Modernization of the Makerbot Replicator+

Micah Mast

Shravan Akula

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School of Sciences, Engineering, Art and Nursing

Eastern Mennonite University

Abstract

The intent of this project was to revive a MakerBot Replicator+ by replacing its proprietary control system with modern, open-source electronics. The original printer, while capable in its time, had been put out of service in part due to its discontinued parts and incompatibility with modern slicers. By installing a BTT Pi, SKR Mini E3, and open-source Klipper software, the printer was brought up to current standards while retaining its original mechanical frame and gantry system. Every part of the machine, with the exception of the frame and gantry, can now be sourced from online retailers or 3d printed. Throughout the build, several unexpected issues arose, including failures in the Pi's stock 24 V buck converter and incompatibility with the first purchased touchscreen, but these were resolved with alternative hardware. The result is a fully functional, easily maintainable printer that offers improved print quality, faster workflow, and long-term serviceability using only open-source tools and components.

Introduction

Makerbot was a brand founded in 2009[1], [2] and was crucial in pushing 3d printing forward. As time passed, their printers became closed source and they were marketed more on ease-of-use than quality. Makerbot printers were especially prevalent in the education sector from around 2015[1] to 2022 when they were bought by Ultimaker. Due to the closed source nature of Makerbot printers, simple upgrades such as modern slicers, or automatic bed leveling are not possible; thus leaving thousands of high-quality printers collecting dust. These printers simply have no chance of competing with current day printers, even low-cost models. EMU owns a Makerbot Replicator+ that is in this out-of-date condition. This main objective of this project is to replace all proprietary electronics in the printer with open-source alternatives, thereby enabling easy and inexpensive updates in the future. The second goal is to keep the two most important aspects of the original printer — ease of use and visual appeal. There are a few changes outside the scope of this project and would also detract from the intent of the project.

Changes to the movement system or physical structure of the printer are the two things that fall into this category as there would be little reason to call that an upgrade when realistically it would be building an entirely new printer. The most important two constraints in this project are both price. The first is the gross sum if all added parts were bought new. This limit is set at $249.00 because this is the price of a stock extruder replacement on the Makerbot+ [3]. The second constraint is a $150.00 limit on buying new parts. The other $99 can be taken from parts that are already here at EMU; they will be priced according to their current market value. These constraints keep the project within the $150 budget given by EMU and attempt to give a better alternative to replacing a broken stock extruder.

Requirements

The stakeholders in this project are the professors and lab manager, who would like to have an additional easy-to-use 3d printer for student projects. The users are EMU Engineering students. To support this userbase, the printer must support USB flash-drive printing and control from a touchscreen. Users typically slice models on their own computers with PrusaSlicer and save the G-code to a USB drive, and printers at EMU that cannot follow this workflow are used far less. The other requirement also comes from this same workflow and that is the slicer. The most used printers at EMU are currently the Prusa printers. One of the objectives for this project will be the creation of a slicer profile for Prusa Slicer. This will fit the workflow EMU students already have, making this project as a whole far more useful. Another design constraint comes from the original XY gantry. The linear rail on the X-axis faces downward toward the print bed, so any additional height of the new extruder compared to the original will reduce the printer's maximum build height.

Background

History

Makerbot introduced the Replicator+ in September of 2016 at a price of $2,499 [4], [5], [6], [7]. By this point in time, Makerbot had lost most of it's hobbyist consumers due to it's move to closed-source hardware and software as well as the release of printers like the Prusa MK3 which could produce higher quality prints for cheaper. Makerbot shifted it's focus to being a brand for schools, attempting to make easy to use, plug and play printers [8], [1], [9]. In 2022, Makerbot was bought by Ultimaker and currently exists as a sub-brand under Ultimaker; Makerbot is now the classroom-focused branch of Ultimaker [1], [10].

