- Automatic bed leveling in Marlin Firmware
- Filament holder incorporated into frame
- Rotary cooling fan installation to rid the need of two larger 50mm X 10mm cooling fans
- Y-axis bearing holders
- Dual extruder setup (reduces print volume but will allow printing of more complex parts)
- Printed enclosure for electronics

8 Build Process

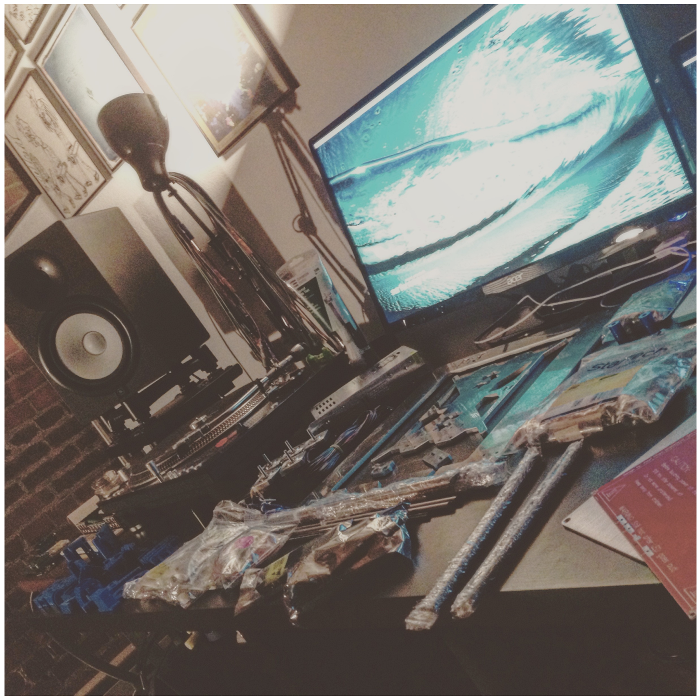


Figure 45: Build Day One (1/2)

Figure 46: Build Day One (2/2)

