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Mr. Speice

ISM I

26 January 2018

Original Work Assessment

Research:

For the majority of the research I did on my original work, the information came from 3DHubs, an informational website with a focus on 3D printing as well as a 3D printing and CNC service which had several articles about the design stages of 3D printing and CNC machining as well as the manufacturing and cost evaluation of each process. The rest of the research came from the various articles I had annotated and had typed research assessments for which analyzed the accuracy of CAM-path generation for CNC machining, the costs associated with each process, the accuracy of 3D printed parts, and the application of parts created with each method. Such applications included the rapid-prototyping capabilities of 3D printing which I featured in my original work.

Source: 3dhubs.com

Materials:

For my original work I had to enlist the use of digital calipers, CAD software; more specifically Dassault Systemes Solidworks, a 3D printer, and a CNC machine. I also had to use a slicing software for the 3D printing process called Simplify3D and CAM software (Autodesk Fusion 360) for Solidworks. I used my home 3D printer to create some of the FDM (a type of 3D printing called fused-deposition modeling) parts while I used the assistance of my brother at his university for the CNC machine and industrial-grade 3D printer for the rest of the FDM-created parts. With the 3D printed parts I used PLA (polylactic-acid) filament as that is one of the most prominent filaments used in the 3D printing industry while also maintaining a good balance between cost and strength properties. For the parts milled on the CNC machine, I chose to use aluminum for the stationary parts as it is a popular choice in CNC machining while also choosing to use nylon for the mechanical parts which included the gears as they allowed for less friction and smoother motion during operation of the grabber.

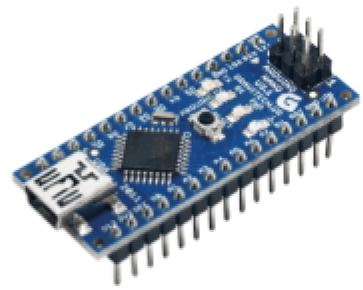
Picture of CNC machine at GA Tech

Objective:

My primary objective for my original work was to design and create identical parts using both CNC machining as well as 3D printing and compare their mechanical properties, cost, appearance, and accessibility. Over time, my objective would change slightly as I decided to focus on creating a physical product which would showcase each of these aspects which in the end was a grabber arm with both 3D printed and CNC machined parts.

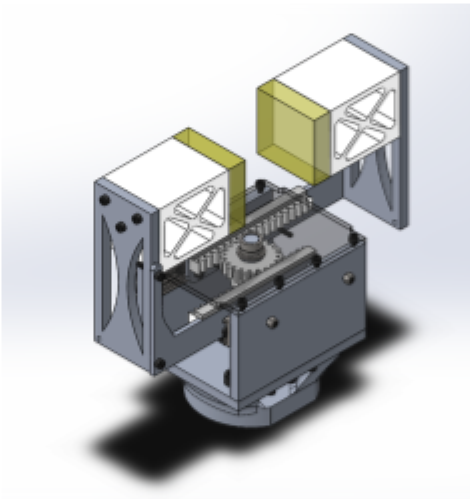
Description of Process:

When I was first planning my original work, I chose to design my parts to test machine limitations such as overhangs or holes in parts made with both CNC machines and 3D printers. While a CNC machine uses a subtractive method to cut away at material such as metal, a 3D printer uses an additive process of layering plastic to create a finished part. During the design process I brainstormed multiple ideas about what to actually create, often keeping in mind the idea of using gears or some sort of mechanical interaction between parts which would showcase machine accuracy and tolerances while also presenting functional application for parts. In the end, I decided to settle on a relatively simple but still quite complex design for a grabber arm featuring a servo motor as well as an Arduino nano for controlling the servo itself once a signal is applied. I chose to include an Arduino because of the growing integration between mechanical engineering, machines, computer science, and computers as well as its cheap cost but powerful potential for controlling devices such as servos. For the actual designing of the parts, I chose to use Dassault Systemes Solidworks as this software is used much more in engineering applications than other software such as Autodesk Inventor are used. I also chose to use this software as I had obtained a student license for use while also allowing me to explore the more powerful features in Solidworks than Autodesk software.



