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A Capstone Project on Design and Development of a Digital Light Processing 3D Printer

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Introduction

A search in the ASEE Conference Proceeding database is yielding 108 entries in the field of 3D Printing. The numbers of papers focusing on 3D Printing has been increasing rapidly since the last few years and include works like utilizing Rep-Rap machines in the engineering curriculum[1] or in new novel experiential learning practices in engineering education[2], and an interdisciplinary senior design project to develop a teaching tool: Dragon Conductive 3-D Printer[3].

This paper documents an undergraduate 3D printer design and development capstone project spanning multiple semesters. Recently, a team of five undergraduate mechanical and manufacturing engineering students were given the task of rebuilding a non-functional Digital Light Processing (DLP) printer which was originally designed and built at this institution. DLP process is based on curing heat sensitive resin in printing 3D objects in layers, patented by EnvisionTec[4]. This project had been worked on two previous semesters before this team took charge and had multiple problems needed to be addressed. The project team also inherited an overheated projector as the heat source, inefficient resin box, and old resin supply. The team's task was to fix the necessary problems with the 3D printer, make alterations to its design and equipment to increase its functionality, and get the printer to a working condition by printing a 3D part before the semester ended. The Internet resource Dimensionext was reporting that the Rochester Institute of Technology has been working on a similar printer[5]. According to the same resource, there were multiple do-it-yourself (DIY) or open source machines are available.

The instructor presented multiple possible projects in his ERNGR 4950 Integrated Engineering Design course. These presentations include background expectations, background requirements and basic safety concerns. The team members selected this project as a challenge, since none of the team members had significant background in the machine design area. One team member was very familiar with machining and fabrication, which was significant help during the fabrication process of machined components. Another member was familiar with SolidWorks and using Fused Deposition Modeling (FDM) printers. This background was taken advantage of while designing and printing parts which were used as cooling fan enclosure and resin box. The team also had a member who had experience with the ProMetal RXD 3D printer and had limited background in optics. All of these skills were very valuable to the team during the project. However, the greatest skill the team had was the dedication, team skills, and high level problem solving abilities.

The objective of the project was to build a working printer that makes multi-layered parts with good repeatability. Accuracy was to be judged after a repeatable printer was obtained. An original scope of work was determined at the beginning of the project in September 2013 and followed the sequence below:

- *Creating schedule*: The team was instructed to use Microsoft Project to make a project schedule. A preliminary schedule with deadlines was prepared in the form of a Gantt chart. The team used this as an initial guideline to set short term goals and task markers for itself.

- *Cleaning printer enclosure*: At the beginning of the project, an immediate concern was the cleanliness of the printer cabinet. The previous group had made an ineffective resin box with poor adhesive that had led to a massive spill of resin throughout the container. It was the team's first priority to clean up the spilled resin and any components that had been contaminated.
- *Applying protective tint:* Machine's enclosure has a window that allows operators to observe the print while in progress. However, to create a safe environment the team decided to apply tint film to this window to protect the viewer from Ultraviolet (UV) being emitted by the projector as well as any light source other than the projector that could cure the resin entering from outside.
- *Disassembly of the previous design*: To gain a better understanding of what the prior team was working with and what needed to be altered, the team began looking at each piece in the printer enclosure. The team quickly found out that the z-axis stepper-motor and modular frame was reusable. However, almost all the other components needed to be redone.

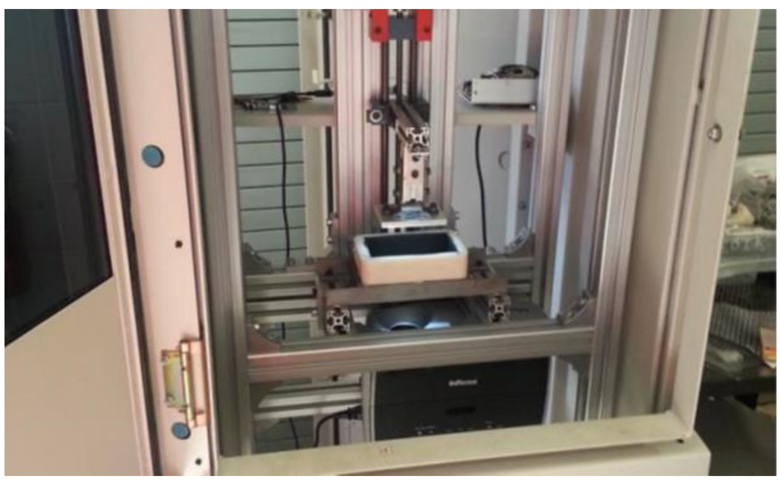

Figure 1. The DLP 3D Printer – including its internal structure, projector, resin box, build platform, and z-axis controls

- *Ordering a new projector*: The previous team believed to have damaged their projector. Furthermore, due to the resin leak mentioned above, their projector was covered in resin, making it useless. Therefore the team ordered an identical projector to be used for the project.
- *Researching Creation Workshop*: The team needed a software package to run the stepper-motor, projector, and the entire print process. The previous team had used an open source program called, Creation Workshop. The team began to look into what version of it can be used and how it could be obtained.
- *Purchasing new supply of resin*: The existing resin was very old, thick, and did not seem to be of a good quality in general. Therefore it was decided to purchase new resin for the printer.

