Low-Cost 3D Printer for High School Summer Camp

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Abstract

The project's goal was to design and create a prototype of a low-cost 3D printer for a high school summer camp under $300. Since an instructional summer camp will replicate the printer, it needed a long enough build time without being too complicated. The project team reviewed available 3D printer kits as a reference model to create a DIY printer. The project team found DIY printer instructions through Instructables, and the team made revisions to meet the requirements that the advisor, Dr. Crawford, set for the team. Once the project team conducted the research, they made a bill of materials covering the frame, electronics, and power source. Construction began shortly after the parts arrived, and the build time was about a week. The Instructables provided incorrect measurements for some features, which delayed the project's progress; the delay was combated by meeting more frequently and re-ordering multiple parts. After the project team had completely assembled the DIY printer, the testing and revision phase began since several kinks needed to be resolved. Once the electronics were running smoothly and everything was working well, a test print was initiated to test the printer's function. The test print successfully proved the feasibility of the project proposal. In the end, the team created a successful DIY printer from scratch that is fit for a high school summer camp.

Introduction

This low-cost 3D printer research project requires the team to collaborate on designs and prototypes while researching current cheap printers that may help to meet their needs. The team utilized resources such as Reprap or Instructables to give them a general idea of a 3D printer's necessities to construct their printer. 3D printers are currently used around the world for different industries. From toys to conduits for hearts to education about machine learning, 3D printing has a plethora of applications. However, one of the main issues is that 3D printers are often costly and hard to fully understand because they come in kits. Since the kits are designed for convenience, there is usually barely any construction that needs to be done, which completely overlooks the beneficial education that students could receive from assembling a 3D printer. Additionally, since they are convenient, many printers have high price tags, which is not optimal for a high school summer camp. Since 3D printers are currently being used in countless industries, an affordable yet educational printer needs to be created. Thus, the objective was to find a model of a 3D printer kit and use it as a replica to create a DIY 3D printer that would take the high school students about four to five hours to build.

By viewing individual printers through each member, the team could learn more about building different 3D printers and then collaborate the findings to decide whether or not the idea is intriguing. Some existing 3D printers explored were the Prusa i3 MK3S and the Anet Evolution 3D printer. Large portions of the printers had 3D printed parts that contributed to their overall function, which alleviated the total cost of the build. Additionally, the construction of these printers is relatively easy-to-follow as there are no intricate designs present, making them possible design choices. Secondly, utilizing laser cut frames and purchasing the most economical parts for our 3D printer also became a priority. Research from each member shows the advantages of using a particular RAMPS motherboard, electronics system, power supply, etc., over other options to ensure that our build was as cost-effective and efficient as possible. An example of this is shown in the Pugh Decision Matrix (Figure 2). The team researched several RAMPS compatible boards and compared them to the Ender 3 printer they would later construct to evaluate the best option.

The team met every week with their advisor, Dr. Richard Crawford, and followed his instructions to ensure that the team could complete the project before the end of the semester. This meeting time allowed the group to discuss their short-term and long-term goals for the semester. The first significant goal was to construct a Gantt Chart (Figure 1) to properly base progress upon and advance the project. At the start of every meeting, the team looked at the chart, which told them whether or not they did enough work for the week and if the team needed to do more the following week. Other team goals included building an easy-to-follow 3D printer, not exceeding our limited budget, communicating well with one another, and simply understanding the construction of 3D printers. It is imperative to acknowledge that this project would eventually help teenagers in high school to get hands-on experience with CADing, manufacturing, and working with electronics. The team recognized that they also needed hands-on experience before constructing their printer, so they built the Creality - Ender 3 Max 3D printer. After completing the first printer, the team kept in mind that they could utilize it to 3D print parts for their 3D printers, such as brackets or parts of the structure. Following these initial steps meant that the team could follow a correct path to construct our 3D printer for the high school summer camp and achieve their project goals.

Figure 1 (Gantt Chart)

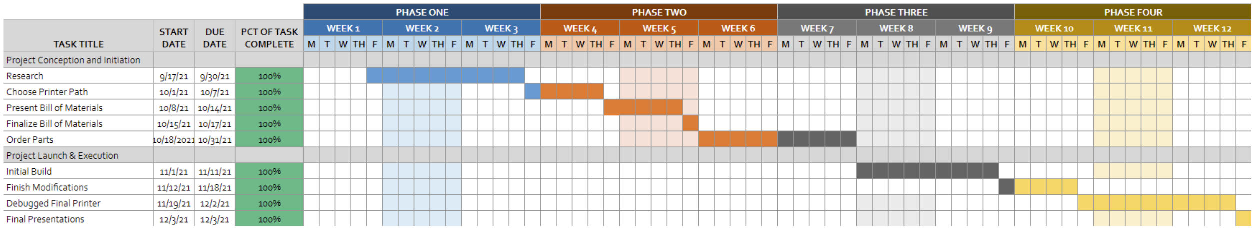

Figure 1 shows the Gantt Chart that was created to manage the progress of the team. Tasks on left followed by the start/due dates then the percentage of completion Phase 1, Phase 2, Phase 3, Phase 4 (Research, Choose Printer/Bill of Materials, Assemble/Debug Printer, Present).