Similar Implementations

Similar implementations of this project have been done before, each taking a slightly different approach. Many projects document upgrades for the Replicator 2 and 2X, but far fewer address the Replicator 5 or Replicator+. There were two good examples taken into consideration before the project. The first was a conversion of a Replicator 5th Gen to Klipper firmware with a Bowden-style printer [11]. A Bowden-style printer is simply one where the extruder motor is mounted on the chassis and feeds filament to the hotend through a PTFE tube. This contrasts with a direct-drive extruder, where the extruder sits directly above the hotend and moves with it. While direct drive adds weight to the hotend, it also provides greater precision. This first example of a Replicator 5th Gen breaks the constraint of using a direct-drive extruder. This was also designed for the slightly older 5th generation model whereas this project is designed for a Replicator+. The second example [12] is based heavily on the first example but was adapted for a direct drive extruder and Replicator+. This project misses the objective of easy-to-use and USB drive compatible and is somewhat outdated. Inspiration was taken from both projects as well as some shared parts, such as the SKR Mini E3, but no 3D models from them were used.

Deciding on Parts

Many parts for this project were chosen based on a guide by Tommy Houghton [13] about upgrading an Ender 3 for $100. This guide was chosen as a baseline for three reasons. The first was its age: it was less than a year old when this project started, so it contained relevant information. The second reason is the cost,$100 is within the $150 spending limit. Many of the other parts for this project came from a for-parts Ender 3, so any parts he bought would be compatible with the other components used. This compatibility was the third reason for the choice.