- *Researching resin*: The team needed to ensure that the resin used was the appropriate type for its build strategy and light source, UV light from a projector.
- *Designing and fabricating a new resin box*: Due to the previous resin box being so poor, it was needed that a new box is designed and fabricated to hold the resin.
- *Fabricating a new build platform*: The team didn't like the previous mesh-based build platform since it allowed UV to go through while curing more resin than it was supposed to do. Therefore, a different material and design for the platform were sought.
- *Removing color wheel*: The printer only needed UV light to cure the resin, therefore once the new projector was received, the color wheel was removed from the projector.
- *Create a fan installation*: The team located the fans left over from the previous team's project and decided to utilize them to alleviate some of the excess heat being generated in the enclosure during the print.
- *Printing:* Once all of the scope work had been completed, the team began printing parts in an attempt to meet and surpass our project goal.

Development Process

At the start of the project intense research was conducted to ensure the team followed the right path, as detailed in this section. First a brief cost study on the available projectors was completed. The team was not initially inclined to use the same projector. When looking at alternatives, the members did not find a much cheaper option and decided to stick with the current projector type. The team also needed to decide on resin to purchase. The team was directed towards a site called muve3d.net[6] for possible resin products by MakerJuice. After researching them, it was decided to use SubG+ resin for the project. Attached below is a brief summary on the resin properties according to the resource above[6]:

- Polydimethylsiloxane (PDMS) friendly, fast curing, low shrink (3.5%) material.The trade-off is higher viscosity (90cP at 25°C compared to SubG which is 12cP), but the benefit of the SubG+ resin is that it holds pigment for longer without as much settling. SubG and SubG+ cures under UV A, B, and C light around 420 nm. You can cure it with a DLP projector, a UV laser, or UV Light Emitting LEDs. When using UV lasers or LEDs, the cure time is extremely fast, so the users don't need much power.
- Finished prints are tough but not brittle due to MakerJuice's custom resin formulations.
- This resin is truly low odor, zero Volatile Organic Compound (VOC), and only mildly irritant.
- This resin will not affect Polylactic Acid (PLA) immediately. Constant exposure will soften PLA parts over time.

Once the projector and resin were ordered, the team began looking into how 3D printers were operated and built. This went from looking at laser and UV curable resin printers, to looking at the enclosures they were built in. This led to the choices of stationary versus z-axis printers as well as straight light versus mirrored light designs. A decision was made to utilize z-axis design without mirrors.

A budget was also created for this project and is presented in detail in Table 1 below.

Material	Quantity (Q)	Price (P)	Total Cost (Q*P)
Projector	1	$530	$530
Resin	2(Liters)	$42	$84
Tint	1	$10	$10
Permatex Ultra Black Hi-Temp RTV Silicone Gasket Maker	1	$6	$6
Non-stick sheets	4 (Boxes)	$3.50	$14
Stepper motor	1	$23	$23
Printer enclosure	1	$100	$100
UV Light Filter	1	$150	$150
Aluminum frame	2(10-Foot Sections)	$125	$250
Steel	1(1 foot Flat)	$10	$10
Screws & Nuts	2(Boxes)	$13	$26
Grand Total:		$1203	

Table 1. Estimated budget for the project

Manufacturing Scope

Once the research stage was completed and the enclosure was cleaned up from the previous resin spill, the team began to make the changes to the printer and its enclosure. The team was split into sub-groups to increase productivity. Following are the list of major tasks taken in completing the machine:

- *Window Tint*: The old tint was poorly applied so a fresh new tint was applied to the printer enclosure window to improve safety and reduce unwanted resin cure.
- *Metal Enclosure for Resin Box*: When creating a new resin box, it was noticed that the metal enclosure holding the old box was poorly fitted and machined. Therefore the team utilized the machine shop to make a stronger, cleaner, and more effective enclosure to hold the resin box.
- *Build Platform*: The previous team used a meshed platform to build their parts on, however it was noticed that this caused less surface area to interact with the base of the part (which gets cured onto the build platform) and caused a weaker foundation to the build part. Also the mesh design allowed light to pass which partially cured additional resin. Therefore, the team machined a solid metal platform that could be used to build platform.
- *Resin Box*: A massive concern was the old resin box and its major leaking issue. Therefore, the team decided to create a new resin box. The resin box had to be a five sided box with an open top. The bottom side had to be made of glass so that the UV could pass through it. The other sides needed to be able to repel UV and any other light so that the resin inside would not be cured accidentally. The team designed a box with an open bottom side in SolidWorks and built it with an Fused Deposition (FDM) machine. Once the box was printed, the glass bottom piece was inserted afterwards and a silicon

adhesive was applied to bond the bottom glass piece and resin box as shown in Figure 2 (Left).

- *Testing leak-proof of resin box*: After using the initial silicon adhesive, the team decided to test if the resin box would leak. Therefore the team placed the box in a safe environment and filled it with water. A few days later it was found that all the water had leaked out. The team then looked for alternative adhesive products to use. It was suggested to use a ultra-black adhesive to try and remove any possible air bubbles or sealant leaks in our box. This resolved the leakage issue permanently.