Figure 2 (Pugh Decision Matrix)

	A	B	C	E	F	G	H
1				RAMPS Board Kits (compared to Creality Ender 3 3D printer)			
2	Topics	Criteria	Weight	Eiechip CNC 3D Printer Kit https://www.amazon.com/Eiechip-CNC-3D-Printer-Kit/dp/B07BKVPZ71	ESTONE 3D Printer Kits RAMPS 1.4 https://www.walmart.com/ip/ESTONE-3D-Printer-Kits-RAMPS-1-4-Mega2560-12864-LCD-Controller-A4988-for-Reprap/835700564	Mega2560 3D Printer Kits RAMPS 1.4	Longruner 3D Printer CNC Controller Kit https://tinyurl.com/longruner3dprinter
3	Reliability	Warranty	8	Same	Same	Same	Same
4		Long Term Quality	7	Better	Better	Better	Better
5	Cost	Upfront Cost	7	Worse	Better	Same	Better
6		Cost Per Item	6	Worse	Better	Better	Same
7		Within Our Limit	10	Same	Same	Same	Same
13	Comfort	Meets Our Needs	7	Worse	Worse	Worse	Same
14		Technology	6	Same	Same	Same	Same
15		Size	6	Same	Same	Same	Same
16		Customer Review	6	Same	Same	Better	Better
17		Rating	5	Same	Same	Same	Better
18							
19		Better		1	3	3	4
20		Same		6	6	6	6
21		Worse		3	1	1	0
22		Weighted Better		7	20	19	25
23		Weighted Same		0	0	0	0
24		Weighted Worse		-20	-7	-7	0
25		**Overall Score**		**-13**	**13**	**12**	**25**
26							
27		Best Decision					
28	r 3D Printer CNC Controller Kit https://tinyurl.com/longruner3dprinter						
29							

Figure 2 shows factors/topics of each piece on the left (Cost, Reliability, Comfort) followed by Criteria and the Weight that each section has in the decision matrix. On the top right, there are several brands of RAMPS boards with Same=no real benefit, Worse= not favorable, and Better= highly favorable when compared to the Ender 3's parts.

Methods

Before the team could build a DIY 3D printer, they had to research the different types of existing printers to use as a reference. After consulting with their advisor, Dr. Crawford, and investigating current printers, it was decided that three main goals needed to be fulfilled for the first printer build. The first was reliability, which included the printer's warranty (if it had one) and the long-term quality. The team examined this through customer reviews and the printer's warranty description. The second component was cost, which was most important with the second printer. The first printer would have an upfront cost since it includes all the necessary parts and assembly instructions. However, the second printer would have costs per item and different prices based on the website of the ordered parts. This goal was the most important since the goal was to create a cost-efficient 3D printer that a high school summer camp could replicate. The last goal was practicality, referring to the technology and size of both printers. Both printers needed to be relatively small since it is designed for a summer camp, and they have to utilize technology simple enough for inexperienced high school students. Since the project has multiple parts, it was essential to stay on track and establish a timeline. Thus, the team used a Gantt chart to highlight the team and advisor's deadlines. The chart was especially helpful in keeping track of the main steps that had to be taken, such as finalizing the bill of materials, ordering parts, and building and modifying the printer.

After creating the criteria for the two printers, different printers were explored to determine which could be replicated within the given time frame of one semester. For instance, ideas such as a laser-cut 3D printer and 3D printed 3D printer were proposed; however, these options were deemed too complicated, and many components of the build were difficult to order. Ultimately the Creality Ender 3 was selected to be the model for the DIY printer because it was low cost (about 189 dollars) and had a short build time (approximately an hour). It was essential to consider cost and time efficiency when building the first printer because the second printer would take much longer. After the first printer was assembled, it was used as a reference model, and it printed 3D parts for the DIY printer.

