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SUGGESTION OF A DLP BASED STEREOLITHOGRAPHY 3D PRINTER

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Abstract – The Digital Light Processing (DLP) 3D printer is a tool that utilizes Additive Manufacturing (AM) technology to build a 3D model straight from the CAD model. There are various 3D printing technologies that differ in many ways, including the material used, the techniques used to create the sample, the speed and accuracy, and a wide range of other factors. Choosing the best production method depends on the work at hand, ensuring that the product's material and quality meet the necessary standards. Although the DLP technology has a straightforward design, it offers an impressive array of quality and adaptability. This study offers a customized design that assures high manufacturing quality. To verify the functionality of the developed 3D printer, three distinct types of experiments using various CAD designs were conducted. Surface quality, minute details, and precise measurements have all been achieved in these trials. Additionally, two separate tests were created to confirm the desired output results.

Keywords – *3D printer, DLP 3D printer, additive manufacturing, rapid prototyping, resin printer.*

I. INTRODUCTION

DLP based SLA 3D printer is apart from additive manufacturing besides the other technology like FDM and SLS etc. in general 3D printing technology starts from 1981 by Dr. Hideo Kodama with the patent, he is the first one who applied the laser beam to cure the resin as what we know now as SLA in Japan. While in France, there was a team of three people Jean-Claude André, Olivier de Witte, and Alain le Méhauté. They were trying to get the patent to make the "rapid prototyping device" in 1984, but because of the funding problem, they were forced to leave the project. In 1986 Chuck Hull had established the term Stereolithography technology and making a patent in the same year, and he released his first commercial product in 1988 (1987 [1]) and it was called SLA-1 [2].

In 1988 Carl Deckard at the University of Texas has filed a patent for SLS technology, and he used laser instead of a UV light to solidify the powder polymers layer by layer making the desired 3D object. After that, in 1989, Scott Crump from Stratasys Company filed the patent for FDM technology. After the release of the SLA-1 by Hull in a few years, the first FDM was released in 1991 by Stratasys, and in 1992 DTM Inc. released its first SLS 3D printer.

Till 2012 there was nobody able to produce and affordable SLA 3D printer in the market, this changed after 2012 by B9Creator company, they started from Kickstarter to produce a similar technology to SLA called DLP; also a startup company called Formlabs used the Kickstarter, but they produce an SLA 3D printer called Form1.

In 2014 the most patents of 3D printing has been expired, and one of them was Chuck Hull's patent, and this means giving the individuals more space for innovation to process the SLA 3D printing [1], this thing allows some companies and individuals to work on different 3D printing technology including SLA and DLP. They tried to develop it and make it smaller and less costly, so it can be available in the standard market not just for industrial usage, as what can be noticed these days they become more available at some reasonable price.

The standard SLA and DLP 3D printers still cost a lot (from 3000 to 10000 USD for the basic models) in comparison to other 3D printing methods [3]. A similar issue with the speed that the SLA provides is considered a much slower option in comparison to DLP and many other affordable printing technologies [4]. Although they provide a unique quality and a wide range of materials, they still provide a limited space of flexibility, as they are limited to their manufacturer's plans. Therefore this study suggests using open-source programming software alongside altering the components to maintain a lower price and a more extensive range of experiments and adjustments.

In this study, a custom DLP 3D printer will be made and will go through a series of tests examining the replaced equipment on different levels, such as speed, quality, and durability. The test will also expand to different forms of adjustments and measurements that expose the final sample's quality and accuracy. Therefore this study will focus on designing and developing a custom DLP based SLA 3D printer made from commercial components.

II. Materials and Method

Going through different 3D printing technologies and builds, DLP 3D printing has been found as the most suitable form of printing to study and develop in this study, based on the possibility to use a different mechanism for image generation and the high flexibility that allow not specialized but tweaked components to be a part of the project.

For hardware component they are projector Dell 2400MP, The lens, The resin vat, and The Actuator for Z-axis linear movement, they were assebly in a square aluminum profile 40x40 mm.

