

Sean Ding

Mr. Speice

ISM I

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Final Product Setup and Summary

Research:

Much of the research I had done for my final product came from various sources which all revolved around the central idea of the Prusa printer. Since the Prusa design is the most common 3D printer design out on the market today, I felt that it would be easier to obtain and assemble a printer based on this design. The majority of my research came from YouTube channels focused on 3D printing with one primarily being that of Thomas Sanladerer which provided not only helpful tips for building 3D printers, but also the calibration phase which would be helpful for achieving the high quality prints which I hoped to have as an end result. From both his YouTube channel and website I was able to learn a fair bit of knowledge about 3D printing processes and the types of issues I might run into while constructing my printer. The rest of my research for this product came from the guidance of my mentor Dr. Choi as well as his student Mr. Jin who provided helpful examples and tips for building my printer.



Source: toms3d.org

Materials:

The most difficult part of this entire final product process was actually the acquiring of materials for building my printer. First, I had to actually devise the parts list for the printer which involved tediously hunting down what parts were actually needed to be purchased and which ones had to be printed on a pre-assembled 3D printer. For the most part, I was able to create the parts list using Prusa's build guide on their website which had nearly every part neatly cataloged which made it exceptionally easy to transfer into the parts list. However, I did have to modify several of the parts required such as the frame which I decided on cutting out of MDF (medium-density fiberboard) as it was readily available as well as easy to cut with a jigsaw. Many of the parts I had to order were actually fasteners such as nuts and bolts which I managed to order from Bolt Depot while the other electronics parts involved I had to order from



Source: boltdepot.com



Source: aliexpress.com

Aliexpress, an offshoot from the Chinese website Alibaba. For this project I ended up having a list of about 50 parts which I had to order all from different sellers on the website. However, in the end I still managed to acquire all the parts for cost at

a comfortable \$170 which was still much cheaper than most 3D printer DIY kits which can be found on eBay and Aliexpress. In the past I had also actually built a printer from a kit before which allowed me to have few but at least some parts for this project in case parts didn't arrive in time due to inconsistently long shipping times from China. Other materials I had used for this project included a soldering iron, a couple of wrenches, a set of screwdrivers, hot glue gun, and

pliers which I all had on hand already. For the 3D printed parts, I managed to get these printed on my home 3D printer which I had purchased a few years back while some other fasteners I was actually able to purchase locally from Grainger which was much more convenient than waiting 2+ weeks for shipping.



Source: grainger.com

Objective:

My primary objective for my final product was to successfully design and create a 3D printer from scratch using readily available and accessible parts which could be purchased from online as a way to show the ease and accessibility that 3D printing has today. Originally I had planned on focusing on improvements I could make with the printer in order to improve quality, but as the product creation progressed, I began to realize that the quality was actually quite better than previously expected and did not require many improvements other than a simple spool holder which I designed, prototyped, and installed onto the printer. I found that simple calibration was actually able to make quite the difference in quality rather than new printed parts.



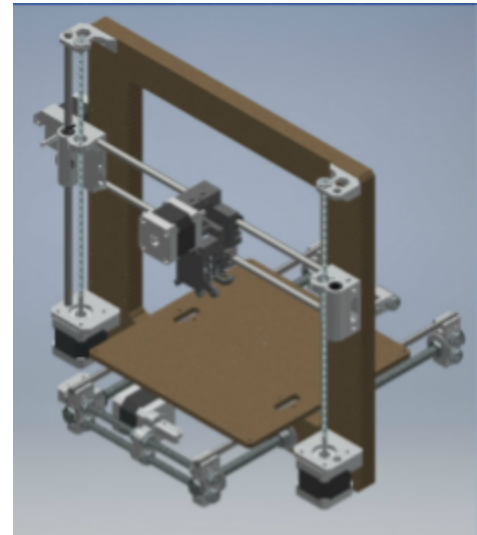
Spool Holder

Description of Process:

During my initial planning stages of my final product I wanted to find a way which could show how accessible 3D printing has come in the past few years while also somewhat extending the research I had done whilst working on my original work. Being that I had previous experience actually working with both pre-built as well as DIY-built 3D printers, I wanted to see how difficult it would actually be to source and build a 3D printer completely from scratch. Initially I was worried that it would be quite difficult to create the printer as I had encountered many pitfalls and setbacks when originally building a 3D printer from a kit in the past. I hoped that by building the printer from scratch, I could show possible applications of a low-cost budget-friendly printer such as this. Over the course of several weeks I then consulted with my mentor about my 3D printer idea and received some helpful feedback on design suggestions. Since I wanted to make sure my printer would be able to make high quality prints, Dr. Choi recommended that I possibly use a material other than wood for the frame as it would be sturdier and ensure that all my mounted parts would be level on the frame to eliminate possible factors for poor quality. However, in the end I still settled on wood for the frame as I found that other materials were much more expensive and would add both cost as well as time to my product creation. I found that the wooden frame was also used by many other DIYers on the internet who had also built their printers using wood. Overall this wooden frame still allowed for the printer to have adequate sturdiness and still managed to result in decent prints from the printer.

After this brainstorming phase of the printer, it was onto the design phase. For this project I chose to use Autodesk Inventor rather than Solidworks as I found that the performance with Inventor was generally smoother which would be especially important for an assembly with a large number of parts such as this one. I chose to model my printer off the Prusa i3 design as it

was both popular as well as familiar as the commercial printer which I own at home is actually based on this design. However, during this design phase I ran into several issues involving the constraint features of Inventor which I found to be quite buggy. Several times a part wouldn't constraint properly leading to periods of frustration and switching between programs, but in the end, I still settled on Inventor for the CAD model. Throughout the design phase, I had to tediously look back and forth between the parts list I had so painstakingly created as I had mentioned before to model each of the parts required for building the printer.



CAD model of printer

These included having to find models for the stepper motors, pulleys, threaded rod, nuts, bolts, and printed parts which were all part of the printer. For the frame and bed pieces which I would be fabricating myself out of MDF board, I had to design and create the parts in Inventor myself.

After both creating the parts list as well as the CAD model, it was time to move on to actually ordering all the parts from China and having to impatiently wait for the extensive overseas shipping time. During this long wait period, I focused on cutting my printer frame out of the MDF board as I had mentioned earlier which I managed to do with a jigsaw. During this time I also printed out all of the parts which needed to

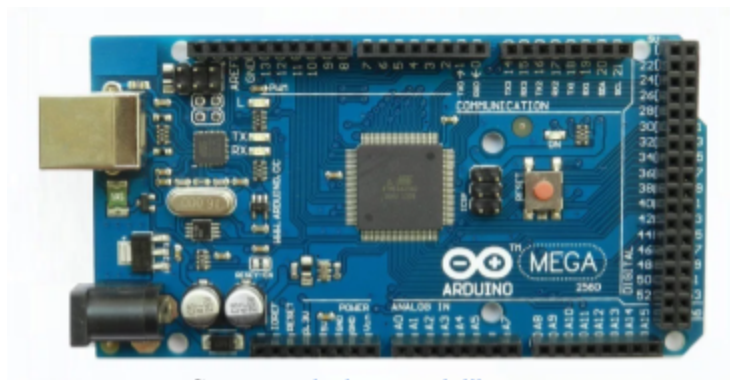


White parts: PLA - Black parts: ABS

be printed for assembly which were obtained from the Prusa website. The majority of the parts were printed in white PLA I had on hand while the hot-end parts were printed in ABS as these parts would be exposed to hotter temperatures which ABS could endure while the PLA could not. For the rest of this time, slowly but surely, parts started trickling in one after the other for my printer. After a grueling total of 3-4 weeks had passed, nearly all my parts had arrived and it was time to start building my printer.

First I had to assemble the frame itself which was comprised of several 3D printed parts, the MDF frame, 8mm threaded rod, and 8mm smooth rod as well as a handful of M8 nuts. During this phase I was extra careful as to make sure my frame was square as this was a crucial component of the entire printer. I was able to accomplish this with the help of a triangle square which ensured I had 90 degree angles at each of the 4 corners. Once this frame was assembled, it was on to installing the bed for the printer. The bed base was cut out of MDF board as well, but a much thinner one - $\frac{1}{8}$ in - instead of the $\frac{3}{4}$ in used on the frame. This piece had slots cut out for the bearings to slot into with zip ties which would allow for free movement of the bed when printing. At first I was skeptical about the zipties, but in the end they worked much better than expected when properly tightened. After installing the bed frame, I moved onto installing the heated bed which was essentially just a large resistor. I installed this using several nuts, washers, and bolts, which fixed the heated bed circuit board to the MDF bed. During the assembly process of the printer I also had to install all of the printed parts, control boards, endstops, stepper motors, belts, pulleys, and threaded rod. Once the physical assembly of everything was complete, it was onto the hardest phase of all: the wiring.