A. Creality Ender 3 Max Build Process

Building the Creality Ender-3 Max was a relatively simple build with few challenges. Starting all the parts were removed from the packaging, and the team did an inventory of all the items. The first step on the build manual was assembling the frame of the printer. The gantry frame already had the extruder mounted, and the lead screws for the z-axis were simply attached to the base with four M5x65 socket head cap screws. Next, the power supply box that converts the AC from the outlet into DC was taken out of the packaging. The power supply box was mounted to the instructed side of the 3D printer using two M4x25 hexagon socket button head screws. Then, the team had to install the screen/control board that displays all the important data about the printer, like extruder/bed temp, and that also allows control over the printer and what files for printing. The screen was mounted with two M5x10 hexagon socket button head screws to the printer base right of the preinstalled USB and micro SD slots. Next, the spool holder was installed to the base of the printer. First, the team locked the cylindrical part into the spool rack by rotating it, and then it was clipped into the printer base to the right of the Power Supply. Next, the team added the glass plate to the heated bed since the printer can't print directly on it. To install it, the metal clamps were turned in the front, outward, and then slide the glass plate into the metal clamps in the back, lay it down on the heated bed, and then turn the front metal clips back to secure the glass plate. Finally, all the wires were connected, which proved to be the most challenging build step as there were quite a few wires to connect. The first was the motor cables which had to be plugged into the stepper motors on their respective axes, fortunately, the wires had labels which made it easier to find what motors to connect the cables to. The X, Y, and Z stepper motors were plugged in, and since each motor has a partner limit switch, they had to be connected to the wires with the respective axes. The last small cable was for the filament sensor, which was easy to locate. Lastly, the power supply had to be connected to the 3D printer using the yellow XT60 connector. At this point, the build for the Ender 3 Max was complete, and the power outlet just needed to be plugged in.

B. 3DIYP

The first step of creating the DIY printer was creating a bill of materials and ordering parts. The Creality printer was the model for the look of this printer, but an Instructables was used to guide the team. Due to the large number of parts that a 3D printer requires, every step of the reference printer was examined and followed carefully. The Instructables creators had their bill of materials, but several parts were outdated or missing, so the team had to account for those. For instance, almost all 3D printed parts, such as the corner brackets, were missing from the Instructables, so the team had to CAD their design. Additionally, many of the parts that had to be ordered, such as the linear rods, were not the correct dimension and had to be reordered. The Instructables stated that there needed to be six 8 mm linear rods, 400 mm in length, ordered, but in reality, only four were needed and two others were supposed to be 6 mm linear rods. The glass plate link that was provided in the Instructables' bill of materials was incorrect and the holes on the four corners did not line up with the holes of the extruders where the plate needed to be placed. Another aspect that was changed was that the screws for the bed. Instead of following the Instructables, the team used six 32*2.5 inch screws and wing nuts were used to tighten them. In terms of electronics, the motherboard ordered was different as well. On the motherboard, the plastic connectors had to be flipped for the LCD screen in order for the screen to work. In addition to the different materials and custom-made brackets, the team omitted several steps that the Instructables had to reduce the overall cost and complexity of the build. Due to the inconsistency of the Instructables, there were several delays in the project that could be avoided next time when the high school students built the 3D printers. Though there were obstacles during the project, all the parts came in time.

The parts were mainly ordered from Amazon and Misumi to ensure fast shipping times. Once they arrived, the assembly of the 3D printer's frame started. The frame was created using various sized extrusions ordered on Misumi and corner plates that were laser cut at Texas

Inventionworks located at UT Austin. Two 40*40 400 mm extrusions were attached to two 20*40 400 mm extrusions with the corner plates, T nuts, and screws. Once the base was created, two more 40*40 400 mm were attached vertically on the other 40*40 mm extrusions. Finally, a 20*20 400 mm extrusion was laid horizontally on the vertical extrusions and attached with corner brackets that were 3D printed. Once the frame of the printer was created, the frame of the glass bed was created by attaching two 20*20 220 mm extrusions to two 20*20 190 mm long extrusions with more 3D printed corner brackets. The final frame and heat bed frame can be seen in Figure 3. This step was one of the easiest because the most difficult part was lining up the T screws correctly on the extrusions.

Figure 3: Extrusion Frame

Figure 3 shows the DIY printer's frame created using aluminum extrusions and corner pieces laser cut in Texas Inventionworks. The corner pieces that attached the vertical extrusions were 3D printed with the Creality Ender.

Once the frame was built, the Y-axis construction began. Four extrusion bearing blocks were 3D printed using the Creality Ender, the instructables initially suggested we use dry-lin bearings but we replaced these with linear ball bearing in order to deal with less friction that the dry-lin bearings experienced. The blocks were attached to two sides of the extrusions on the heat bed frame using screws and T nuts. Next, four rail mount brackets that were 3D printed were attached to the extrusions on the printer's frame. The heat bed frame was oriented to the bearing blocks were facing the ground, and the holes of the bearings lined up with the holes of the rail mount brackets. Then, two 440 mm long linear rods were inserted into the holes of the bearings and brackets, which attached the heat bed frame to the printer frame. Next, the Nema 17 Stepper Kit motor was attached to the extrusion right in the center of two rail mount brackets using screws that came with the kit. After the Y stepper was put together, the Y tensioner was assembled. An idler pulley was attached to a 3D printed part by lining up the holes, inserting a bolt, and attaching washers. Then, the pulley and 3D printed part were attached to the extrusions opposite to the stepper. An M3 screw was attached in the center of the 3D printer part to control the tightness and tension of the belt. The belt was then attached with a small bonding plate, screws, and T nuts. Once the bonding plate is fastened onto the extrusions of the heat bed, the belt is zip-tied to the bonding plate. Finally, the excess belt is trimmed off to prevent it from getting caught or creating clutter. The final product of the Y-axis can be seen in Figure 4.