SolidWorks is used for designing the desired 3D parts and Creation Workshop software to control the Arduino Uno card to control the Z-axis stepper motor throw the A4988 driver with the projection synchronization.

A. DLP Projector Dell 2400MP

The core element in this DLP 3D printer is the curing device that can convert the liquid resin to a solid form according to the CAD model. In this study a regular digital image projector has been used as a UV image producer that will reflect the due model slice as a light image to cure the resin precisely, mimicking the required layer underneath the previous one which will eventually form the required structure alongside the supporting elements that holds the fragile elements of the structure during the printing process.

This model was chosen depending on some feature that makes it one of the compatible devices for this work because it usually works as a video projector, not for 3D printers. Therefore, better results have been achieved by modifying the device.

Some parts need to be modified during the curing process of the resin to make the projector work efficiently. Each projector has UV filter in front of the lamp, as shown in Figure 2 to reduce the UV light from reflecting on the human eye in normal usage, while the UV light is what we want from the projector for curing purpose; therefore this filter need to be removed from the projector, the UV filter in this projector is made from rectangle glass with diameters about 1.5x1.5 cm [5, 6].

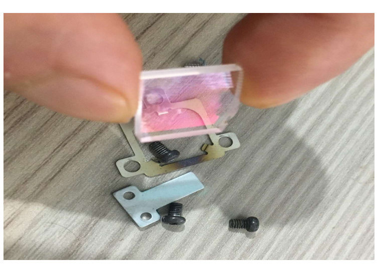

Fig. 1. The UV filter

The second thing that has been improved is removing the color wheel (see Figure 2) that is placed in front of the lamp to prevent the color during projecting. The result of this improvement is that the final light came out from the projector is in black and white to prevent the disruption while curing and also reduce the UV filtering [5,6,7].

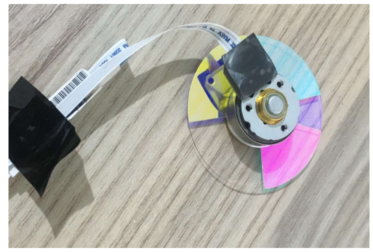

Fig. 2. The color wheel

The third thing that the same built-in lens has been used that came with the projector (dell 2400mp), but this lens was designed for long-distance projection the minimum distance is 1.2 m [8], and to make it fit our needs some changes were made to make it fully compatible with this 3D printer with a distance of 20 cm between the lens and the building platform.

B. The Resin Vat

The vat (resin tank) was custom designed. It was made from a 4 mm transparent acrylic plastic cut with a laser machine to achieve the fine assembling details. It consists of two parts; the base is plane acrylic with a square canal of 2 mm depth in the outer size of cubic (see Figure 3 A), the second part is square 40 mm height with base and 8 round hols, the second part was designed to go inside the 2 mm canal depth in the base (see Figure 3 B) to make the FEP film more tension, with the eight screws to hold the two parts as given in Figure 3 C.

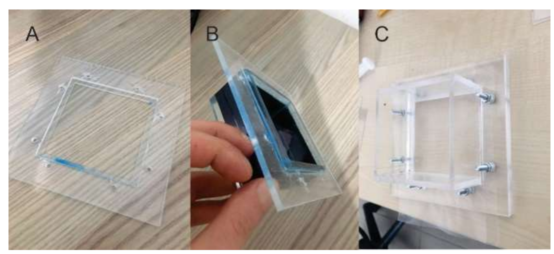

Fig. 3. The resin vat

C. Working Principles and Methodology

The process starting from making the desired 3D object (part) in CAD software like SolidWorks or any other software can produce STL format files, after that, transferring the designed object to another software in my study an open-source program Creation Workshop has been used, throw this program slicing process can be managed depending on the desired part resolution, even 0.001 mm can be achieved, by the help of the same software each layer can be projected to the building platform (as shown in Figure 4) which is in the lowest point of the resin vat to cure the first layer and it will be the first attached layer on the building platform after that Z-axis will move one step up to let the uncured resin collect under the first cured layer so the projector can cure the second layer and so on until the part is reaching the last layer that's mean the part is completed, then the building platform will move up to easily remove the part, and cleaning the part by apply isopropyl alcohol mixture and water.