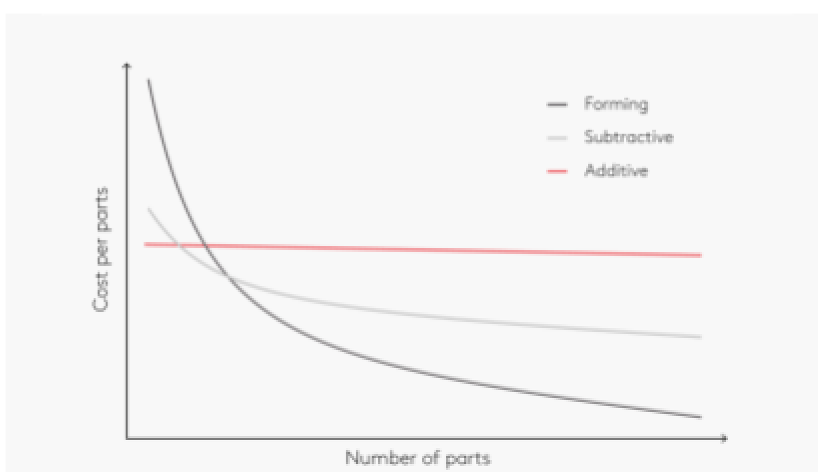
Source: Arduino.cc

The design itself of the parts was also quite simple and tried to save on material cost in various places such as making the brackets as minimalistic as possible while still being able to provide enough strength to grab objects. Such areas included the semi-hollow shape of the mounting bracket for the foam grabbers as well as the simple boxy shape of the housing itself which made it easier to manufacture with printing and CNC machining. The seemingly strange pattern on the bottom of the grabber itself is meant as a mounting plate for various robotic arms such as those made by Universal Robots' UR5 arm. For ease of manufacturing, I also had to consider sizes of screw holes which would be able to be manufactured on both 3D printers and CNC machines alike, eventually deciding to use M4 bolts as they were both cost effective as well as standardized on both types of processes. I also had to consider the orientation of the parts when I had to slice them in the Simplify3D slicing utility to make sure I had minimal amounts of support material and overhangs. For most of this, I simply rotated each part until it was flat on a face or in the most logical orientation for printing.



Grabber CAD Model in Solidworks

To create the 3D printed parts and CNC machined parts I looked online for places with which I could order parts, but later realized that fees for using each service could skew the cost of each process and cause inaccuracies with my research. To create the 3D printed parts, I had some made right on my home 3D printer with the rest of the 3D printed and CNC parts being made at my

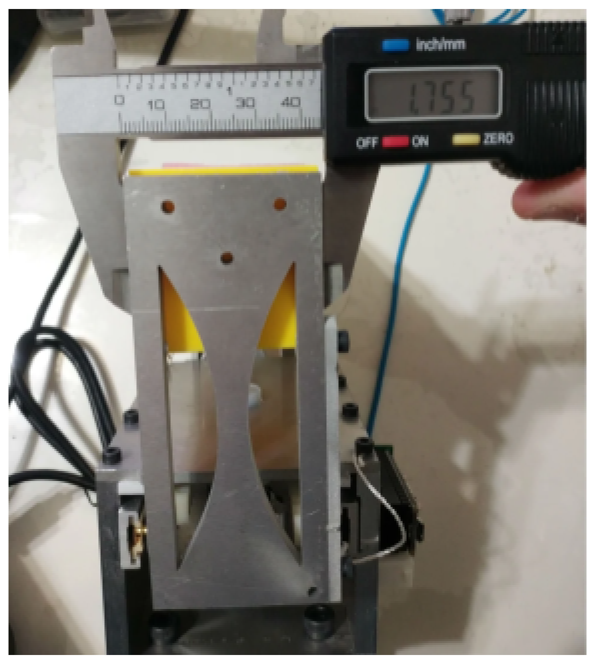


Source: 3dhubs.com

brother's university 3D printer and CNC machine. This allowed me to save on material and service cost as well as the high cost of CNC machining in small quantities.

The parts for the CNC machine were created using the CAM functionality of Fusion 360 where various parameters such as drill bit and layer height could be set before manufacturing while the 3D printed parts were imported into Simplify3D, a slicing software, to adjust parameters such as infill (how hollow a part is) and resolution before manufacturing. While these processes may seem different, they still both cut away or add on layer by layer until the finished product is reached.