Figure 4: Y-Axis Construction

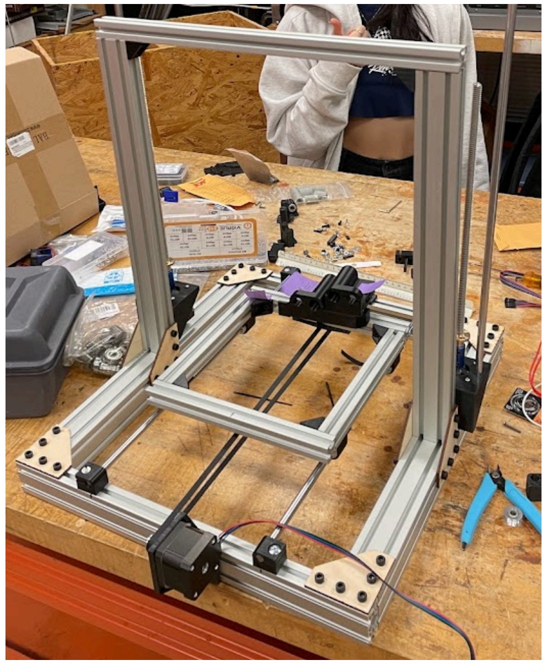

Figure 4 shows the Y-axis that contains the belt, motor, and heat bed frame. The heat bed frame was constructed using aluminum extrusions and secured with corner pieces that were 3D printed.

After the Y-axis was created, the next step was the X carriage and the Z-axis. The first step of assembling the X carriage was putting two linear ball bearings into a 3D printed left carriage mount. The brass nut used to hold the lead screw was attached to the second hole in the carriage. The same steps were repeated for the right carriage mount, but M3 screws were screwed into the mount to create a place for the tensioner screws to push off of. The tensioner was also 3D printed and M3 screws were also inserted to push off the socket cap screws in the right carriage mount. Once the two carriage mounts are finished, three 3D printed pillow blocks with one bearing in each of them were attached to a flatbed that was also 3D printed. Once they were fastened in place with M3 screws, another part was 3D printed that would hold the nozzle of the printer. The flatbed was turned over so the pillow blocks faced the ground and the nozzle holding part was attached to the top of the flatbed with M3 screws. This entire assembled piece is called the carriage. Then, two 400 mm linear rods were inserted into the holes of the left carriage mount, and the carriage was attached by sliding the bearings of the pillow blocks through the rods. Lastly, the linear rods were put into the holes of the right carriage mount, which finalized the creation of the X carriage. The last step, other than setting up the mainboard and testing the printer, was the Z-axis.

The first part of creating the Z-axis is printing out two linear rod mounts, which will attach the linear rods of the X carriage with the motors. Once the mounts were printed out, they were preloaded with M5 screws and T nuts to attach the rod mounds to the vertical extrusions of the printer frame. Next, two 400 mm linear rods were inserted into the holes of the mounts. The other ends of the linear rods were inserted onto two 3D printed linear rod holders that were attached to the top of the vertical extrusions with screws and T nuts. On the bottom, two stepper motors were put into the large holes of the two linear rod mounts and secured with M3 screws. Then, one blue coupler was attached to each motor on the left and right side of the printer, which assisted in the assembly of the X carriage that was created previously. The lead screws were then twisted onto the brass nuts mentioned in the X carriage portion until they rested in the couplers on either side of the printer. When the lead screws were secured, the linear rods were secured once again into the mounts at the bottom of the frame. A couple of long screws were inserted into the X carriage to hold the belt and nuts were placed over the other end to hold them in place. Once the belt was overlapped and zip-tied, the excess belt was trimmed off. The final construction step was securing any loose screws to prevent the printer from malfunctioning. The X and Z-axes can be seen in Figure 5.