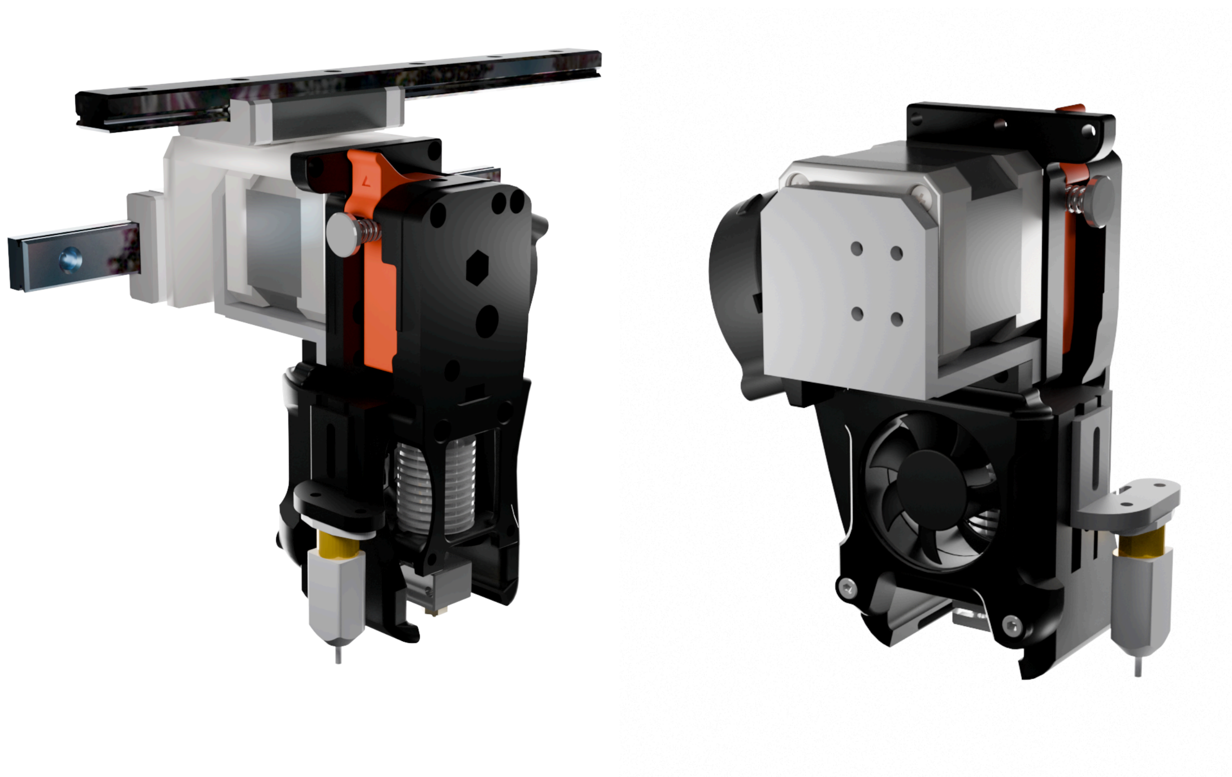

Figure 1: Renders of the new toolhead

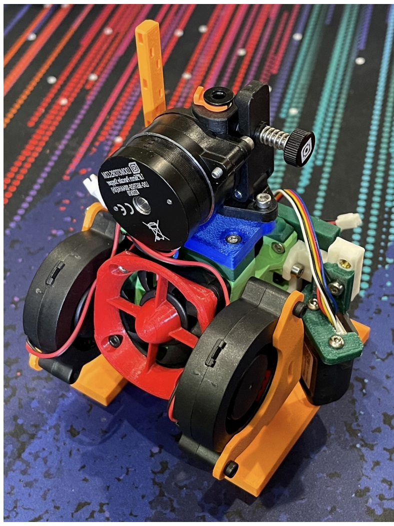

Figure 2: The Hero Me Gen 7 [14]

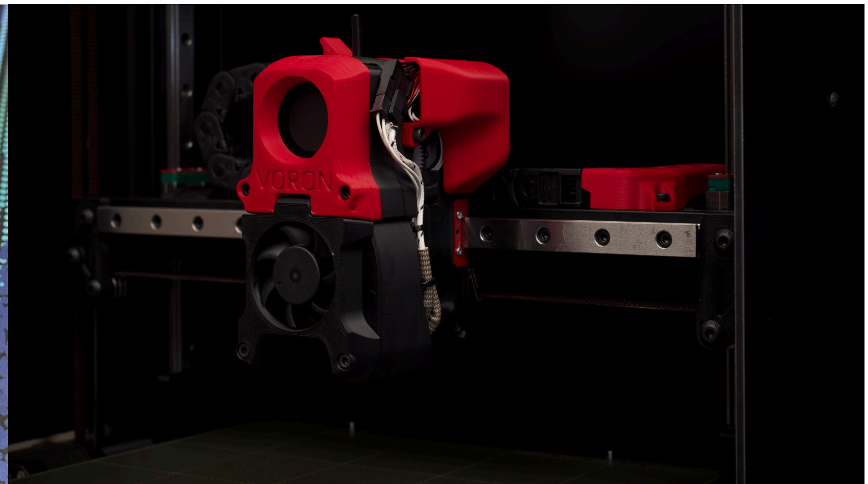

Figure 3: The original unmodified Voron Afterburner [15]

The next step was deciding what design to use as the basis for the new toolhead. Of the designs reviewed, the two that seemed most promising were the Hero Me Gen 7 [14] which can be seen in Figure 2 and the Voron Afterburner [15] which can be seen in Figure 3. The Hero Me is a very modular toolhead, but carried a lot of characteristics that were not suited for this project. It's modularity was limited by the fact that no CAD files were provided, only STLs. Since large modifications would be required regardless of modularity, the extra time required to edit mesh files was not worth modularity. This toolhead was also very wide. This means that valuble Y axis space would have been sacrificed. The Y axis on the Replicator is already shorter than most printers so this was also not a compromise that could be made. The Voron Afterburner is an older toolhead, released in 2021, but was the right choice for this project. Not only was a STEP file provided, but so was a Fusion 360 file, which is the editor that was used for this project. The Afterburner is also a visually appealing toolhead, which is one of the constraints for this project. This toolhead has a Voron clockwork extruder built in which is a quality extruder which uses only cheap, off-the-shelf gears to work. It is also much narrower and was easy to modify to make it even narrower. This was the correct choice for this project and fit well after heavy adaptations as can be seen in Figure 1. Although a small amount of Z distance was lost because of the height of this toolhead, this was a better compromise than losing room on the Y axis. The Voron Stealthburner was also considered but was ultimately passed over due to the mounting style of the Clockwork 2 extruder.