In this setup, four parameters play the primary role in 3D printing: the Z-axis speed and lens focus, light intensity, and resin composition. An experimental study has been made to find the optimum parameters for the linear speed of the Z-axis and light intensity.

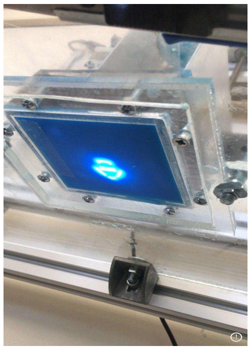

Fig. 4. Light under resin vat (curing)

III. THE EXPERIMENT, VALIDATION AND RESULTS

Complete results have been obtained in the first set of experiments. Before that, there were several failed experiments before the resin vat, and the building platform has been changed.

A. The first experiment

In this experiment, almost exceptional results are obtained, as given in Table 1. The 3D CAD model was chosen as given in Figure 5; it is a cubic with two supporting legs from the bottom.

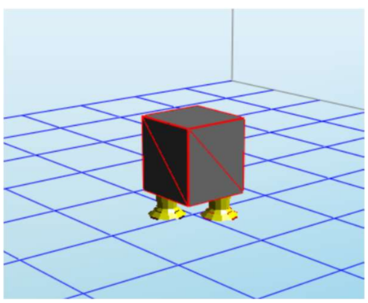

Fig. 5. The CAD model for the first experiment.

Table 1. The first experiment

No	Z speed in mm/m (milimeter / meter)	Slice thickness In mm	Exposure time in ms (miliseconds)	Bottom exposure in ms	Bottom layers	Z lift distance mm	picture
1	80	0.100	1100	8000	3	4	Figure 6 A
2	80	0.100	1300	10000	3	4	Figure 6 B
3	80	0.050	900	10000	3	4	Figure 6 C
4	30	0.050	900	10000	3	5	Figure 6 D

In Table 1, 2 and 3, "No" column represents the number of experiments. Column "Z speed" represents the speed of the Z-axis axes movement, up and back down. Column "Exposure time" represents the time for each normal layer to be cured. Bottom exposure column represents the time for the few bottom layers for the base of the object. Z lift distance column represents how much mm the building platform will move up after each cured layer.

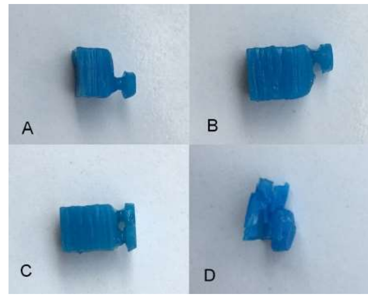

Fig. 6. The first experiment samples (A, B, C, D)

In the first try, the object did not complete because of the few exposure time, and one of the supporting legs was lost, in the second try, a completed object is printed by increasing the exposure time and bottom exposure time. In the third try, trying to decrease the layer thickness from 100 um to 50 um, a better result has been achieved compared to the second try with 900 ms. In the fourth try, trying to reach a better result by decreasing the Z-axis speed from 80 to 30 mm/m, but the worst result has been got, from this result, it was clear that the more speed that has been implemented on the z-axis movements the best result will obtain with some limits that will be discovered later on.

B. The second experiment

In this second experiment, a Benchy 3D model (see Figure 7) was tested with three parameters, relying on the first experience in some parameters. Each experiment is explained in the following sections.