During this wiring phase, I had to route wires from the 12V power supply to the control board which then had wires which needed to be routed to each of the stepper motors and end stops. The control board itself was comprised of an Arduino Mega 2560 clone with a RAMPs (RepRap Arduino Mega Pololu Shield) board on top. The most difficult section of the wiring was actually the wiring



Source: articulo.mercadolibre.com.mx

directly into the power supply which actually would hold mains voltage at 20A. In order to ensure safe operation of the printer, I utilized crimp connectors and ring terminals to ensure the wires would never fall out while also using a switch and AC plug at the back as well as a custom-designed power supply cover to protect the terminals themselves from any possible human contact. Once the wiring was complete, it was finally time to install the firmware for the printer.

The firmware of the printer itself was actually Marlin open-source firmware which is used both by Prusa themselves as well as much of the 3D printer hobby community. This section was rather annoying and repetitive as I can recall the numerous times I had to go back and reflash the firmware every time the printer ran into an issue which could be fixed by settings in the firmware. One of these settings being the auto bed-leveling feature of the printer which for me kept malfunctioning. During this firmware testing phase I consulted Dr. Choi and his student



Source: marlinfw.org

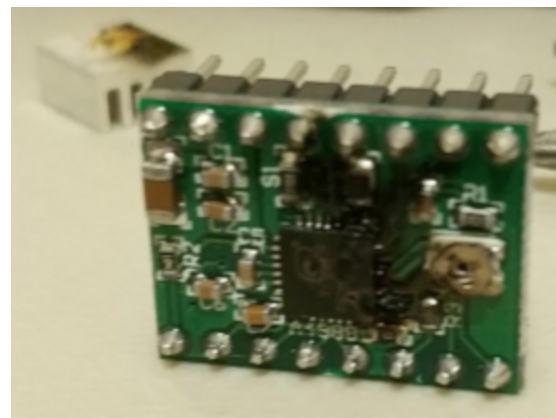
Mr. Jin for help on the subject. On a mentor visit we were able to successfully fix this issue with the

leveling and actually fix a separate issue involving the improper homing location of the print head which led to the nozzle and sensor “zeroing” off of the bed which prevented the printer from properly printing. During the visit we discussed adding 3D printed shims to the carriage in order to offset the endstop for proper homing position. After the visit, I fashioned out some shims using popsicle sticks and hot glue which actually ended up working out perfectly.

After these long and tedious stages of testing and prototyping, the printer was finally complete. I loaded up my control software for the printer (Pronterface) and attempted to do some test prints such as a calibration cube, but each time I tried the printer kept over-extruding. After more periods of frustration, I finally realized that extrusion was the issue and went to work recalibrating my ESTEPS in my firmware which quickly solved the problem. Once I tried printing the cube again, it worked perfectly, resulting in a finished print. However, when I tried getting more ambitious with larger prints, I found that the slight tilt of the heated bed led to improper and uneven bed leveling which led to some poor bed adhesion of the first layer of plastic which ultimately led to failed prints. Realizing this, I fixed the problem by clipping on a glass bed which I had salvaged from an 8x8 picture frame which coincidentally fit perfectly. The glass, being much more straight and harder to deform than the aluminum heated bed when heated allowed for much smoother prints as well as a mirror finish on the underside. However, since the sensor I was using for the hotend for leveling was inductive, I had to affix pieces of aluminum foil tape in order to still use the sensor functionality. After more calibration with printer speeds and flow rate, the printer was making consistent prints one after the other.

Utilization of Higher-Level Thinking Skills:

Throughout the development stages of my printer as my final product, I was able to successfully apply the research and knowledge I had learned from my articles as well as the knowledge I had gained from my mentor. Several times throughout the building process, I had to reevaluate my situation in order to both adapt and improvise when something went awry as it did when I accidentally burned out a stepper driver. I had to not only make sure the board was still intact, but also ensure that a replacement part would arrive in time. During my product development I also felt that the knowledge gained from my mentor visits was quite helpful and really allowed me to complete my product. In addition, I was able to apply the information I had learned from the many YouTube videos and various 3D printing articles I had watched and read which ultimately helped me to ensure success in my build. In addition, I was able to apply the prior knowledge I had with building a 3D printer from a kit to building a 3D printer from scratch as much of the wiring and assembly was similar, with both printers even sharing the hotend which I had to swap due to a faulty heater cartridge.