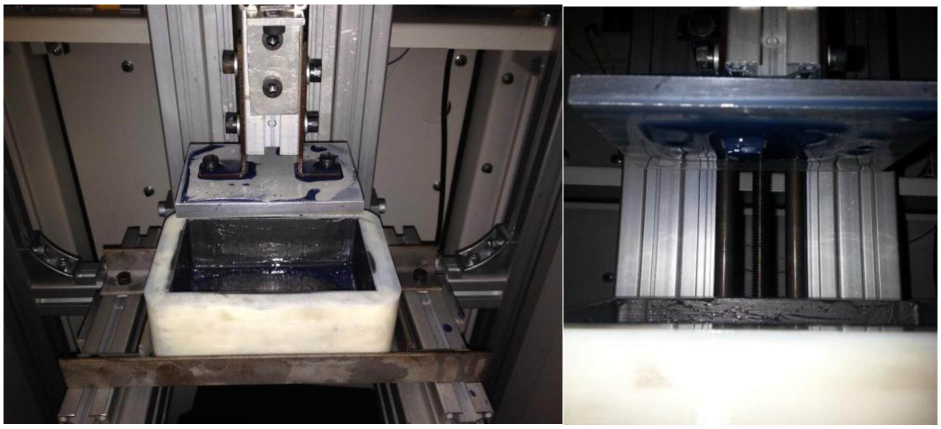

Figure 2. (Left) Partially filled resin box and elevated build platform (Right) Recently built part sticking on the build platform

- *Removing color wheel from projector*: It was mandated that the team remove the color wheel from the projector so that only black/white and UV light would be emitted from it. Therefore the team took the projector apart and removed the color wheel along with a motor attached to it. However, when the team reassembled the projector it would no longer work. Even though the motor did not seem relevant to anything else at the time, it must be relevant for the projector to run. After the motor was returned to the projector, the projector started to work appropriately.
- *Ventilation:* It was realized that the enclosure was bound to overheat without proper ventilation. Therefore the team took an existing fan and created an enclosure for it in SolidWorks before it was printed. The fan was attached to the cabinet as shown in Figure 3. It effectively started to run and moved air from inside the enclosure out.
- *Obtaining Fan Power:* The fan was wired to an old DC cell phone battery and gave it power by converting AC power from the power strip. The power strip was plugged into a wall outlet.
- *Projector Location:* The team had to find the optimal location for the projector. It was decided to lower it and increase its distance from the build platform. This was to gain a clearer image projected onto the platform as well as a more accurate size for the build. The support beams holding the projector had to be lowered to move further from the rest of the structure as well.

Figure 3. Cooling fan addition

Software Scope

Software scope of the project is as critical as the design and development of the DLP hardware. The following steps were taken by the team within the software scope:

- *Installing the Firmware and Drivers*: After trying out a couple different computers, the team came to the realization that it should use a compatible laptop to run the open source Creation Workshop host software. Teacup Arduino firmware and RobotC Arduino driver were installed successfully into the microcontroller and laptop respectively.
- *Setting up Multiple screens:* Surprisingly when the team hooked the projector up to the laptop, it did not project the desktop on both screens. It only showed the desktop on the laptop. Nothing but a blank screen showed on the projector. The team had to go into Control Panel and allow the laptop to recognize the projector as a second monitor. Then the team had to initiate that second monitor when they ran their slideshow on PowerPoint.
- *Using PowerPoint*: Originally the team ran the 3D printer using MS PowerPoint. This was done for two purposes. Firstly, the team wanted to test and make sure the stepper motor worked accurately. Second, the team wanted to make sure that the projector was emitting enough UV light to cure the resin. A PowerPoint slideshow depicting a pyramid over about twenty layers was done. In between each layer slide, a blank slide was inserted. This was so that the team could cover the projector lens and change screens to the stepper motor drive. The team had to manually move the build plate up to the next layer height. The team next would go back to PowerPoint, remove the cover, and resume the slideshow. First couple tests were unsuccessful in producing any good 3D objects.

- *Downloading and Installing Creation Workshop:* Creation Workshop was downloaded from Download.com[7] and installed onto the laptop. Current version of this program (Beta 13) can be found in the Thingiverse[8].
- *Setting Up Creation Workshop*: The team needed to get Creation Workshop to recognize all of the tools of the DLP machine. Stepper motor was recognized first. This was very helpful. No longer had the team had move the build plate manually. Creation Workshop would move the build plate in between each section, having also able to control how big the slices were. The projector was recognized next, which in turn let object show on the projector, but the Creation Workshop screen would show on the laptop. Finally, SolidWorks link was installed. This would allow the team to upload files from SolidWorks, and Creation Workshop would be able to recognize and build them.
- *Running Creation Workshop:* The goal was to get the program to run smoothly without any human intervention. It took the team a few trials before they could set the starting point to the exact millimeter for its first layer. The team also decided to add large bases to the object designs as shown printed part in Figure 2 (Right) and 4; the resin seemed to stick better to itself than it did the build plate. Once the team resolved these issues, it was able to run Creation Workshop successfully. All the team had to do was center the object so that it was projected in the center of the resin box and use the start function. The program did the rest, layer by layer. At the end of the program, the team had to manually move the stepper motor up to pull out the finished 3D object. Figure 4 illustrates the main user interface while Figure 5 is showing machine control commands. Figure 6 is indicating the slice viewer and Figure 7 is the DLP process parameters.

