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Massive 3D Depositor Senior Capstone Design

*Design Team*

Josh Booth, Dillon LaBonte, Caleb Coldsmith

*Design Advisor Sponsor*

Joao Dias, Sankook Lee Mark Booth

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# Abstract

# Problem Definition

## Identification of Need or Opportunity

Over the past decade, 3D printing has become a popular manufacturing technique, due to its rapid per-unit production speed and low cost. However, traditional FDM printing is shied away from for heavy duty use due to the low printing temperatures (~200 °C) available on most printers, and commercial-grade, high temperature printers cost in the five figures. In this report, we outline the steps needed to build a 3D printer capable to printing large items (1’x1’x4’) at high temperatures (400 °C) while costing less than $5,000.

# Basic Research

## Existing Solutions

Below is a table of existing solutions of printer that can print PEEK [1]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| PEEK Printer Name | Build Volume (mm^3) | Max Extruder Temp (°C) | Max Bed Temp. (°C) | Max Chamber Temp. (°C) | Price |
| Intamsys Funmat HT | 1.76E+07 | 450 | 160 | 90 | 6,000 |
| Tractus3D T850P | 3.14E+07 | 450 | 175 | 80 | 15,000 |
| CreatBot PEEK-300 | 3.60E+07 | 500 | 200 | 120 | 17,000 |
| Apium P220 | 4.77E+06 | 540 | 160 | 220 | 46,000 |
| Zortrax Endureal | 3.60E+07 | 480 | 220 | 200 | 58,000 |
| Roboze One+400 Xtreme | 1.65E+07 | 500 | 150 | N/A | 50,000 |
| 3ntr Spectral 30 | 2.70E+07 | 500 | 300 | 250 | 110,000 |
| Essentium HSE 180 HT | 2.07E+08 | 550 | 100 | 200 | 149,000 |
| 3DGence Industry F340 | 2.65E+07 | 500 | 160 | 85 | 30,000 |
| MiniFactory Ultra | 1.07E+07 | 480 | 250 | 250 | 50,000 |
| Stratasys Fortus 450mc | 5.85E+07 | 450 | 250 | 350 | 160,000 |
| Aon-M2+ | 1.30E+08 | 450 | 200 | 135 | 50,000 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Averages** | 5.01E+07 | 490 | 193 | 165 | 61,000 |
| **M3DD Printer** | 1.12E+08 | 450 | 200 | 80 | 2,500 |

## Market Analysis

In 2018, the 3D printing industry was worth 1.53 billion. By 2026, it is predicted to more than double to 3.78 billion. [6] While printer software and related services make up part of that, the printers themselves accounts for half the market. 3D printing is expanding into even the largest of industries, such as medical, automotive, and oil (which is our focus). [7] As shown by the large number of companies that are trying to expand into printing high-temperature plastics, printing PEEK and similar plastics has a promising future since it overcomes a lot of the strength and temperature shortcomings of lower-temperature plastics.

# Design Requirements

Functional Requirements

* System should respond to movement commands in the X,Y, Z, and Extruder directions
* System should be able to heat nozzle up to 450 °C, bed up to 200 °C, and chamber up to 80 °C
* System should be able to print all common filament types (PLA, ABS, PETG) with and without the heated chamber
* System should be able to print PEEK and PSU objects
* System should have a total usable print volume of 300x280x1330mm
* System should be able to operate at the maximum chamber temperature for at least 3 days continuously without overheating or having part failure

Usability Requirements

* System should be able to operate on a local 20A breaker without the heated chamber and with the heated chamber on three separate 20A circuits
* System will have thermal protection for the hotend, heated bed, and chamber
* System will have fused connections in the event of a short circuit

User experience requirements

* User can monitor and control the temperature and movement of the system locally through the LCD
* Through a web interface, the user can:
  + Control nozzle, bed, and chamber temperature
  + Control X, Y, Z, and E movement
  + Send commands
  + Start, Stop, and monitor prints
  + View print through real-time system

# Initial Concept Generation

## Frame

For a frame, aluminum extrusions are the de-factor standard for 3D printing frames due to their structural rigidity, low cost, and high functionality. We chose aluminum frames for the movement system an any structural pieces needed in a traditional FDM 3D printer. For the chamber frame, we chose to use a server rack. We found an server rack out-competed aluminum extrusions considering the overall size and mounting ease. This is a piece that would be trivial to replace given the required critical dimensions if another unit needed to be manufactured. The server rack will have insulation mounted to the outside of it and will provide a structural foundation for mounting our aluminum extrusion-based movement system.