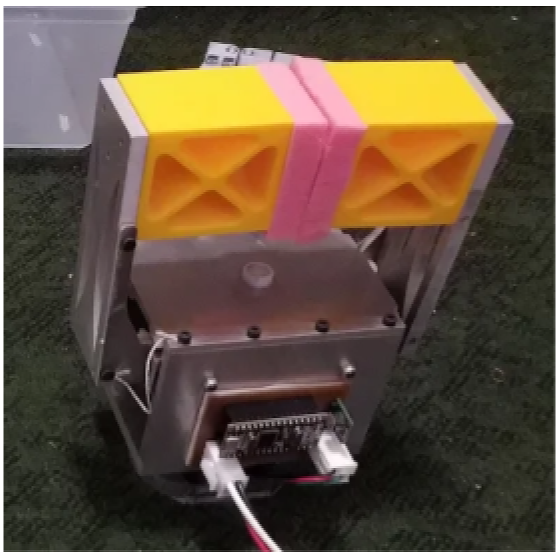
Once the parts were made, I took my digital calipers and measured and recorded the dimensions of several parts and compared it to my CAD model to determine the accuracy and tolerances of each. For the 3D printed parts the tolerances were about ±0.03 in while the tolerances for the CNC machined parts were about ±0.004 in. With the CNC-created parts the machined metal came out much more accurate than the 3D printer, but at a much higher cost. After this process was completed it was time for the assembly of the actual grabber arm itself. For this stage, I used M4 bolts which threaded into the holes cut by the CNC machine on each CNC'd part as well as nylon locknuts. For the 3D printed grabber arms, I also had planned to use bolts, but did not have threading on the inside for the bolts to thread into which resulted in the



Measuring CNC machined part using digital calipers

use of gluing them on rather than fixing them on. The foam attachments on the end of the grabber which allowed it to grab more delicately were also fixed to the 3D printed parts using glue. The Arduino was fixed to a perfboard first, then affixed to the grabber using glue as well.

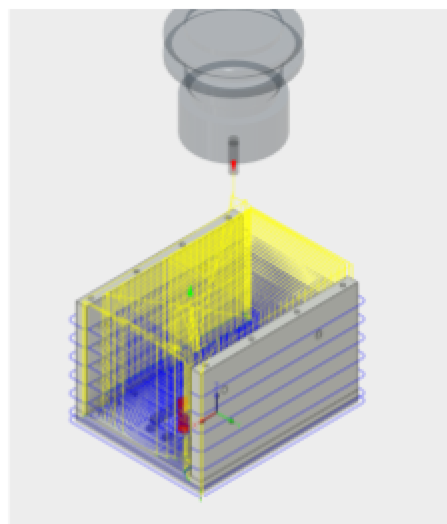
For the wiring of the servo and Arduino, Molex connectors were used as they were more secure and reliable than simply using duPont connectors. The wiring was also quite simple, with 3 wires for input: one positive, one ground/negative, and one signal wire, the first two of which provided power to the Arduino and servo with the signal wire toggling the grabber arm to open and close. The open and closing action is made possible with the use of the switch (green square button) on the orange input wire which switches between opening and closing the grabber with the default state being open and with the switch having to be closed (held-down) in order to close the grabber. The grabber itself is able to run on both 9v as well as 12v power, using either the supplied 9v battery which can be connected to the circuit using the snap on connector, or the supplied AC power adapter in the 12v mode (changed using slider) which can also be connected using the snap on connector. The resistors in the circuit reduce the 9v and 12v down to 5v and 3.3v which can be used by the Arduino and servo motor. The Arduino itself is also running a very simple program to control the servo motor, with a loop increasing the value of the servo until a certain limit and having another loop decrease the value when a signal is applied using the switch.



Picture of fully assembled grabber

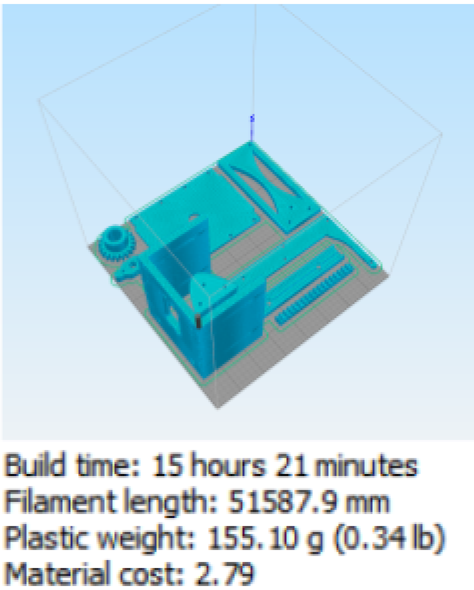
Utilization of Higher-Level Thinking Skills:

Compared to the research I had done on the topic of 3D printing and CNC machining, the creation of my original work was actually quite similar. In one of my more recent research assessments comparing the processes of 3D printing and CNC machining, I had learned about the various filament types, materials, costs, and finishing processes that could be used with each method of manufacture. I had learned about the prominence of PLA in most consumer 3D printing applications as well as commercial which led to me choosing that certain filament in my original work while I had also learned about the various materials that could be milled with CNC machines such as nylon and aluminum; both of which I used in my original work. During the creation of my product I also had to evaluate which methods were most efficient for manufacturing such as when I had to place multiple parts on one print bed in the most efficient manner possible while also minimizing the amount of support material needed by adjusting the orientation of parts in the 3D printing stage. For the CNC machining side of things I had to use Fusion 360 to generate the CAM path which the machine would follow which was similar but different from the 3D printing slicing software. When using Fusion 360, I tried to keep in mind the research I had done on CAM-path generation in a previous research assessment which mentioned how the different orientations of designs in CAM software could also impact the final outcome similar to 3D



CAM Functionality within Fusion 360

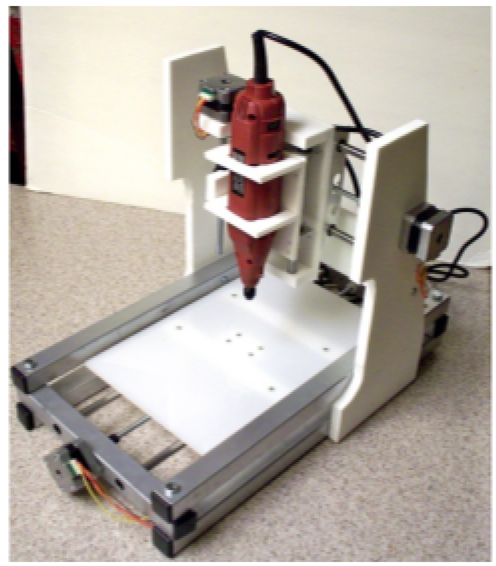
printed parts. When designing my parts I also had to take into account the amount of support material needed and kept overhangs and hollow areas to a minimum, thus reducing the amount of support material needed. After the creation stage of the parts, I had to effectively compare the properties of each part such as cost, material, and appearance as mentioned previously. For the 3D printed costs, the pricing was about the same as I had researched with filament being as cheap as $15/kg on some sites and around as high as $40/kg on other sites. For CNC machining the material costs were about the same as I had researched with the cost of aluminum being about $25 for a 6"x 6"x 1" piece. When analyzing the actual produced parts, I referred back to my research I had done on FDM-printed part accuracy and compared the tolerances I measured with calipers to those I found in my research. While the research I did managed to aid much of the process toward making this grabber arm design such as the cost and limitations involved, I found that I learned more skills and knowledge through the creation of the physical product than simply from reading articles and conducting research.



Estimated time and cost for 3D printing parts using home 3D printer in Simplify3D

Results:

When analyzing the cost, mechanical properties, appearance, and accessibility of CNC parts when compared to 3D printed parts, I found several large differences. For example, the estimated cost of milling just the central section of the grabber arm would have costed over $400 from some services while 3D printing the same part was as low as $10 on some sites. This difference was not only huge, but a lot higher than I had expected the difference to be based on my research and knowledge of material and machine cost. The cost factor also connects to the accessibility of CNC machines and 3D printers which also differ greatly. While 3D printers, primarily FDM (fused-deposition modeling) but also resin printers have been progressively growing cheaper due to the rise in consumer demand as well as a cheap source of parts from China, CNC machines still range upwards of $10,000 and are not as accessible. 3D printers nowadays can be as cheap as $150 while CNC machines are nearly non-existent in the same price range or are limited to a certain number of materials such as wood. While the cheaper 3D printers can be upgraded to some extent and sometimes even rival middle to higher-end 3D printers, cheaper CNC machines are very limited in upgrades and often cannot perform as complex cutting tasks as desirable as can be performed with commercial CNC machines. As a result, accessibility for CNC machining has consistently stayed locked to the industrial and commercial side of manufacturing while 3D printing has slowly been transitioning toward the consumer market.



Source: Instructables.com

Regarding the mechanical properties of the CNC'd vs 3D printed parts, the differences were not as large, but still noticeable. While the nylon CNC machined gears and metal CNC machined sliders flowed and interlocked smoothly, the 3D printed gears were significantly worse at interlocking and felt rough around the edges. The 3D printed slider also did not interlock at all despite the same dimensions as the CNC machine created the slider with. With 3D printing we must understand that there is a certain phenomenon called “shrinking” which occurs as the plastic cools and can cause dimensional inaccuracies or interlocking parts to require finishing in order to fit together. For most designs involving 3D printing, tolerances have to be much looser in order for parts to interlock than CNC machined parts. With 3D printing there is also a phenomenon called “warping” which is when the print lifts off the print bed as a result of uneven cooling. Even when I used a certain feature called a “brim”, a set of multiple lines printed around but touching a part to hold the edges of the part to the bed as the part cooled, the warping was still present in the 3D printed version of the housing part. Warping, however, is not a problem with CNC machining as the parts are not created via heated plastic. With the overall appearance of each type of part, one can easily recognize the presence of support material on the 3D printed parts which require support material to print overhangs while the CNC machined parts have a lack of support material.