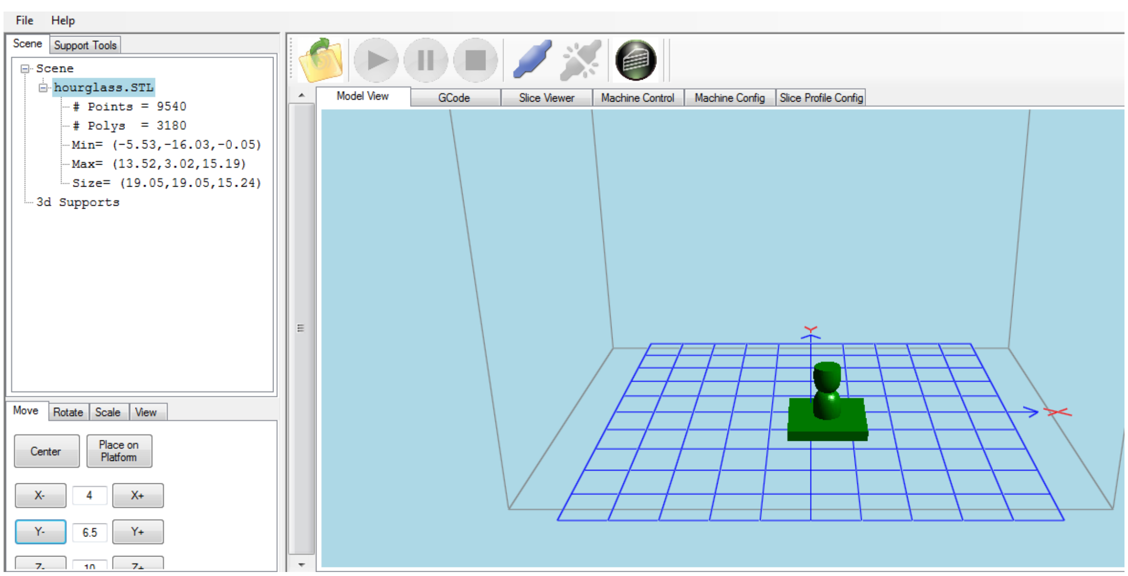

Figure 4. Creation Workshop Interface

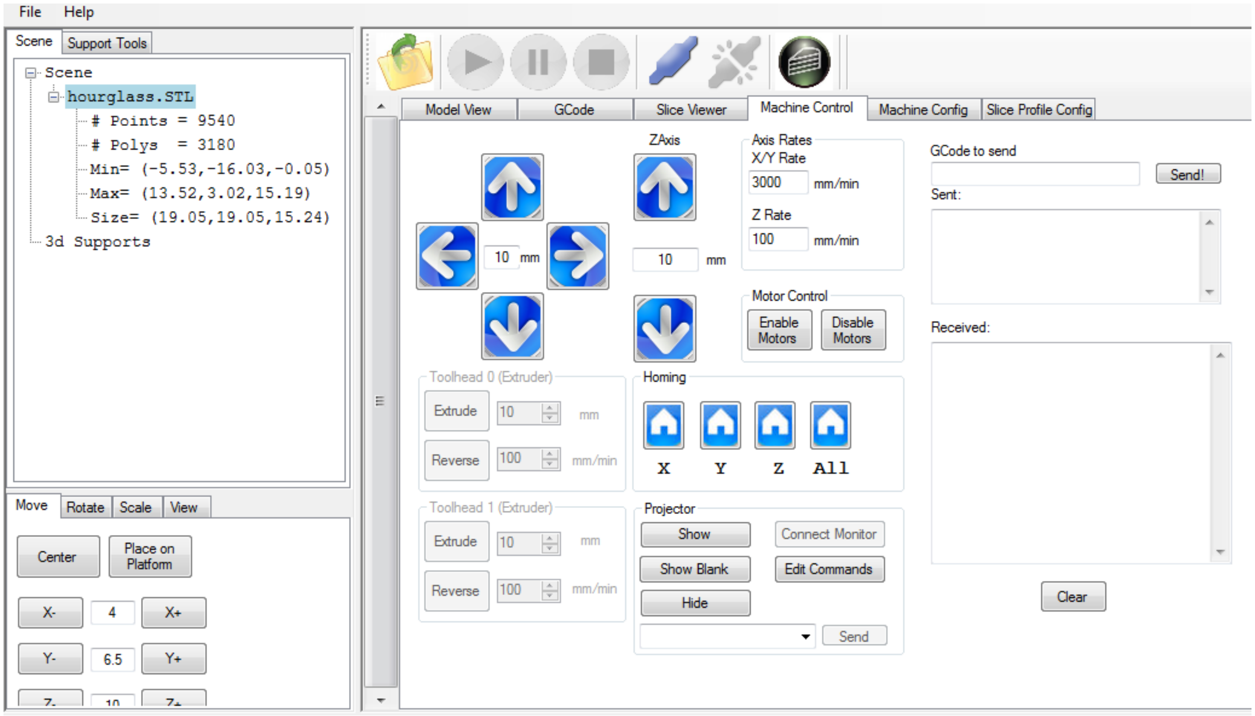

Figure 5. Creation Workshop Machine Control Commands

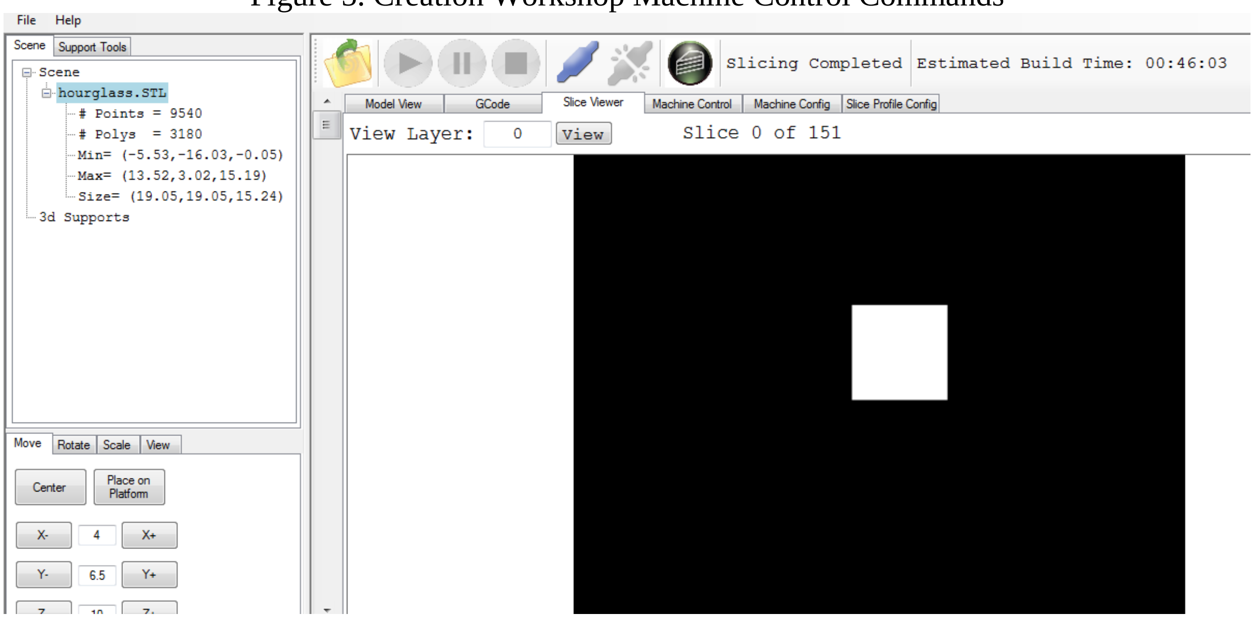

Figure 6. Projection of a layer indicated in Creation Workshop

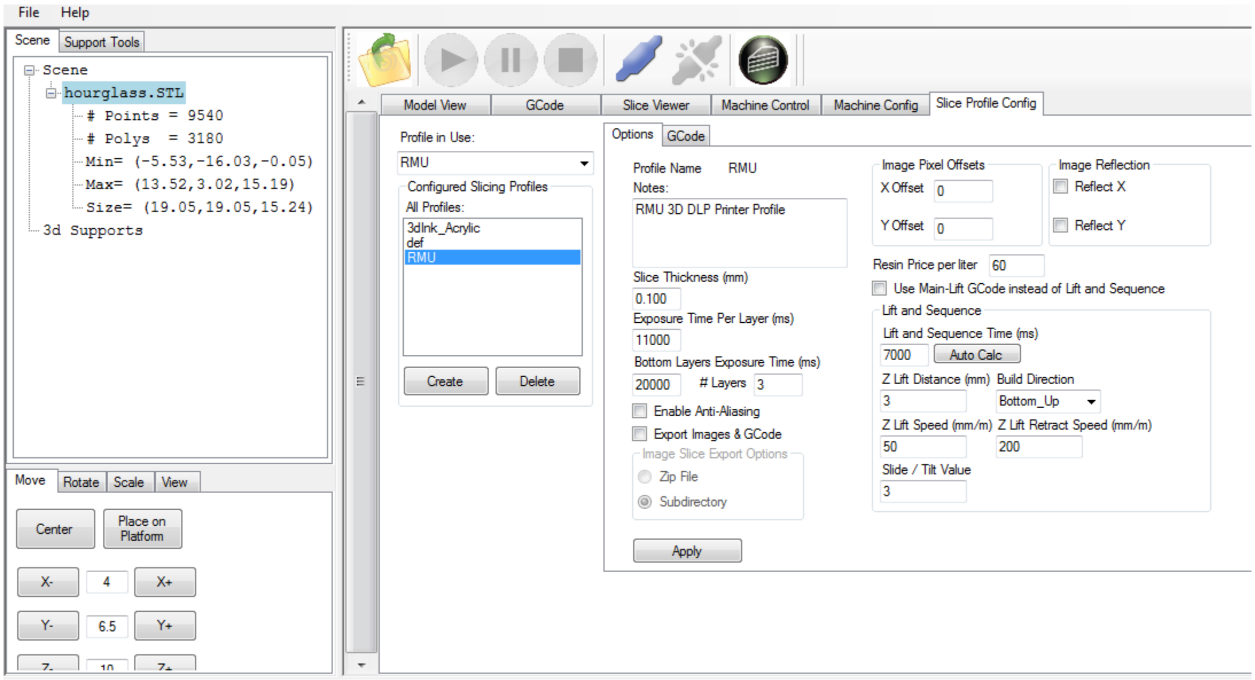

Figure 7. Creation Workshop DLP Process Parameters

Printing a 3D Object

First, users have to create or download an object that contains an ".stl" file extension. Then the file needs to be loaded into the Creation Workshop software. Once the file is properly loaded into Creation Workshop, the features within the software allow users to change certain settings through machine configuration and slice profile configuration, shown above in Figure 7. Users can determine the layer thickness, exposure times for initial and remaining layers. In addition, users have to position the object onto the grid within the software and make sure it is within the foot-print of the build box. Then, the part needs to be sliced into sections or layers so the projector can accurately display each layer of the object when projecting. This is shown in Figure 6.