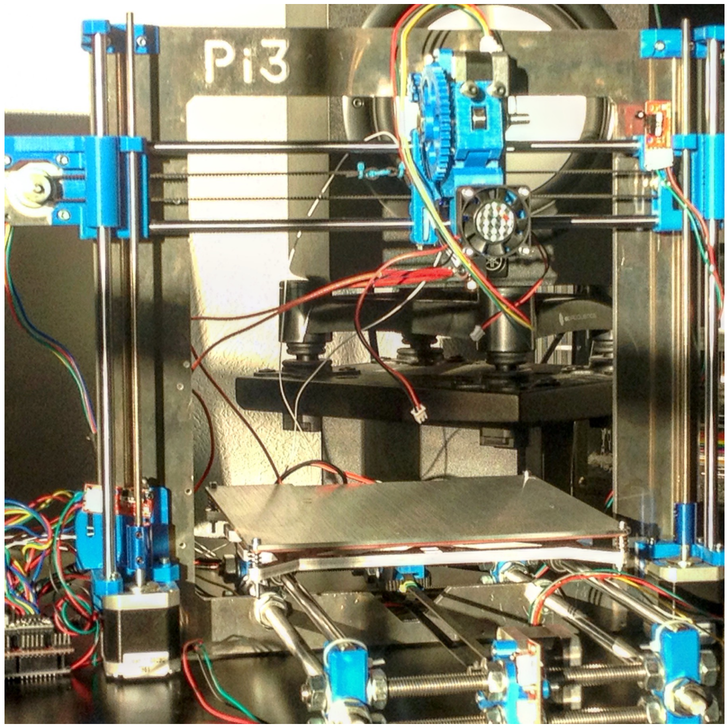


Figure 47: First Iteration

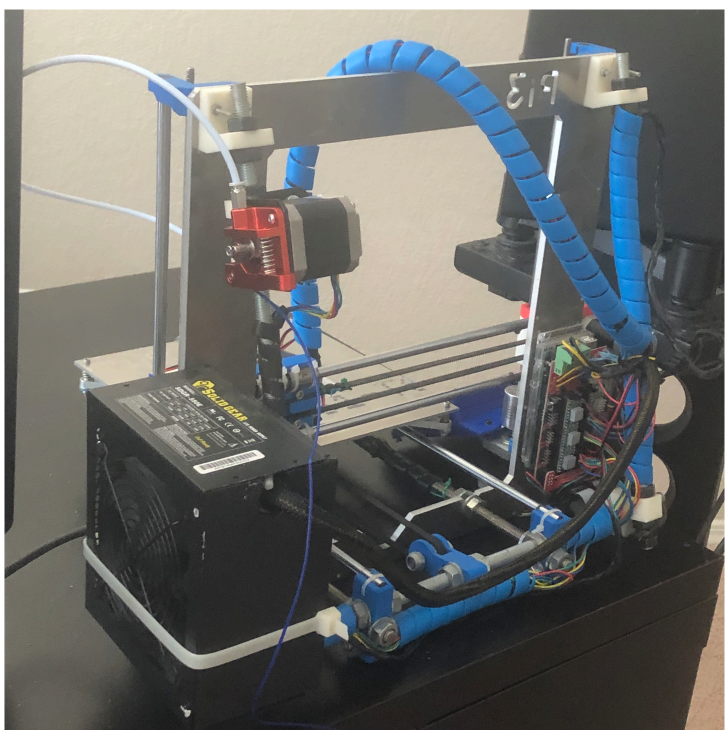


Figure 48: Finished Printer 1/3

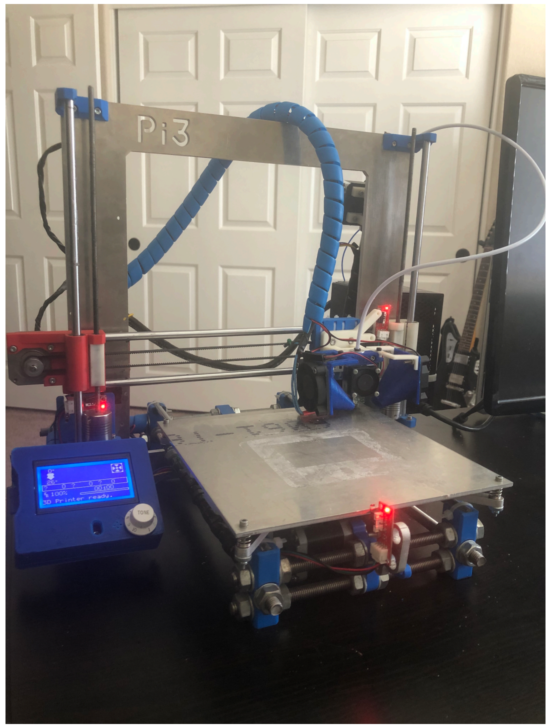


Figure 49: Finished Printer 2/3

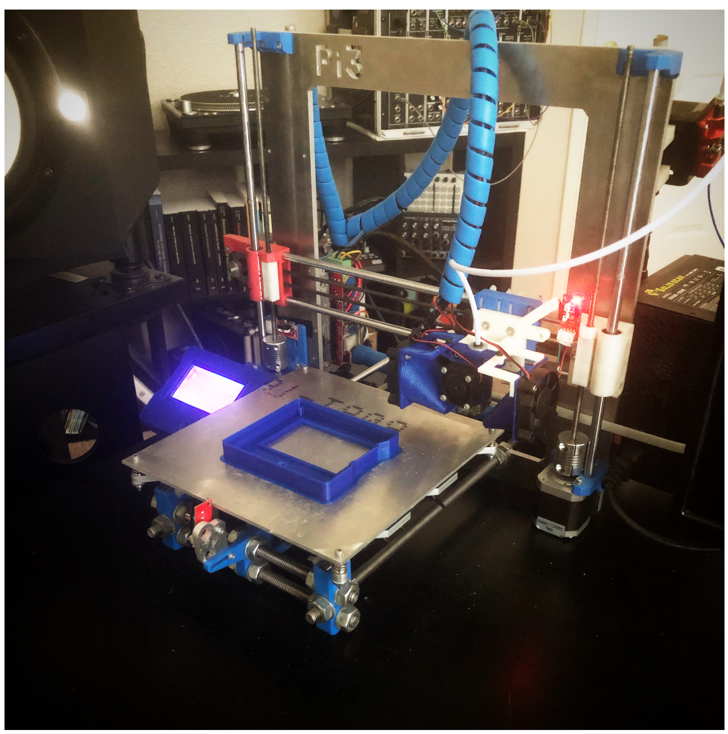


Figure 50: Finished Printer 3/3

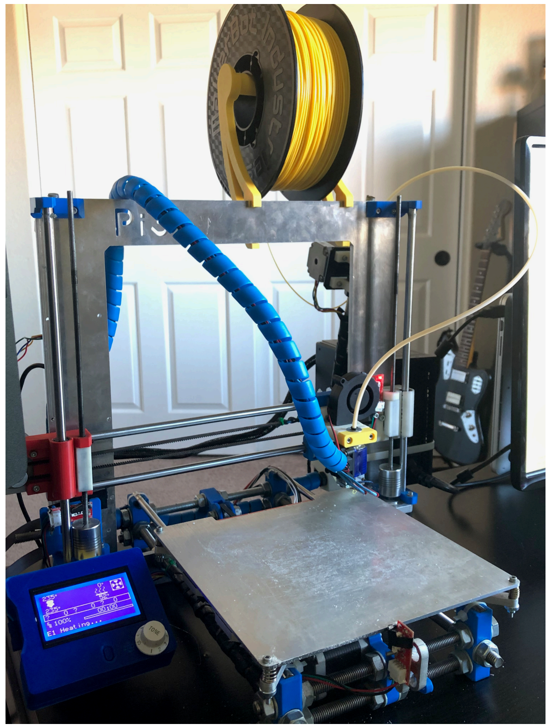


Figure 51: Finished Printer with Second Generation Fan 1/2