Evidence of warping on 3D printed part

With the 3D printed parts each part was also significantly lighter as a result of infill which allows a part to be printed semi-hollow while still retaining most of the strength of the part. This feature is unique to additive manufacturing and grants the advantage of saving materials during 3D printing. With 3D printing, I was also able to create multiple colored parts rather than the color of the material being printed as with CNC machines. 3D printers are also able to create impossible structures such as the "impossible hinge" which is one-piece, prints-in-place, and is freed and can operate as a hinge. For future research, I may consider researching other designs which are only possible with 3D printing such as a form of 3D printed chainmail which is much easier and faster to manufacture than can be done with traditional methods.

Conclusions/Interpretations/Applications:

Overall, from the experience of having to design, plan, and create my original work, I learned several things. Primarily, I learned firsthand and in much more detail how each manufacturing process of CNC machining and 3D printing worked while also comparing each process to how my research had presented them to be. For the most part, the tolerances I found in my research matched quite closely to the ones I measured while other aspects of my project also closely aligned with my research. Some of these aspects included the problem of warping with larger 3D prints, the use of support material for overhanging areas, and dimensional accuracy of parts. For example, my original work featured some warping on the print of the main housing despite using a feature called a "brim" which is supposed to prevent this from occurring. My original work also featured the use of support material in areas where the print had hollow sections while also showcasing some of the tolerances and differences in dimensional accuracy of parts created with each process when

Brim and support material used on 3D printed part

compared to the CAD model they were manufactured from. In the end, I managed to address each part of my original work as I had stated in my proposal.

The process of creating my original work itself overall had some aspects which were both more difficult such as obtaining access to a CNC machine and brainstorming the idea for the grabber as my original work while other aspects such as designing the grabber and manufacturing the grabber using 3D printing were ultimately easier than I had expected them to be. From this journey I had taken to create my original work, I had also learned more about my topic and mechanical engineering as a whole such as new types of 3D printing and new materials involved in the 3D printing process which I had overlooked in my past research assessments. I also learned more about CNC machining in the sense that I was actually able to see the machine in action while also being able to physically hold the finished parts in my hand and feel how much they differed from my initial perception of them. I also learned more about CNC machining in that I learned of more materials which could be machined such as brass, steel, aluminum, and even nylon but unfortunately only had the chance to feature two of these

Material	Price
Aluminum 6061	25 $
Aluminum 7075	80 $
Stainless Steel 304	90 $
Stainless Steel 303	150 $
Brass C360	148 $
ABS	17 $
Nylon 6	30 $
POM (Derlin)	27$
PEEK	300 $

Source: Mcmaster.com

materials in my work. On the subject of materials, I was also limited to using PLA for the 3D printing side of things and did not get to feature some of the more unique materials such as nylon, flexible, or even metal filament.

As I begin my planning and preparation to brainstorm ideas for my final product, I will have to keep in mind both the lessons I learned during this project such as certain ideas which did not execute as well as I thought with the 3D printed slider parts which tolerances were too tight to facilitate smooth operation while also focusing on ideas which I believe worked out quite well such as the integration of traditionally manufactured and standard sized bolts in my design as well as the integration of parts such as servos which I had to design around. I also want to focus more on the variety of materials available to me through both 3D printing and CNC machining while also expanding more upon the idea of accessibility of CNC machines. Some ideas I had about CNC machining which weren't featured in my original work included the recent rise in DIY kits for both CNC machines and 3D printers such as the Shapeoko and X-Carve CNC machines and cheaper 3D printers such as the Anet line of 3D printers which are becoming quite affordable albeit difficult to assemble for someone without an knowledge of electronics. Moving forward

Source: Inventables.com

from my original work, I wish to possibly expand more upon these ideas and research which I can hopefully better integrate into my final product. In the future, I also want to include more about the rapid-prototyping capabilities of 3D printing which I somewhat featured in my original work but hope to expand upon in my final product as well. In beginning to plan for my final product, I hope that the information and skills acquired from the creation of my original work will be helpful and provide a sort of stepping stone to the next stage of ISM.