Resin box needs to be filled and position of the build plate is set slightly above the bottom of the resin box. Once the printer starts printing, the projector will display each slice of the object for a certain amount of time. The first layer will cure onto the build plate with the remaining layers curing to the previous layer before it. After each layer, the build plate will raise to the next layer position before the projector begins projecting the next layer. The object builds from the bottom up, so the base of the object will be built first. Once the print is done, the build plate needs to be manually raised, and then the object can be removed from the build plate. Complete part is then removed from the build plate and uncured resin coating is clean off of it. Resulting part is seen in Figure 8 below.

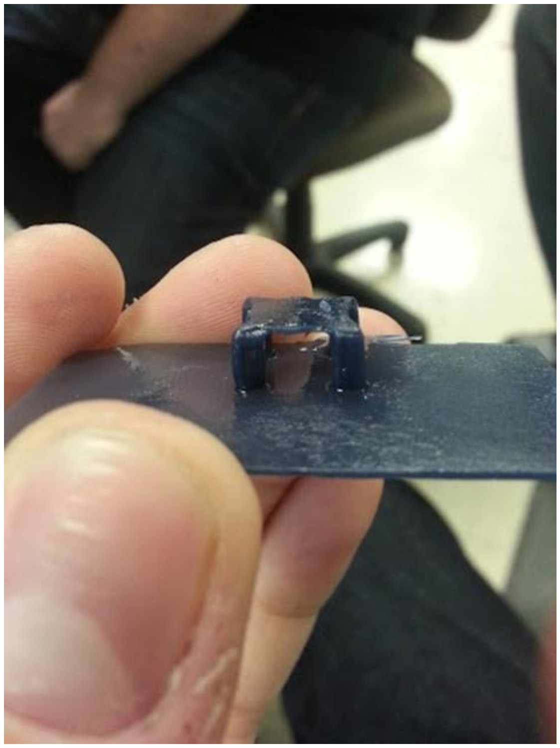

Figure 8. Part with removable large base

A simple experiment was conducted after carrying many trials with the machine. Results of the experiment illustrated below in Table 2. Print 1 was selected as a reference while changing layer thickness, first 3 layers' and rest of the model exposure times. 0.1 mm layer thickness along with 11/20 second exposure time combination yielded the best resolution with an associated grade of "A". In Table 2 slice thickness/exposure times leading to better or worse print resolutions are compared to Print 1. A letter grade was also assigned to each resolution.

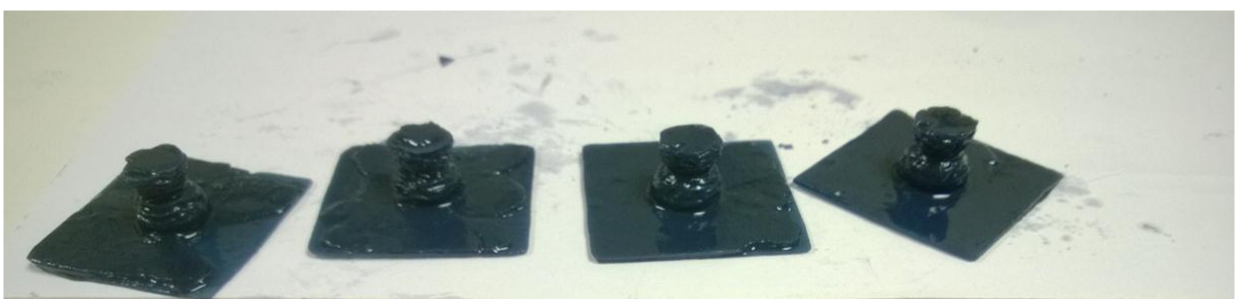

Figure 9. Hour-glass shaped part with its base – print grades are improving from left to right – similar to Prints 3 to 6 from Table 2

Print	Layer Thickness	Layer Exposure	First 3 Layers Exposure	Resolution/Grade
1	0.15 mm	9 seconds	20 seconds	Okay/C
2	0.25 mm	9 seconds	20 seconds	Fail/F
3	0.18 mm	9 seconds	20 seconds	Decrease/D
4	0.12 mm	9 seconds	20 seconds	No Change/C
5	0.15 mm	11 seconds	20 seconds	Increase/B
6	0.1 mm	11 seconds	20 seconds	Increase/A

Table 2. Results of the simple printing experiment

The project team had to deal with multiple issues. These issues and how they were dealt with are presented in this section - below:

- *Build plate would not remain in level*: However, it has been improved from the previous designs greatly.
- *Difficulty determining the exact distance the stepper motor needed to move*: It is difficult to determine how far down the build plate needs to move before starting the print. The team had to estimate how far down it needs to travel to position the build plate to begin printing. It is moved in small increments until the build plate hits the bottom of the resin box. This takes extra time determining the distance to travel and it also not efficient nor accurate. A sensor for the z-axis would create a home position and determine how far the stepper motor needs to travel up or down.
- *Too much wiggle room for resin box:* One of the first issues that occurred was the resin box did not fit tightly in the support frame the previous team manufactured. This was because of two issues. The steel support structures used to hold the resin box in place were not flush against the box. The pieces that were used had curved corners, which prevented the frame to be flush against the resin box. In addition, the screws used to secure the frame to the base elevated the resin box because the box had to sit on top of the screws. To fix these issues, the team wedged the resin box into the support frame using cardboard. This allowed the resin box to be tightly secured. In the future, a more efficient way of securing the resin box can be utilized.
- *Projector was too close*: Once the team began printing parts, they began to realize that the images were projecting smaller than the intended dimensions. The team needed to position the projector further away, so it would be able to produce an accurate image. To accomplish this task, the team attached the projector to support bars that could be loosened to move the projector to the appropriate height.
- *Projector was not levelled:* Once the team mounted the projector to the frame, it was noticed that it projected the images on a slight angle. This meant the images weren't hitting the glass on the bottom of the resin box. After many initial thoughts and ideas, the best method to fix this issue was bending the steel pieces that were holding the projector to the frame. The team was able to calculate the appropriate angles for bending, so that the projector could project at the angle needed. Consequently, the team used a bender to bend the appropriate angles. This was not the most efficient and accurate way of overcoming the issue; however, the results were very effective for the purpose.

- *Resin would not cure the way it was desired*: Initially, the team had issues printing parts that had accurate edges and layers with minimal distortions to the part. The team knew that the problem had to be the type of resin used combined with the default settings of Creation Workshop. Therefore, the team began experimenting with the cure times for the initial layers and exposure times for the rest. Additionally, the team started to change the layer thickness and get accurate edges during the prints.
- *Resin would not always stick to the build platform*: The most difficult problem the team faced was the printed parts would not stick to the build plate. The team thought the problem was based on not having enough initial cure time for the first three layers. The team also believed that some of the pieces were too heavy and forced the part to fall off. To fix these two issues the team increased the initial exposure time and for parts that were deemed "bigger" a larger initial part surface (similar to the support structure as shown in Figure 8) was added, so that there was a larger surface area to help support heavier pieces. Even after fixing these issues, the team still experienced inconsistency in printing. It was determined that the build plate was not close enough to the bottom of the resin box. This problem was fixed by having the build plate touch the bottom of the resin box and then build plate was manually raised by the height of the intended first layer thickness of a part. Since, the team has increased the probability of parts sticking to the build plate.
- *Difficulties keeping resin from dripping*: When removing parts from the printer, excess resin remains on the part until it cures or is dried off. In addition, the resin dripping from the build causes cross-contamination and this problem was being controlled by cleaning, but was not fully resolved.
- *Trial and error attempts to create 3D objects*: The most effective way the team could improve its prints and repeatability is by using trial and error. Trial and error takes an extreme amount of time and can sometimes be very inefficient; however, due to the lack of experience the team had with its software and the DLP printing process, this was the most beneficial method for the team. Trial and error also allowed the team to conduct a sensitivity analysis presented in Table 2.

Areas for Future Improvement

This section of the paper covers the recommendations for further improvement of this DLP machine by the team members:

- *More effective resin source:* Currently, the resin is too unpredictable. The repeatability of creating multiple identical parts is lower than desirable ranges. Each printed part has different layers and sections that end up not curing all the way. Also, some sides are smoother and more accurate than others. If a more effective resin was found, then it may help with the repeatability of printed parts. This can be accomplished by experimenting with multiple different resins.
- *Finding a better way to cure the resin with the projector*: It is hard to determine the best settings to cure the resin. Whether it is the layer thickness, initial exposure time, or the remaining exposure time there is no permanent settings that allow the team to create accurate and repeatable parts. Future work is needed to find settings that lead to creating different parts that are highly accurate and repeatable using the current projector.

- *Creating a glass shield above the projector to protect it from any resin leaks*: Since the previous team allowed the resin to leak down onto the projector and damage it, a protective shield could be created to prevent this from happening in the future
- *Creating an improved resin box with preferably clear sides:* The new build box has been very durable and reliable; however, it would be beneficial to have a box with clear sides. The clear sides (blocking UV) will allow the user to observe the printing process during a build to ensure the part is stuck to the build plate and that there are no issues during the process. This will save time because the user won't have waste time while waiting for the part to be completely finished to catch the mistakes.
- *Finding the appropriate settings for Creation Workshop printing with our projector:* A main issue the team was facing is the software. Creation Workshop is an open source software, so it is unknown for the settings that are most appropriate for the projector. Therefore, further testing and experimenting with Creation Workshop is needed to find settings that create the most accurate and repeatable parts.
- *Creating an opening for cables:* Currently, the bottom compartment of the printer has to remain open to allow the cables to plug into the computer. If a hole was created in the bottom right corner of the printer it would allow the compartment to be shut. This would allow the printer to be completely closed during the printing process and eliminate any additional lighting or air from affecting the printing process.
- *Finding the optimal location of the projector:* This is for the projector to get the strongest source of light and the correct size of the object being printed.
- *Purchasing a funnel:* Purchasing a funnel in the future will help pouring the excess resin from the build box into an appropriate storage container. It will help eliminate slippage and dripping. This will in turn help with the contamination issue explained earlier.
- *Purchasing non-pigment resin:* Currently a dark color resin is used, which makes it hard to see the object during the printing process. If the team had non-pigment resin, they would be able to locate the build plate with respect to the bottom of the resin box. In addition, the team can observe the printing process and stop the print if they see any issues occurring during the build.
- *Conducting thermal experiments:* This is to determine the thermal impact the projector in terms of the chemical reaction for the curing process.
- *Placing a z-axis sensor on stepper-motor:* The team can determine the exact location of the build plate in terms of where it's positioned on the z-axis by adding a sensor. This would also allow the team to set the home position of build plate, so they could easily and accurately place the build plate at the bottom of the resin box to begin each build. In addition, the z-axis movements can be accurately tracked and movement increments can be accurately calculated.
- *Create another fan installation near the projector*: During printing, the projector gets very hot due to the enclosure surrounding it and the many hours of continual printing. To help prevent overheating, it would be beneficial to cut a hole on the side of the printer by the projector to install another fan system to help cool down the projector during printing.