Engineering Design Process

As the project progressed, the goals shifted slightly. For every potential change in the original design plan, a short examination of requirements were performed. This was done to prevent scope-creep and determine if any changes were strictly necessary for the completion or amelioration of the project. The design process for this project started with a disassembly of the original printer to acertain what could be kept and what needed be be replaced. Due to an extensive review period before starting the project, only a few changes needed to be made during construction. The largest change was the switch to a heated bed. Although this was considered during the preparation phase, it was initially rejected due to the additional implementation time and the loss of build width caused by the larger heated bed. Partway into the project, however, it became clear that a heated bed was essential for the printer to compete with modern machines. This was determined after reviewing a journal by Spoerk et Al. [16] which shows that on a glass print bed, the force required to remove a print jumps from less than 50N at room temperature to above 600N when the bed is heated just past the glass transition point of PLA (60.6°C). Another reason to switch to a heated bed was simply because the extra area of the original bed was not usable because it wasn't heated. A heated bed allows for larger prints because curling is prevented by the high adhesion force and the first layer remaining hot for the duration of the print. Because of this, it would be impossible to guarintee that a large print would complete on the original bed. The other consideration was cost. Because the heated bed came from a free Ender 3, it did not eat into the budget and was relatively quick to install.

One scapped idea was to reuse the original Hoboken daughterboard as the display. This was quickly scrapped after a few hours of attempting to reverse-engineer the display protocol were unsuccessful. Because the screen model was decided after the start of the construction phase, it did not go through the proper vetting process to make sure it was compatible. It turns out that the original screen was 3.7″ whereas the new one is 3.5″ and the touch is incompatible with the BTT Pi. This meant that a seperate touch controller and panel had to be bought as a third revision to the user interface. Another unexpected change had to be made when the built-in 24v to 5v buck converter on the BTT Pi stopped working. It was upgraded to a seperate 3 amp unit to try and prevent any future issues.

Project Management

It was very important to keep on schedule for this project. There was a lot to get done and it was necessary to make sure there was buffer time at the end of the semester so that the punch list could be completed and the project could be a polished final product instead of just a rough draft. Below is the progression of Gantt charts over the project. Orange represents changes from the previous week. Red blocks represent cancelled slots and the colors in the tasks roughly represent the percentages done.

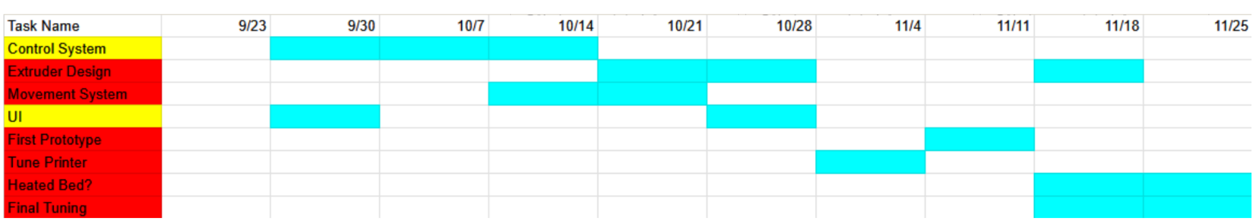

Figure 4: Gantt chart as it was on 10/14.

No major milestones were reached by October 14th. Parts had just been ordered and the most important thing during this week was designing a solid schedule.

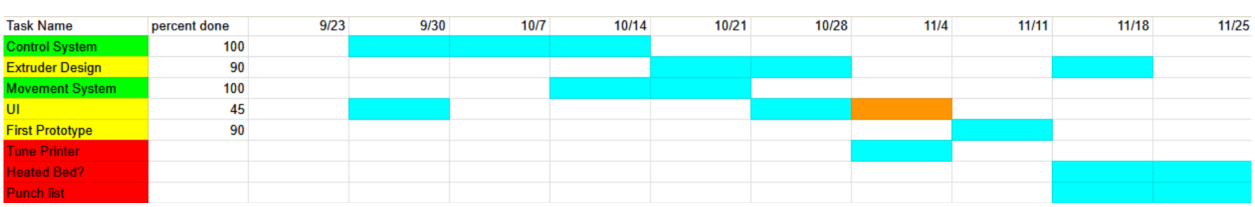

Figure 5: Gantt chart as it was on 10/28.