Figure 5: X and Z-Axes

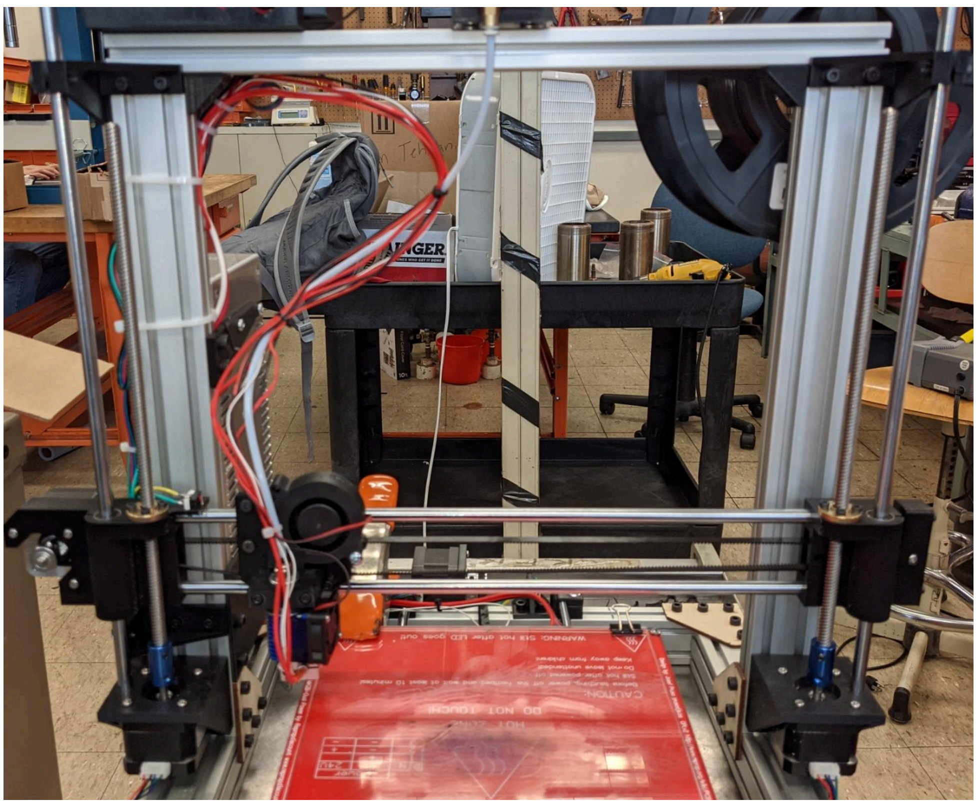

Figure 5 shows the completed X and Z axes that were attached. The X-axis is the part that runs horizontally across the vertical extrusions and the Z-axis includes the lead screws that allow the X-axis to move up and down.

After constructing the mechanical aspects of the printer, the power supply had to be set up. First, the team had to construct the power switch by inserting the fuse into the designated slot. Afterward, the switch was wired according to the video and Figure 6. The two wires coming out of the power switch then had to be connected to the power supply. Since these wires would direct alternating current the team needed to take great care during this step to ensure their safety. Also, a ground wire from the power switch had to be connected to the ground port on the power supply. Once the AC power was connected to the power supply the team inserted wires into the DC output ports of the power supply. These wires were connected directly to the power supply port in the MKS Gen L V1.0 (motherboard) shown in Figure 7. A crucial step to mention for the power supply setup was moving the switch on the side to the 110V configuration to make it compatible with American outlets; otherwise components could have been damaged if this step was overlooked.

Figure 6: Power Switch/Supply

Figure 6 shows the 24V 15A power supply and the power switch that wasthemsed to give the 3D printer power directly from standard outlets.

Once power was connected and tested the team could move on to smaller electrical components like stepper motors, end stops, the heated bed, and hot end. However, before these components could be connected and tested the team had to first flash the Marlin firmware to the motherboard. Marlin is an industry-standard software for 3D printers that is open source which gave the team the ability to customize it to fit their printer's specifications.We downloaded the firmware from the github link at the bottom of the paper and followed the steps to flash it to the motherboard

(Do not follow steps in the videos). After the software was flashed, the team wired the hot end (Figure 8) by connecting the thermistor, heating cartridge, and cooling fans to their respective ports (Figure 7). Also in order for the LCD to work with the motherboard the two black LCD connectors need to be flipped 180 degrees because they come installed backwards. Once they were wired the group heated the hot end to ensure that filament could easily pass through it. Next was the heated bed (Figure 9). Before we could connect the heated bed to the motherboard the group had to desolder its power wires and solder them back in the 24V configuration. Similar to the hot end, the team connected the power wires and thermistor to their respective ports on the motherboard. Finally, the stepper motors and end-stops (Figure 10) were connected to the motherboard, where they were connected to the ports with respective axes. The team had to wire the two Z-axis stepper motors in parallel so that they had a synchronized rotation. The end stops were mounted at the end of each axis which allowed the printer to determine its dimensional limits.