Burned out stepper driver

However, some of the information I had researched previously for my original work did not apply well here as much of the research about 3D printing was primarily about printing parts rather than actually creating the printer. For the most part I found that YouTube videos, Prusa's website, and forums were the most useful for building my printer. While my assessments did provide some foundation for the testing phase, they ultimately did not help as much as they did

on my original work. Mentor visits during this product development were, in fact, very helpful and allowed me to get real time feedback and help on my product which allowed me to fix many of the problems faster than I could on my own.

Results:

In the end, the 75+ hours I put into my product finally paid off: my self-designed and self-built printer was able to successfully print not only simple parts, but also complex structures such as a NASA-designed chainmail which prints in one solid piece which is flexible once removed from the print bed. The printer ended up actually surprising me with the high quality of prints that I was able to achieve. While I did run into several setbacks throughout the design and testing phase such as difficulty cutting the MDF wood and having to replace a circuit board which burned out due to a user mishap, in the end I was able to persevere and finally complete my product. Other setbacks I had run into throughout the product creation process included the issues with the firmware, faulty cables, running out of parts, and having to sand parts of the frame in order to facilitate smoother operation of the printer. The printer itself ended up actually

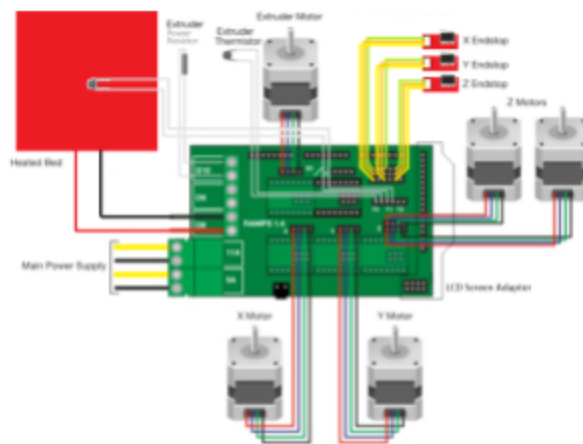
performing better than my commercially built Wanhao Duplicator i3 printer I had owned for several years now. The printer was not only able to do complex prints but also very detailed prints when compared to my old printer. Now in most



cases this would not be a fair comparison since the age of the other printer is also a factor, but for the most part, the self-built printer was working much better than expected. At first I was skeptical about my printer even functioning, but as I kept calibrating, testing, modifying, and improving the printer, I was able to achieve consistently better prints than before. In the end my printer also ended up costing much less than most 3D printers available on the market today such as the Anet A8 which is almost the cheapest printer with a price of about \$180-\$200 which was still higher than my \$170 printer and has reports of having poor print quality without many upgrades.

Conclusions/Interpretations/Applications:

Overall, I was quite surprised through the process of creating my final product that I was actually able to successfully design and build a functional 3D printer from scratch. Granted, I did have significant inspiration from the Prusa lineup of 3D printers, but I was still surprised that I was able to source all the parts needed from the internet and local stores rather rather easily than I had expected. From this product development I was also able to learn more about rapid prototyping designs, wirings, debugging, and testing a product from start to finish. From this experience of building my printer, I have learned so much more about the world of 3D printing while also having more of an interest in applying my research to outside the engineering realm to possibly classrooms where my mentor had



Source: www.nova-labs.org

mentioned the printing of chemistry models such as molecule representations as a teaching tool as well as the use of 3D printing in classrooms for prototyping.

In addition, the development of my product also allowed me to grow in my knowledge of engineering as a whole as I learned about manufacturing and electrical systems while also learning more about 3D printing. I also managed to learn more about how I could solve problems when they arose such as all those times I ran into setbacks throughout the development process. I felt that I was successfully able to expand upon the ideas about 3D printing I had expressed in my Original Work while also further developing a passion for a career in this field. As my ISM 1 journey slowly comes to a close, I hope that I can carry over the knowledge about engineering I have learned from not only my ISM class this year, but also from my engineering teachers and my mentor to my ISM 2 research next year.