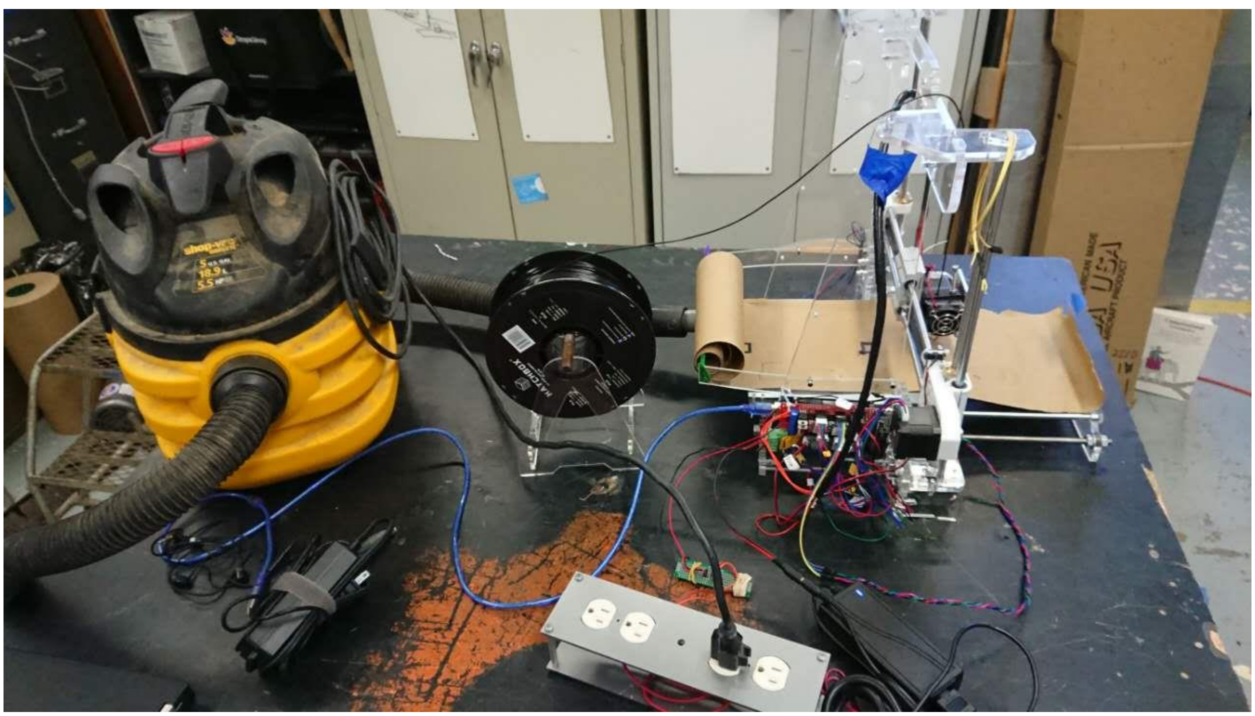
Rapid Prototyping Add-on for FDM 3D Printers

Final Report for this

Independent Study Project

by:

Michael Abadjiev
Quingyuan Chen



Abstract

The purpose of this ISP was to develop an attachment for any FDM 3D printer that would allow the printer to print continuously, without human interaction between prints. To accomplish this, a replacement bed was developed to allow the printer to reset itself after every print, keeping in mind dimensional adaptability for the wide variety of 3D printers today. In order keep the modifications minimal, the bed was designed to use output ports available on many 3D printers for a second print head. The final design is intended to be easy to replicate with a simple online tutorial.

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Background

Filament deposition model 3D printing (FDM for short) is a method of creating 3-dimensional parts by continuously depositing filament onto a build surface, thereby building the model from deposited filament. This is a relatively rapid process that allows for complex parts to be created with reasonable quality in a fraction of the time that it would take to make them using more traditional plastic modeling techniques, such as injection molding. Because of their versatility, FDM 3D printers have become increasingly popular among makers who want to have many iterations of the same part in a short time, as well as in universities, like WPI, where their low cost per part makes them ideal for engineering students working on class projects. At WPI, for instance, the robotics lab has multiple 3D printers that are available to all robotics student for use on class projects. There are also 3D printers in various other locations on campus, such as the 3 in the on-campus makerspace, the Collablab. These printers are almost always running, and are an invaluable resource on campus.