Figure 7: MKS Gen L V1.0 Motherboard

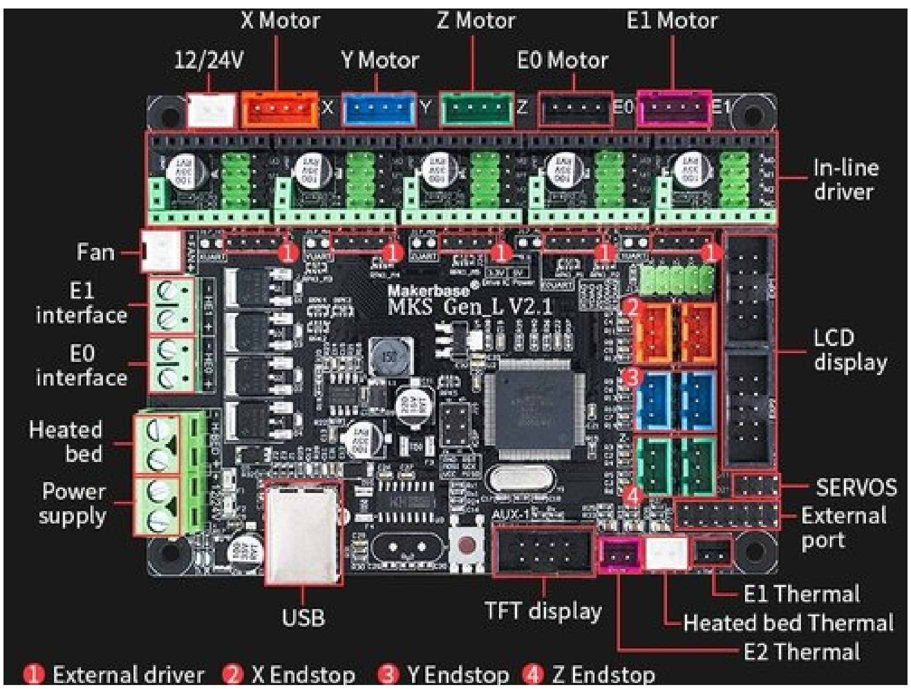

Figure 7 shows the MKS Gen L V1.0 motherboard that the group uploaded the Marlin 3D printing software to, allowing the team to run the 3D printer. It also serves as the central connection point for all of the electronic components.

Figure 8: E3D V6 Hot End

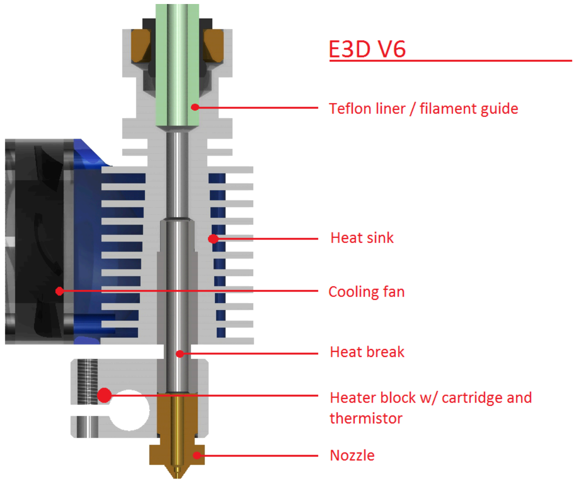

Figure 8 shows the hot end the team used to heat the filament and extrude it onto the print bed.

Figure 9: MK2B Heated Bed

Figure 9 shows the heated bed that was used in the team's DIY build. The heated bed is used to improve the adhesion of the first layers of the extruded filament. However, for materials like PLA it is not a necessary component.