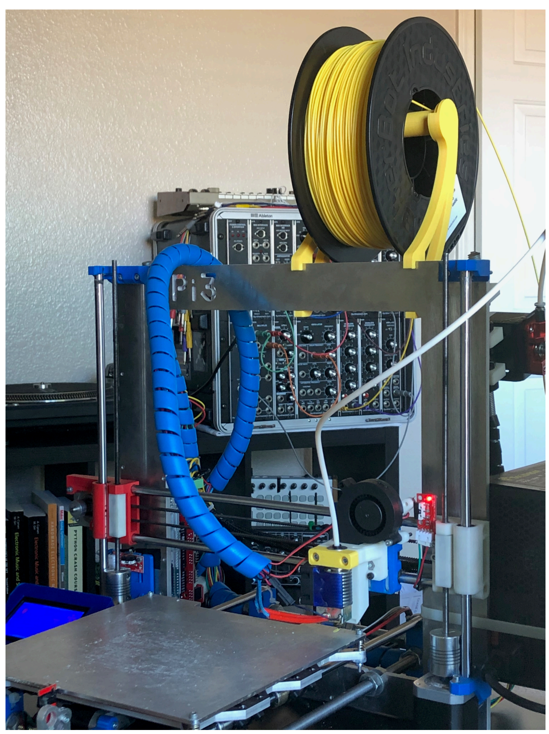


Figure 52: Finished Printer with Second Generation Fan 2/2

References

[1] (2020, May). [Online]. Available: https://marlinfw.org/

[2] (2020, May). [Online]. Available: https://reprap.org/wiki/RepRap

[3] (2020, May). [Online]. Available: https://www.thingiverse.com/Tech2C/about

[4] (2020, May). [Online]. Available: https://www.thingiverse.com/thing:119616