With 3D printers becoming cheaper to manufacture and new technology making it easier to attain high-quality prints, focus has been shifting to optimizing the efficiency of printing to allow more parts to be produced. One aspect of this is printer down-time; after a part prints, the printer must be serviced in order to prepare it for the next print. The primary function of this servicing is to remove the printed part and to clean the bed surface for the next part to print. During the day, this is not usually an issue, because there is someone close at hand to perform the service. At night, however, many 3D printers remain immobile for hours, with no one to reset them at 3:00 AM.

The purpose of this independent study project (ISP) is to create a system that will remove the need for printer servicing between each print.

Figure 1: Skywalker's robotic arm

Design Concepts

With the growing popularity of 3D printers, there have already been some solutions developed in attempts to make automated printing farms. For example, the skywalker project from Voodoo Manufacturing uses a robotic arm to replace the build plate of the printer after each print, as shown in Figure 1. The major benefits of this concept are that it is adaptable to a wide variety of 3D printers, and that there is no loss of print quality. On the other hand, the setup cost for such a project is very high, as it requires a large supply of build plates and printers to become cost-effective.

Figure 2: Blackbelt in action

Another example is the Blackbelt tilt axis 3D printer. This printer uses a tilting XY bed and a conveyor belt on the Z-axis to create prints of theoretically infinite length. Figure 2 shows the Blackbelt in action printing a long part. These capabilities could be harnessed to string together multiple parts, allowing for continuous 3D printing. However, this requires a specific custom-built printer, with different firmware and slicer software, making it hard to implement into an existing lab space.

As the goal for this project is to develop a system that is low cost and easily adaptable, the final design aims to modify only the print bed from a mechanical perspective, and make minor modifications to start and end G-code from a software perspective. In order to accomplish this, a vacuum bed was developed to hold a sheet of paper firmly as the print surface, and then release when it is time for a new print. The use of paper removes the need for a heated print bed, and making a vacuum bed is a relatively simple and cheap process. Additionally, the only controls needed are a switch to control the vacuum and a stepper motor control port for rolling the paper. The removal of the heated bed allows for the use of the heating terminal to control a relay that switches the vacuum on, and a second extruder motor terminal is used to roll paper onto and off of the bed.

Iterations

The printer used for this proof of concept is an Anet A8 kit printer, with the printer controller changed to a Ramps 1.4 Arduino powered controller, which allows for a second extruder. Stock Marlin firmware was used with only minor changes to the configuration file.

Mechanical

The initial vacuum bed used 3 layers made from pieces of laser cut acrylic: a top piece with holes for suction, a middle section with channels for air to flow, and a bottom cap. A high strength vacuum pump was selected to create the vacuum needed to hold the paper. This created a strong seal that held paper on the print bed very well. However, establishing the initial vacuum was quite difficult. As the paper was rolled onto the bed, it rarely laid perfectly flat. This required a high flow rate of air to establish the initial suction, which the vacuum pump was not capable of doing.

Figure 3: The vacuum adapter

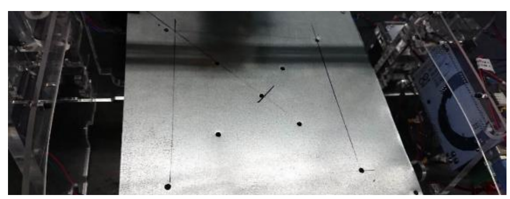

Figure 4: The new bed

The solution was to use a shop vacuum cleaner, which has a much higher flow rate than a normal vacuum pump, and can also create sufficient suction to hold the paper in place on the bed. This also required a bed redesign, as the small holes and channels in the original bed did not allow for much airflow. A new bed was manufactured with larger holes and a large chamber instead of the channels, and had sheet steel for the top surface. Figures 3 and 4 show the bed and the adaptor for the shop vacuum in this second redesign. A simple wheel was designed to roll the paper, along with a motor mount that can be seen in Figure 5.