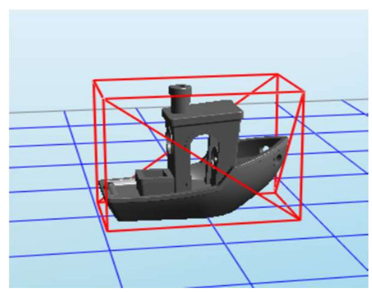

Fig. 7. The Benchy CAD model

Table 2. The second experiment

No	Z speed in mm/m	Slice thickness In mm	Exposure time in ms	Bottom exposure in ms	Bottom layers	Z lift distance mm	picture
1	160	0.200	2500	10000	3	4	Figure 8 A
2	160	0.200	2600	10000	3	4	Figure 8 B
3	160	0.200	2800	10000	3	4	Figure 8 C

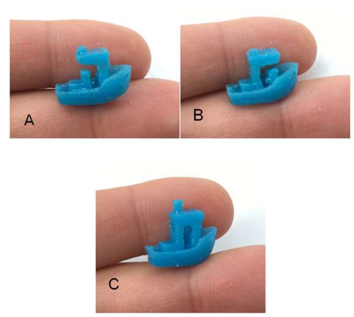

Fig. 8. The second experiment (A, B, C)

The first try entirely printed, but it has some failure in the small details; however, the outline shape was clear with 2500 ms for exposure time. The second try and exposure time has been increased with 100 ms to see if it will go better or worse. It became 2600 ms for the standard layers, a better result has been obtained in comparesion to the first try but still has some missing parts, but there was an improvement. For the third try, by increasing the exposure time with 200 ms and it became 2800 ms, the delighted result has been got for the printed object without any missing parts or merging between small details like holes.

C. The third experiment

In this third experiment, a much detailed model needs to be printed to ensure the printer's ability to print any desired shape. Therefore a custom design has been made by using SolidWorks 2019(as shown in Figure 9), to make a hole cubic with 2 cm diameters with a wall thickness of 1.5 mm, with bricks of 0.5 mm thickness as a texture on the wall from outside.

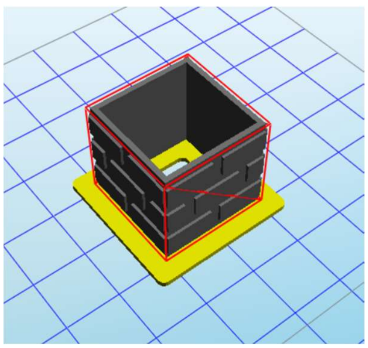

Fig. 9. The cubic CAD model

Table 3. The third experiment

No	Z speed in mm/m	Slice thickness In mm	Exposure time in ms	Bottom exposure in ms	Bottom layers	Z lift distance mm	picture
1	160	0.200	3000	10000	3	5	Figure 10 A
2	160	0.200	3200	12000	3	5	Figure 10 B
3	160	0.200	3200	12000	4	5	Figure 10 C

In the first try, the object is fully completed with good quality, but there was a problem there was the missing part in the first 3 mm from the platform to the object body like a hole, almost the same problem that happened in the second experiment.

With the Benchy model, therefore the exposure time should be increased as happened in the previous experiment and it has been solved the problem, in the second try the normal layers exposure time and the bottom layer has been increased but also the same problem has been got, also missing part next to the building platform, in the third try a 1 mm solid base has been implemented in the bottom of the cubic with the same parameter with the previous try, a perfect 3D model has been obtained without any missing parts with a perfect surface finish.

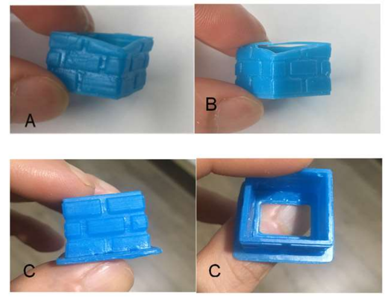

Fig. 10. The third experiment (A, B, C)

After getting very good results in the third experiment with nice surface finish, while the CAD model design was a flat cubic with Bricks and it successfully printed, a more detailed CAD design was aiming to produce for further check about the printer abilities for different 3D models, this shape has been chosen as shown in Figure 11.

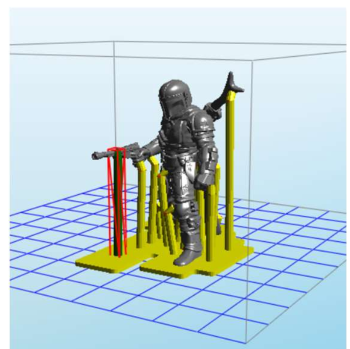

Fig. 11. The CAD model

It was successfully printed out from the first try with the same parameter in the last try of the third experiment as previously explained, the printed model given in Figure 12.