Safety Measures and Concerns

Following safety rules were developed by the team as a part their project ending reflections:

- *Wear gloves when handling resin:* The resin is easily curable and can cure on any surface if exposed to a light source for a long enough time. Therefore, it is critical to wear safety gloves so the resin does get on the user's body parts.
- *Wear safety glasses:* It is important to wear safety glasses around the 3D printer. When the enclosure is open, the resin could splash into the user's eyes. The resin can cure to the eye and can cause permanent eye damage.
- *Wash any part of you that come in contact with resin:* Again the resin can cure to the skin, so if any part of the user's body comes in contact with resin, he/she needs to ensure washing with cold water. In addition, if the user doesn't wash, he/she can cause cross-contamination and may cause positioning if ingested.
- *Don't inhale fumes:* The resin extracts a strong scent that could cause health problems if inhaled for long periods of time.

The Capstone Course and Educational Value of the Project

ENGR 4950 Integrated Engineering Design course was used as a medium for this student driven project. The capstone course encompasses a semester long effort to help senior engineering students to solve a major engineering problem, or develop or improve a product, process, and tooling. Student teams in the course start with a problem statement and follow through the engineering design and development cycle. The projects are expected to be well organized and deliver excellent results in the forms of virtual and physical prototypes. Since one of the strengths of our programs and the instructor lies in 3D Printing, since the last few years the students have been designing and building 3D printers that include FDM, DLP and welding-based processing. Student teams also successfully built a 3-axis NC router.

Designing and building 3D printers is not a novel method. However, doing this in a capstone environment is resulting in an unparalleled experience, especially starting from scratch. We can draw this conclusion from the students' own accounts spanning a time frame of a few years. Some of these printers were the only student built 3D Printers presented at the opening of the US Government's first Manufacturing Innovation Institute, NAMII (now called America Makes). The educational value of this project lies in multiple factors:

- Scheduling, organizational and team skills building
- Student excitement towards the subject area and consequent ownership helping drive the project to a successful outcome
- Multiple high-level problem solving and decision making opportunities in mechatronics hardware and software related issues, mechanical and chemical engineering areas, and optics
- Attention to detail in a very complex project
- Hands-on learning of safety
- Continuous feedback from the students and observation of the progress through face-to-face interactions between the instructor and student teams, periodical oral and verbal presentations.
- Strong final project documentation that can imitate professional engineering reports and papers.

- Plausibility of this low cost and in-house built equipment being utilized in other courses such as ENGR 4801 Rapid Prototyping and Reverse Engineering and ENGR 3080 Design of Industrial Experiments

Conclusions

This paper documents an on-going effort of improving and reworking an in-house designed and built DLP 3D Printer. The paper is a reflection of the student team's efforts from their own accounts. Students who made this project possible are currently, either successfully employed by the industry practicing either mechanical or manufacturing engineering profession or attending a Law School to be a patent attorney. During the process, these students actually owned this project and spent rather large amount of time to deliver a presentable outcome, also improving their confidence as a prospective engineer. Final result was more than acceptable from a senior capstone project.

The current status of the machine is also much more improved with help from another student group, solving accuracy and contamination problems. These improvements will be presented in the RAPID 2015 Conference. However, the z-stage sensor is still to be employed. That and other additions will soon to be realized.

References

[1] Sirinterlikci, A., Sirinterlikci, S., Utilizing Rep-Rap Machines in the Engineering Curriculum, 2014 ASEE Annual Conference.

[2] Jaksic, N., New Inexpensive 3-D Printers Open Doors to Novel Experiential Learning Practices in Engineering Education, 2014 ASEE Annual Conference.

[3] Ertekin, Y., Husanu, C., N.,I., Chiou, R., Konstantinos, J., Interdisciplinary Senior Design Project to Develop a Teaching Tool: Dragon Conductive 3-D Printer, 2014 ASEE Annual Conference.

[4]Technology Overview DLP Process.EnvisionTec. http://envisiontec.com/technology-overview/. Accessed on December 31, 2013.

[5] DIY DLP Printer. Dimensionext. http://www.dimensionext.co.uk/2013/03/diy-dlp-3dp.html. Accessed on December 31, 2013.

[6] Makerjuice SubG+ Resin. Muve3D. http://www.muve3d.net/press/store/. Accessed on December 31, 2013.

[7] Download.com. http://download.cnet.com/. Accessed on February 1, 2015.

[8] Creation Workshop Beta version 13. http://www.thingiverse.com/thing:40778/#files. Accessed on February 1, 2015.