By October 28th, both mainboards (the BTT Pi and SKR Mini) had their respective firmwares flashed and were communicating. They were also able to move the gantry around by this point.

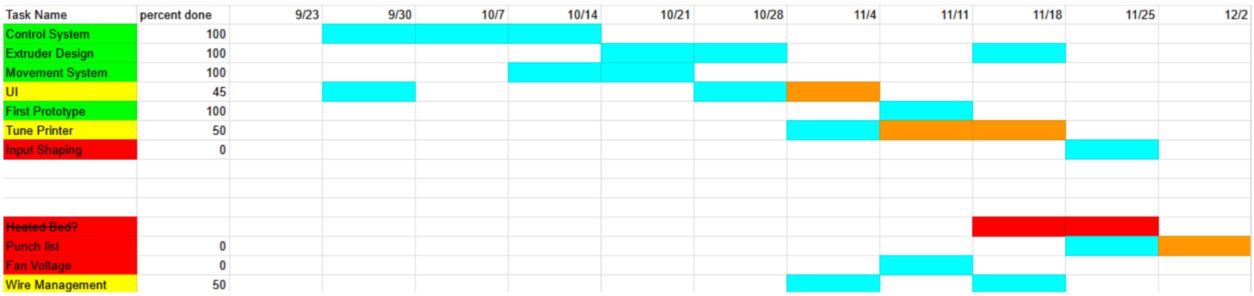

Figure 6: Gantt chart as it was on 11/11.

By November 11th the printer was extruding filament and could start a print but had not yet finished one successfully. This counted as a first prototype and the extruder design was complete. The user interface was delayed an extra week due to the non-working touchscreen and the heated bed was scrapped. A few things are expanded from earlier charts such as the punch list.

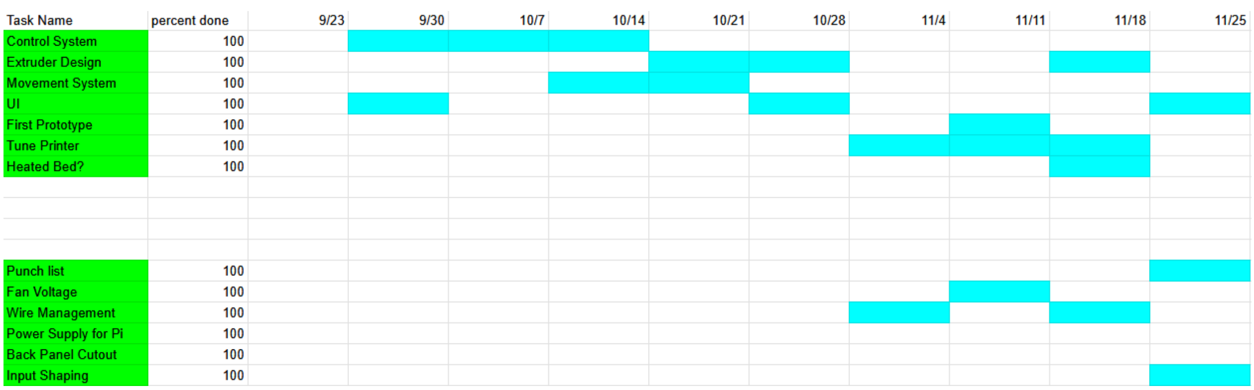

Figure 7: Gantt chart as it was on 11/25.

In the two weeks after November 11, the heated bed had been re-added as a priority and completed. The project was done at this point except for a few minor cosmetic changes such as a wire cover.