Figure 10: Nema 17 Stepper Motors/End Stops

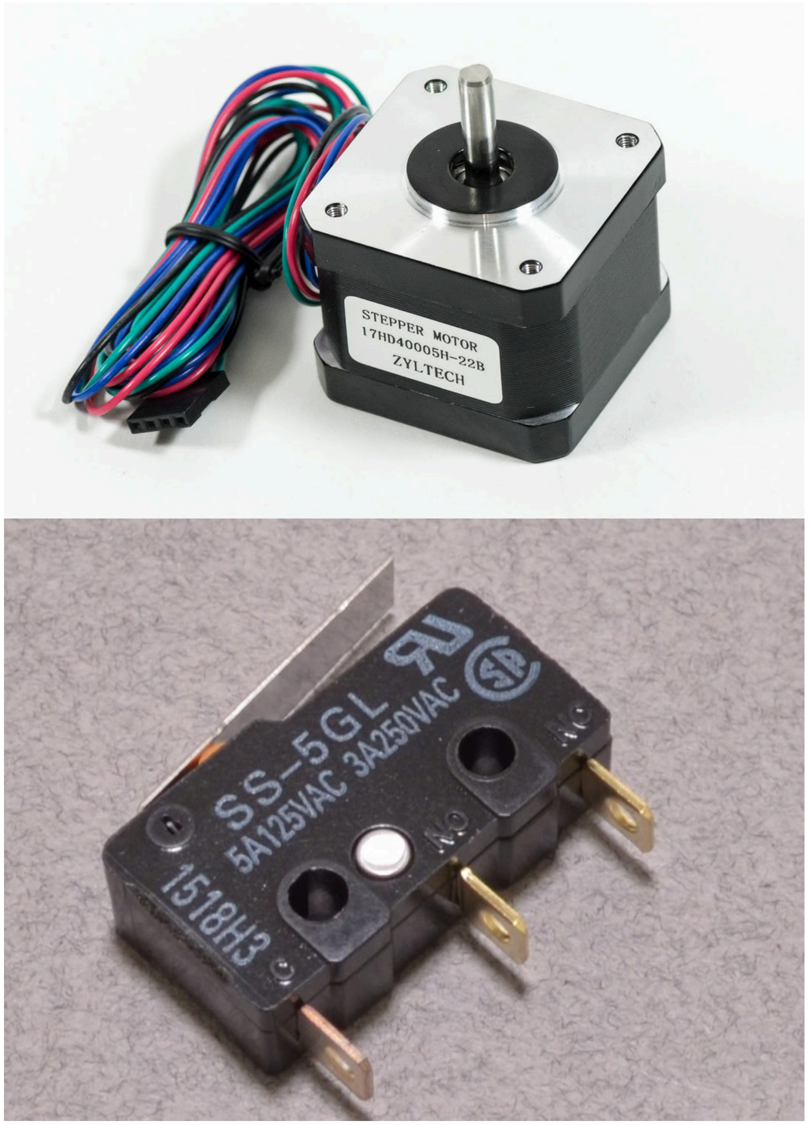

Figure 10 shows the stepper motors that were used for the extruder and movement of the axes. The end stops for homing the printer are also shown.

Results

In total, the build time was about twenty-five hours, which included modifying and debugging the printer. When translated to the amount of time it will take high school students to make the printer, it will be about four to five hours. This time frame is long enough to keep them interested without making it too complicated, which was the original concern of Dr. Crawford. Another concern was the financial cost. The cost of the printer ended up being three hundred fifty dollars, which does not include the unused ordered parts. Several parts were the wrong dimensions or did not work. For example, three heating plates had to be ordered because the holes that the securing screws would go into did not match the holes of the extrusion heating bed frame. The first two heating plates were not used, so they were on the list to be returned. Another part that did not work was the linear rod. The Instructables stated that there needed to be six linear rods that were 400 mm long. However, for the construction of the Y-axis, it became apparent that 400 mm was not long enough. Thus, parts needed to be ordered quickly on Amazon, which led to a higher price. Thus, the incorrect dimension problem was solved by ordering parts on Amazon, but that lead to a higher cost because of the fast shipping that Amazon provides in comparison to bulk sellers that take months to ship. Additionally, some 3D printed parts broke when removing them from the Creality Ender. One of the parts that were particularly difficult to remove was the tensioners, which had two long antenna-like sticks coming off of them. This part was printed four times in total since one of the antennas came off every other time it was taken off the printer bed.

Once the difficulties were overcome, a DIY printer was successfully built and tested within the semester-long time frame. The printer also achieved its main purpose of taking about four to five hours (not including complications) to complete, making it achievable for high school students. As seen in Figure 12, the printer is functional, and the parts all came together well. The printer was also able to print a longhorn created on Cura, which can be seen in Figure 13. The longhorn that the DIY printer printed was as good quality as the Creality Ender that was store-bought and assembled, showing that the DIY printer is comparable to a pre-made one.

Figure 12: Final DIY 3D Printer

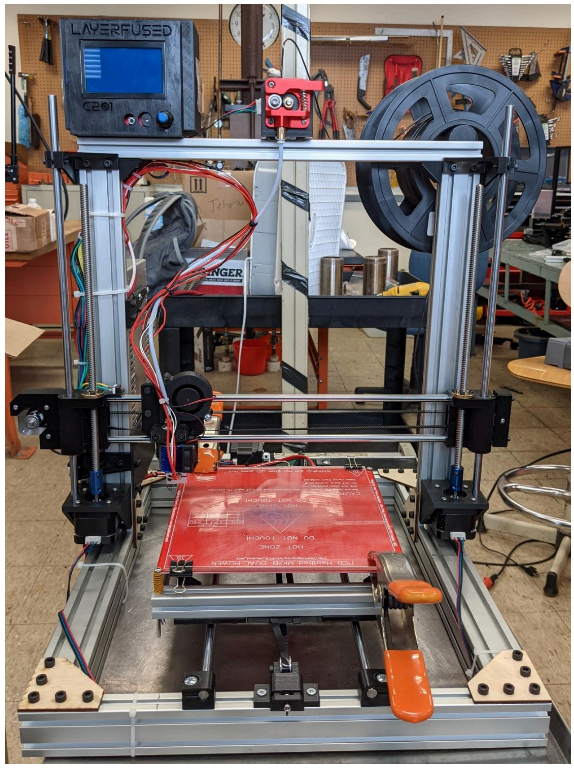

Figure 8 shows the fully assembled DIY 3D printer that has the frame, X-axis, Y-axis, Z-axis, and electronics finished. The finished printer will be used as a reference for the high school summer camp and the kinks in the system were fixed.