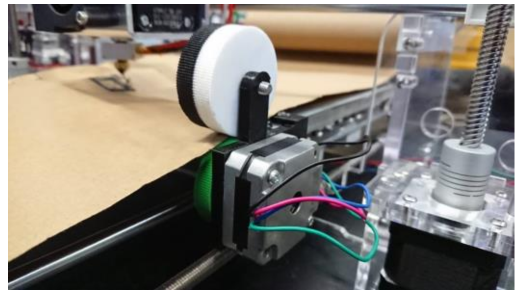

Figure 5: The vacuum adapter

Electrical

The easiest and most apparent way to control the vacuum is by using the signal that would normally be used for the heated bed to switch a relay. However, most firmware for modern 3D printers has safety considerations that disable the whole printer if the thermocouple for the heated bed is not plugged in. At first, this was circumvented with a resistor that simulated having a temperature on the thermocouple, however there are also safeguards to disable the printer if the temperature does not change for an extended period of time.

While it is possible to disable all of these features by modifying the printer firmware, it was decided that these features should be preserved for the sake of safety, especially on a printer that could run for a whole night surrounded by flammable paper without monitoring. Instead, the part cooling fan output was used. This is controlled solely by the G-code, and printer firmware does not impact its operation. The output is a simple on or off signal, making it the perfect choice for triggering a relay.

The only other output needed was the stepper control that would otherwise be used for a second extruder. This actuation can be done entirely with off the shelf parts, making it simple for anyone to do. The benefit of using a stepper motor here instead of a simple DC electric motor is that the stepper allows for precise degrees of rotation. This means that, in the future, a function could be added that rolls only enough paper to get the most recent print out of the way, thereby conserving materials and minimizing waste.

Software

While this project has significant possibility for growth and development with more advanced software, the current project focused more on proving the feasibility of this method of continuous 3D printing than making a fully useable product. As such, the only firmware modifications made were to define a new motherboard, and enable both extruders. The following lines were added to the configuration file:

```
#define MOTHERBOARD BOARD_RAMPS_14_EEF
```

Which defines the default terminal setup to have a hotend, fan, and fan2, removing the heated bed output. Then the second extruder was enabled, while still defining the printer as having a single nozzle, with the following lines:

```
#define EXTRUDERS 2
#define SINGLENOZZLE
```

This allows for the use of the second extruder motor, while tricking the printer into ignoring the need for a temperature reading from the second nozzle.

As explained earlier, the concept behind this method relies on modifications to the start and end G-code of prints to remove finished parts. The following start and end G-code were used to perform these functions:

```
;Start GCode
T0                                  ; Set to the extruder
G21                                 ;metric values
G90                                 ;absolute positioning
M82                                 ;set extruder to absolute mode
M106                                ;turn on fan/Vacuum machine
G4 S2                               ;wait 2 second for paper to be griped
G28 X0 Y0                           ;move X/Y to min endstops
G28 Z0                              ;move Z to min endstops
G1 Z15.0 F9000                      ;rise the print head a bit
G92 E0                              ;zero the extruded length
G1 F200 E3                          ;extrude 3mm of feed stock
G92 E0                              ;zero the extruded length again
G1 F9000
;Put printing message on LCD screen
M117 Printing…
;Start printing

;End GCode
G91                                 ;relative positioning
G1 E-1 F300                         ;retract filament before lifting nozzle, to release some pressure
G1 Z+2 E-5 X-20 Y-20 F9000          ;move Z up a bit and retract filament even more
M107                                ;Turn the fan/Vacuum off
M104 S0                             ;extruder heater off
G4 S5                               ;wait for 5 second for the Vacuum machine to stop
G28 X0                              ;home X
T1                                  ;Change control to roller (second extruder)
G1 E40 F500                         ;roll paper off/new section on
T0                                  ;Change control back to extruder
G4 S2
M84                                 ;steppers off
G90                                 ;absolute positioning
;End of the print
```

Future Redesign Elements

As this project served primarily as a proof of concept for the feasibility of this approach to continuous 3D printing, there are a few considerations that should be taken into account if this project is continued in the future. The primary improvement should be a new vacuum bed that holds a better seal with paper, eliminating the need for a shop vacuum that wastes a lot of electricity. One way to accomplish this might be to use some sort of seal around the perimeter of the bed that creates a better vacuum. This modification would definitely be necessary in order for this solution to be applied to a printer farm, allowing for the use of a centralized vacuum supply, instead of needing a high flow rate vacuum machine for each printer. The roller mechanism should also be improved to eliminate the possible misalignment of paper while rolling. It could also be extended to incorporate some sort of cutting device that separates the prints as the come off the printer. Another potential improvement could be a control software that automatically loads the next G-code for printing, as the current setup requires an operator to manually append two files together with the proper code in between them.