Fig. 12. The printed model

D. Test and validation

To ensure the validation of the printer, for the printed samples, two tests were performed. The first one was about the Repetition while the second one was about positioning in the building platform.

The repetition test

In this test, ten samples were printed in almost the same weather condition and time, the weather was changing from 30 to 24 centigrade degrees, and the time was from 1:30 PM till 1

AM. The printed sample consists of a solid cylinder over a solid cubic (see Figure 13).

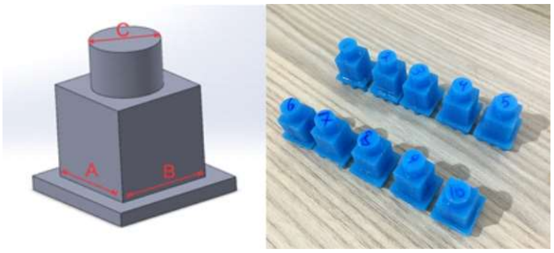

Fig. 13. Test CAD model and printed ten samples

Where A is represent the height and B represent the width for the cubic, and C is representing the Diameter for the cylinder.

The test results are given in Table 4, and the location of the parameters shown in Figure 13. The test was made using a micrometer with the accuracy of one micro (see Figure 14). Data analysis is performed using SPSS (version 21; IBM Corporation, New York, USA) within a 95% confidence level. A, B, and C differences are analyzed using descriptive statistics (see Table 5).

Table 4. The result of the repetition test

No	A (mm)	B (mm)	C (mm)
1	10.004	9.988	7.000
2	10.004	9.988	6.995
3	10.001	9.987	6.998
4	10.005	9.988	6.997
5	10.006	9.990	7.002
6	10.008	9.992	7.000
7	10.000	9.983	6.992
8	10.000	9.982	6.994
9	10.001	9.983	6.995
10	10.001	9.982	6.988

In Table 4; considering A, B, and C for 10 samples (N), a mean of M=10,0030 is calculated for A, a mean of M=9,9863 for B and M=6,9961 for C with standard deviations SD=.002789, .003561, .004202 respectively.

Table 5. Descriptive results for A, B, C

	N	Mean	Std. Deviation
A	10	10,00300	,002789
B	10	9,98630	,003561
C	10	6,99610	,004202
Valid N (listwise)	10		

Fig. 14. The micrometer instrument

Positioning in the building platform test

In this test, five samples were printed and tested under the same circumstances with the previous experiment. The same shape has been implemented under this test. The only difference was the position of every one of the five samples; they were distributed in a 3x3 matrix (see Figure 15 and Figure 16).

1		2
	5	
3		4

Fig. 15. 3x3 matrix of the samples

Fig. 16. Separated samples in the building platform

The test results are given in Table 6, and the location of each sample is represented in Figure 15. The test was made by the use of a micrometer with the accuracy of one micro (as given in Figure 14).

Table 6. Result of the Positioning test

Position	A (mm)	B (mm)	C (mm)
1	10.018	9.985	6.993
2	10.002	9.981	6.994
3	10.011	9.985	6.990
4	10.009	10.006	7.008
5	10.000	9.983	6.992

As seen in Table 7; considering A, B, and C for 5 samples (N), a mean of M=10,0080 is calculated for A, a mean of M=9,9880 for B and M=6,9954 for C with standard deviations SD=.007246, .010198, .007197 respectively.