With the exception of the UI, which was delayed until the very final week of the project, everything was done in time (or very nearly in time) with the original Gantt chart. Planning time for a punch list was extremely useful and ended up being critical to the project's success. Spending a bit more time to break down the larger objectives would have helped with organization as well as progress tracking.

Engineering Analysis

An important change between the original printer and the modernized one was a change to 24v. This change provides many advantages such as faster stepper speeds and acceleration, as well as faster nozzle heating. This allowed for a larger range of parts to choose from, as many 3d printer parts are designed for 24 volt systems. Most components of the toolhead were 3d printed. PLA has a low glass-transition temperature where it begins to sag and fail. This low temperature is one of the reasons PLA is so easy to print with, but it also makes this an unusable material for the toolhead. Most parts of the toolhead were instead printed in PETG which is relatively easy to print with and works well in high-heat applications. This project also includes input shaping which is shown to be significantly better at damping resonate frequencies in mechanical systems than notch or low-pass filters [17]. This is used to reduce ringing and other artifacts that occur at fast printing speeds. An example of this can be seen in Figure 8. Klipper measures the frequency response with an accelerometer and then attempts to damp resonances with different models as can be visualized as a graph in Figure 9. This figure was generated by Klipper specifically from the resonances on the X axis of this specific printer.

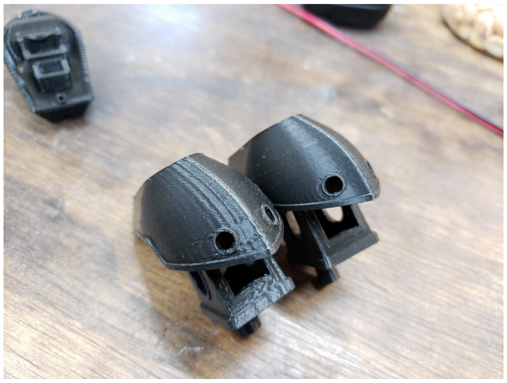

Figure 8: Difference between input shaping on the right and without on the left.

Source: https://imgur.com/cGawjnT

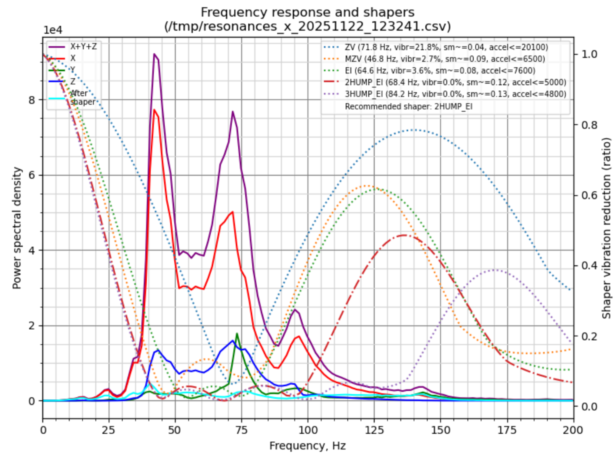

Figure 9: Input shaping when measuring vibrations on the X axis. Notice the resonate frequencies at roughly 40Hz and 75Hz and the damping on the cyan line.

FMEA Analysis

Component	BTT Pi	Hotend	Motor	Thermistor	Toolhead
Failure Mode	Failure to turn on	Does not heat	Does not spin	Incorrectly measures temperature	Crash
Effect of Failure	Inoperative	Inoperative	incorrect movements	over or under heating	Damage to toolhead
Cause	Overcurrent	damage to ceramic coil	Loose or failed wire	resistance change	Failed print
Current Controls	3A rated buck converter	none	Wires glued in place	temperature and current limits	Camera
Severity (1-10)	8	8	5	7	4
Occurence (1-10)	2	1	2	1	3
Detection (1-10)	1	1	1	2	4
RPN (S*O*D)	16	8	10	14	48
Recommended Actions	replace buck converter	replace	reset wires or replace wires	replace	reprint or replace damaged parts