## Movement System

To move the hotend around the build volume, we are using a cartesian movement system with a pulley/belt combination for the X and Y directions. The X and Y axes were easy to design and build as they fall within the typical size, so we were able to look at comparable products. However, the Z-axis requires a lot of engineering due to its unorthodox size. For most cartesian printers, using a lead screw is the best options since it is sturdy and cost-effective. A 5’ lead screw, like we need, will bend in the middle no matter how perfectly the screw is made. This will require a lot of fine-tuning of our lead screw mounting. This is the only movement system that will work for our application. A coreXY printer would require an assembly the size of the bed volume to move through the entire print volume. This drastically increases complexity and would leave no room for auxiliary components like the heating elements. A delta printer would work in theory, but we will lose a lot of our build volume because of the circular build platform. However, we want to use the Z-movement system for the delta of belts, as it would eliminate our bent lead screw. We would add a counterweight to reduce the amount of power needed to move the X-carriage and to stop the X-carriage from dropping in a power-loss event. We also plan to add off-closed switches to the top and bottom to catch the X-carriage to prevent it from bottoming or topping out.

## Computing

For the intelligence of our printer, we chose an SKR 2 Turbo due to its high ability to be customized along with TMC2099 stepper motors. They can drive 2A, which is the max capable for our SKR 2. The SKR 2 allows us to connect to OctoPrint to monitor prints through a web interface and connect an LCD for locally control and monitoring, per our design requirements. We plan on running Marlin firmware since it is open-source, high customizable, and supports thermal protection. We are also going to host OctoPrint on a RaspberryPi running OctoPi, with custom software to run our chamber thermal protection, since Marlin’s chamber thermal protection may not cover our complex-use scenarios, such as someone opening the chamber during a print. This will cause a drop in the chamber temperature, which Marlin would register as an error and stop the print, but the act of opening the chamber itself isn’t cause for triggering the thermal protection.

## Heating System

While we are still in the early development stages, we plan to use space heaters to heat our chamber, but plan to use lights as a backup in case our space heaters can’t get the temperature hot enough. The nozzle and bed heating elements by themselves will raise the internal temperature of the printer above ambient, but that combined with space heater elements should easily bring our chamber up to the needed temperature. The main question of our heating system is what heating element to get. We want one that both provides an adequate temperature and is safe. Household space heaters only get up to between 120°C-200 °C for safety reasons, which would be our ideal temperature. However, we have concerns about their construction and need to make sure they can fill get the chamber temperature that high instead of just the heater elements. However, our preliminary tests should that they should meet to temperature requirements, so we just need to make sure they are safely constructed.

## Thermal Management

While we want our chamber to be hot, certain components should not get hot, such as the stepper motors. To cool our stepper motors, we are mounting the possible ones, such as our Z and Y motors outside of the build chamber and only have the shaft inside the chamber. This would allow us to keep those stepper motors at the ambient temperature. The X and the E motors can’t be located outside the heated chamber, so we decided to use Peltier Plates to cool the motors. The cold side would be on the motor, and the hot side would be attached to a heatsink and fan to reduce the temperature. Additionally, the temperature of the camera that monitors the print should be thermally managed. It doesn’t get anywhere near as hot as the motors, but to reduce the temperature, we surrounded the camera is aluminum tape to minimize the heated air on the camera.

# Preliminary Analysis

## Initial Power Analysis

We plan on splitting up the power up onto 3 circuits to satisfy the design requirements. We are having 2 AC circuits for our chamber heating elements, and then a 3rd AC circuit for all other components. The heating elements of the space heaters we are planning on using are 1500W each. At 120V, this yields per space heater. We are assuming to use 2 space heaters, although we won’t be able to know for sure until we complete full thermal analysis.

For the DC components, we need to pick an adequate power supply. Below is a table of the power draw requirement estimates for each component. For the voltage conversions, we are assuming a conversion efficiency of 90% for our buck converters. [8] These currents are also over-estimates assuming max-load on each component. We won’t be able to test each unit for the actual power draw (such as the raspberry pi and SKR board until we can power them up). We are only able to off manufacturer specifications and tests done by 3rd parties.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Part | Voltage/unit | Amperage/unit (with conversion efficiency included) | Quantity | Total Amperage Used |
| Name 17 2A motor | 24 | 2 | 3 | 4 |
| Nema 17 motor (high power) | 24 | 0.58 | 2 | 1.74 |
| SKR Board | 24 | 0.5 | 1 | 0.4 |
| Heater Cartidge | 24 | 2.08 [4] | 1 | 2.08 |
| Space heater fans | 12 | 0.33 | 2 | 0.726 |
| RPi | 5 | 0.4 [5] | 1 | 0.55 |
| LED Strip | 5 | 0.06 [2] | 5 | 0.33 |
| Peltier Plates (@ 5V) | 5 | 1.5 [3] | 2 | 3.3 |
| Bed heater element (AC power) | AC | 4.1 | 1 | 4.1 |
|  |  |  | **Summation:** | 17.226 A |

We are using 17.226A for the primary AC connection. We need 14.1A for our power supply since the heated bed doesn’t contribute to the load on the power supply. The power supply we chose was a Meanswell 24V/21A power supply. This gives us wiggle-room, so we aren’t always stressing our power supply. The price difference between a 24V/15A and 24V/21A power supply was negligible.