Table 7. Descriptive statistics for different positions

	N	Mean	Std. Deviation
A	5	10,00800	,007246
B	5	9,98800	,010198
C	5	6,99540	,007197
Valid N (listwise)	5		

IV. DISCUSSION

After doing the three experiments, the output results seem to be acceptable after which was mentioned in Previous sections. One of the most effective parameter was the exposure time both for the normal layers and the base layers (normally they are first layers attached to the building platform from 3 to 5 layers), and the exposure time can be fixed for each printed layer thickness. For example, if the desired printed part in 50 micro it will be 900 ms and for 100 micro it will be 1450 ms and for 200 micro it will be 3200 ms and so on. The time increasing when the layer thickness is increasing (these numbers has been extracted throw many experiments). On the other hand, for the based layers, 12000 ms is needed to let the object fully attached to the building platform. The second parameter was the speed of the Z-axis. It is proved that, 160 mm/s is the ideal speed for it, also low speed does not give better results. The other important point was the lifting distance for Z- axis during printing to let the cured layer separate from the FEP film and letting the fresh resin to gathering again underneath the printing part.

This printer is based on the simplicity in usage, so any one can use it. However there are some recommendations that should be followed before using it. The place where this printer will work must have an air circulation mechanism because the curing mechanism can produce smell emission and it may be harmful for health. The person who use the printer should wear a mask for filtering the air and also should wear gloves during working with resin. Furthermore user should avoid looking directly to the light source for the eye safety.

V. CONCLUSION

In this study, a DLP 3D printer based on SLA technology has been successfully made, with an available component in the market with several self-made components, together they assemble this printer with the lowest costs. One of the aims of this research is to make this technology more spreaded in the future for the academic students and for the manufacturers to benefit from this technology along with the other AM technologies.

Different 3D models and self-made 3D designed models ensure the printing quality in different sizes and shapes and have been printed using this DLP printer with satisfactory surface quality and dimension measurements using the commercial 3D printing resin. The printing procedure was so easy from the beginning until the end of the 3D model that even the post-process mechanism was simple, and anyone can use it without any previous knowledge by just following some steps. However, it still has the problem that after the printing process is finished some cleaning process has to be made to ensure there is no resin remain in the resin vat or the building platform unlike the other AM technology like FDM is not require any cleaning process.

There is still more room for improvement of this DLP 3D printer; as given in the previous chapters, the printed 3D models' surface is not very soft. It has some obstacles, and it appears in some shapes in some parts of the model.

The next step to get a good surface is to use a more specific projector for this purpose with UV light, not a regular light as it was used in this study.

The aim after this study is to implement this technology in the medical production to produce a biocompatible material that can be implemented in the human body such as dental implants, dental coverage, and fillings. These products can help the dentist to produce more accurate shapes with much lower time

REFERENCES

[1] 3D sourced, "The Complete History of 3D Printing: From 1980 to 2020" Internet: https://3Dsourced.com/guides/history-of-3D-printing/, February 13, 2020 [Nov. 29, 2022].

[2] Leo Greguric, "History of 3D Printing: When Was 3D Printing Invented?" Internet:https://all3Dp.com/2/history-of-3D-printing-when-was-3D-printing-invented/, Dec10,2018 [Nov. 29, 2022].

[3] Matthew Mensley, "2020 Best Resin 3D Printers" Internet: https://all3Dp.com/1/best-resin-dlp-sla-3D-printer-kit-stereolithography/, Mar15,2020 [Nov. 29, 2022].

[4] Hironori Kondo, "SLA vs FDM: Is Resin 3D Printing Faster?" Internet: https://all3Dp.com/2/sla-vs-fdm-is-resin-3D-printing-faster/ Apr 7,2020 [Nov. 29, 2022]

[5] Vice,"How to remove a DLP color wheel (and in my case also destroy the projector)."Internet: https://packet39.com/blog/2016/03/19/how-to-remove-a-dlp-color-wheel-and-in-my-case-also-destroy-the-projector/, March 19, 2016 [Nov. 29, 2022].

[6] Demetris Zavorotnitsienko "11 - Projector Modifications." Internet: http://www.os-rc.com/en/ilios-documentation-page/37-11-projector-modifications, [Nov. 29, 2022].

[7] Philip Le Riche "Acer S1210 DLP Projector Colour Wheel Replacement" Internet: https://www.ifixit.com/Guide/Acer+S1210+DLP+Projector+Colour+Wheel+Replacement/95071, [Nov. 29, 2022].

[8] "Dell 2400MP Key Specifications :," no. March, p. 78682, 2006.