The top concern from the FMEA analysis is a crash due to a failed print. There is no good way to prevent this other than watching the printer. Fortunately, there is a camera so the printer can be watched remotely. Another option would be to use something like the Spaghetti Detective

—an Ai model designed for detecting failed prints— to lower the chance of damage occurring if a print fails [18]. Failure of the BTT Pi buck converter is something that did happen during development of this project. The RPN is much lower for this now that it has been switched to a buck converter with plenty of headroom for excess amperage. This was rated at a 8, 5, 1 for SOD originally which multiplies to 40 wich is significantly worse than the 16 that it is now. Damage to the ceramic coil is also something that occurred during this project but is easily preventable by taking care when making changes to the printer hardware.

Safety, Ethics, Sustainability & Societal Impact

This printer is relatively safe. It does have pinch and heat hazards, but safety has been put as a priority as much as possible. On the electrical side of things, all wires have a gauge low enough to safely support the amount of current running through them as according to the National Electric Code (NEC) [19]. The pinch hazard and the possibility of burning oneself are hazards tied to the function of the machine. This could be improved with an enclosure, but this machine is not any less safe than any 3d printer that can be bought in a store. This project is ethical and sustainable. Reuse is an important but often forgotten piece of sustainability. This project is a prime example of how something can see a second life with a few inexpensive changes. This also illustrates the sustainability of open-source designs, since future modifications will be significantly easier to implement and therefore more likely to occur than this initial overhaul. This project doesn’t have much of a societal impact but it is an attempt to change the societal perception of outdated objects. If out-of-date paraphernalia can be seen as a project instead of trash, our world would be more sustainable.

Conclusion

The MakerBot Replicator+ was a solid printer in its day, and with a few upgrades it can once again achieve high-quality prints. The primary goal of this project was to replace the proprietary electronics with modern open-source alternatives, and that goal was achieved. All components aside from the printer’s frame can now be purchased from online retailers, and all 3D models used in the redesign can be downloaded and modified. Another goal was to maintain the ease of use of the original printer, which was accomplished through the integration of a touchscreen interface and support for USB flash-drive printing.

The goal of maintaining visual appeal was mostly met, although some components—particularly the touchscreen—and a few mismatched filament colors fall short of the standard set by the original machine. These are cosmetic issues that could be resolved with additional time. The one significant compromise was a reduction in build volume, caused by the original Replicator+‘s non-standard bed size and the limited space available for the new extruder design. This was a necessary tradeoff for achieving faster, higher-quality prints.

Future improvements should focus on wire management around the toolhead, which has several viable solutions and would meaningfully enhance reliability. An additional aesthetic improvement would be reprinting the extruder in the correct color scheme, as is shown in Figure 1.

Overall, this project represents an important first step. The printer now produces higher-quality prints at faster speeds, relies on open-source components, and is positioned for ongoing, sustainable upgrades in the years to come.

Appendix A - Design Files

All models and configuration files can be found on my github at

https://github.com/Micah-Mast/Replicator-Klipperfication

Appendix B - Bill Of Materials

Component	Part	Price	Buy
Control Board	BTT Pi V1.2	32	Y
Motor Controller	SKR Mini E3 V3	44	Y
Extruder	BMG Extruder	6.53	Y
Heating Core	Triangle Lab CHC Pro	5.53	Y
Heatsink and Heatbreak	V6 Heatsink	7.58	N
Nozzle	Came with Heatsink		N
Screen	MPI3501	10.25	Y
Touch Panel	3.7" resistive touch panel	6.68	N
BLTouch	3DTouch	10.87	Y
wires	Taken from Ender 3		N
Power supply	Creality 24v power supply	30	N
Input shaping	ADXL345	16	Y
Heated Bed	Ender 3 heated bed	24	N
HDMI adapter	Micro HDMI to HDMI Adapter	3.49	Y
5v buck converter	24 to 5v Buck Converter	7.49	Y
Touch screen adapter	Resistive Touch Screen to USB Mouse Controller - AR1100	9.95	Y
		Price using existing parts	
		146.11	
		All new parts	
		214.37	

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