Figure 13: Longhorn Print on DIY Printer

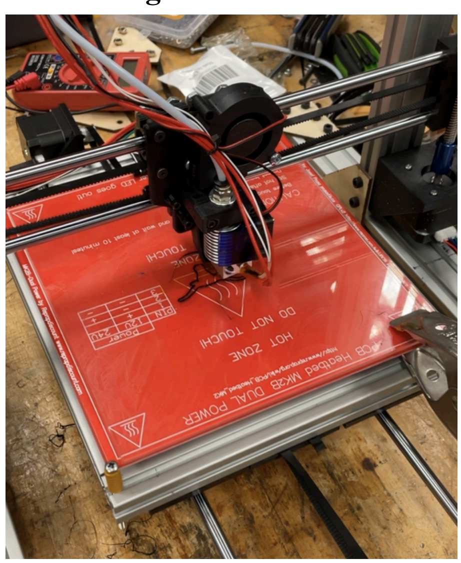

Figure 9 shows the longhorn design created on Cura that is being printed on the DIY 3D printer. This design was printed out multiple times to ensure the quality of the printer and they all printed successfully.

Conclusion

The semester-long research project has finished with a high-quality DIY printer catered towards high school students that comes with detailed instructions visuals to guide them. An instruction manual that summarized the methods and provided the correct dimensions for the store-bought and 3D printed parts will be provided for the students in the summer. While there was CADing and some high-level construction skills needed for the prototype built over the summer, the high school students will not need to have prior knowledge because the parts will be provided for them. The CADing and laser cutting were only needed for creating parts that were not provided with the initial research. Presenting the instructions for the high school students clearly with plenty of visuals provides ease of understanding and accessibility for the summer camp.

While the printer was constructed there were many different testing being done to confirm different aspects of the printer worked. The first aspect was the testing of the most dangerous components of the printer, the power supply to ensure it was safe for use and can be safely incorporated into the 3D printer as well as be used safely by students. Once the power supply worked, next came on the visuals along with the RAMPs board to ensure they were both working. Following that, once additional portions of the printer were added, such as the X, Y, and Z-axis, then tested by hand to make sure the mechanical systems worked, then it would be easier to evaluate them when they were powered. Once most of the mechanical components were set, the next was to integrate them with the electrical systems in place and sample both the motors along with the limit switches by running Auto-Home and validating that they stop at the precise position. The heating elements were our next issue as the heating bed came as a 12V bed, but it needed to power it with 24V due to the power supply, and after some modifications were able to produce something viable and tested to verify the heat cartridge on the extruder heated up to a consistent temperature by using the values coming from the thermistor cables. The last main item that needed to be tested was the extruder motor and had the most difficulty as an error caused it to not extrude filament until finding an important gear that was placed wrong. Once that was taken into account, the gear pushing on the filament solved the issue. Finally, some small issues needed to be resolved, including the tensioners and the belts where they could be used reliably as well as the springs. Then came the time to see how the whole system worked with the test of the first print following a few tests there were a few problems, one of which was the bed was not completely flat, and such made it difficult for the filament to stick to the bed that had been fixed by small adjustments to the springs. Some issues came to light when the whole build was complete. The most apparent was the problems faced when the printer thought the bed was larger than it had been and resulted in errors when running the printer. The printer was then able to perform effectively and was able to print out its first prints, which came to be a flat piece then followed by test prints of longhorns.

However, these issues were combatted by moving the main vertical extrusion frames to allow the prints to be fully centered on the print bed. The other issues can be future extensions to improve the next DIY 3D printer. Another issue is that the price is over 300 dollars, which was the allocated price for this project. This problem can be resolved since Dr. Crawford will be ordering the parts in bulk from different suppliers that will have cheaper unit costs. He needs many more parts for the summer camp since the students will be building multiple printers, so each one will be much more cost-efficient. Overall, the project was successful in creating a DIY 3D printer that can be easily replicated, with detailed instruction and pictures, by a high school summer camp.

Important Links

Github: https://github.com/guzmanster360/Marlin-2.0.x
Thingiverse: https://www.thingiverse.com/thing:5164730