## Initial Movement Analysis

## Initial Thermal Analysis

# Schedule

|  |  |  |
| --- | --- | --- |
| Week | Date | Timeline |
| Week 1 | 01/18 – 01/21 | Capstone introduction |
| Week 2 | 01/24 – 01/28 | Project selection |
| Week 3 | 01/31 – 02/04 | Part selection for movement system  CAD all parts for movement system for future analysis  Setup project requirements  Initial budget |
| Week 4 | 02/07 – 02/11 | Continue CADIng all parts for the movement system  Design case for mounting electronics  Determine a Z-axis mechanism for movement |
| Week 5 | 02/14 – 02/18 | Design Y tensioning mechanism  Install movement system into frame  Preliminary report/presentation |
| Week 6 | 02/21 – 02/25 | Make movement system work  Install electronics/ run wiring |
| Week 7 | 02/28 – 03/04 | Debug movement system  Design/replace parts that need it |
| Week 8 | 03/07 – 03/11 | Calibrate printer w/o heated chamber  Start thermal analysis |
| Week 9 | 03/14 – 03/18 | Determine thermal materials and order it  Critical design report/presentation |
| Week 10 | 03/21 – 03/25 | Install thermal materials and get printer up to temperature |
| Week 11 | 03/28 – 04/01 | Run test prints at max temperatures |
| Week 12 | 04/04 – 04/08 | Debug thermal/electrical issues |
| Week 13 | 04/11 – 04/15 | Debug thermal/electrical issues  Create final report |
| Week 14 | 04/18 – 04/22 | Work on final report and presentation |
| Week 15 | 04/25 – 04/29 | Finish final report/presentation and dry run presentation |

# Preliminary Budget

|  |  |  |
| --- | --- | --- |
| Name | Cost | Quantity |
| SKR 2 | 49.99 | 1 |
| Rpi | 34.99 | 1 |
| Buck Converter | 9.99 | 1 |
| LCD | 16.95 | 1 |
| SSR | 10.49 | 3 |
| Fuses | 8.47 | 1 |
| Power Supply | 35.99 | 1 |
| Aluminum Extrusions | 23.25 | 2 |
| High power motor | 13.99 | 2 |
| Low power motor | 10.99 | 2 |
| Extruder | 12.99 | 1 |
| Peltier Plates + heatsinks | 31.35 |  |
| 24V fans | 11.99 | 1 |
| pi camera + 6ft cable | 15.04 |  |
| End stops | 9.99 | 2 |
| Mosquito hotend | 149.99 | 1 |
| mosquito thermistor | 69.99 | 1 |
| heater cartridge | 15.99 | 1 |
| led strip | 11.92 | 1 |
| Garolite | 15.95 | 2 |
| Heated bed | 159.99 | 1 |
| wires | 20 | 2 |
| Lead screws | 55 | 2 |
| anti-backlash nuts | 10.98 | 1 |
| Insulation | 100 | 1 |
| Kaolin cloth | 20 | 1 |
| High temp belt | 11.99 | 1 |
| high temp wheels | 21.99 | 1 |
| breaker | 9.99 | 1 |
| outlets | 9.99 | 1 |
| switches | 9.99 | 1 |
| sheet metal | 30 | 1 |
| frame | 0 | 1 |
| bowden setup | 19.99 | 1 |
| printed parts (estimate) | 100 | 1 |
| wifi adapter | 10.55 | 1 |
| bltouch | 40.26 | 1 |
| capacitors | 11.65 | 1 |
| **Total:** | **1626.43** |  |
| **30% price increase** | **2114.359** |  |

# Conclusions and Next Steps

The next steps are the continue following our schedule. In the coming weeks, we will build our movement system and verify functionality as a 3D printer without a heated chamber. We hope to have this done before the critical design report is due. After that, we will be able to perform full thermal analysis after we have determined our movement systems and begin designing our heated chamber. Of course, when building our movement system, we are selecting components that can withstand ambient temperatures of 80 °C. At the time of writing, we are perfecting the design of our Z-movement system, overcoming the obstacles of a very tall build volume.

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