THE EFFECTS OF MINITUARISATION OF PROJECTION STEREOLITHOGRAPHY EQUIPMENT ON PRINTING QUALITY

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Abstract: Additive manufacturing methods are popularly used in rapid prototyping and rapid manufacturing in the industry and recently they have gained popularity also in hobbyist crowds. Miniaturization of an additive manufacturing device would make it more portable, affordable and thus more accessible for everyone, but it is also important that the manufacturing quality is not remarkably reduced. In the scope of this survey, a miniature stereolithography 3d printer was built to study the effect of low cost, system components on the printing quality.

Key words: projection stereolithography, additive manufacturing, portable.

1. INTRODUCTION

Stereolithography (SL or SLA) is the oldest method of additive manufacturing, patented already 1986 by Charles Hull. In SL, solid objects are often made by curing resin with light rays of the ultraviolet region or by a high power laser (Figure 1). If a projector is used as a source of light, the method is called projection stereolithography (PSLA). As SLA is one of the oldest additive manufacturing methods, it is also one of the most accurate ones to date. Resolutions of manufacturing axes can go as low as 50 nm. The SLA is however restricted by its materials which are typically polymer based.

Fig.1. Setup for SLA equipment. CAD file is uploaded to a computer which controls the laser, scanning mirrors and platform in the tank filled with resin to build the desired object. [3]

The purpose of this study was to build a low-cost, small and even portable, PSLA device which could also compete with the commercial devices with its printing quality. In PSLA manufacturing, thin layers (usually < 300 µm) of the object are formed on a platform one at a time by projecting an image with resembles a single layer of the object being manufactured. This platform has one movement axis which allows these layers to be stacked on top of each other. Stacked layers form the final three-dimensional object.

2. RESEARCH METHODS

For research purposes a testing apparatus was built, that would allow the testing of benefits and downfalls of each component orientation setup used in SLA –systems. These orientation setups can be seen in Figure 2. Movement of the platform was achieved by a 1 mm screw pitch. Tests
were done with a layer thickness of 125 μm which corresponds to a 1/8 turn of the screw.

The problem could be solved with a sweeper that flattens the surface just before curing \[^9\], but with the size limitations that was not possible to carry out.

The third method is a less traditional horizontal setup (Fig. 2.c). In this method the projector is set to project the picture through the side of the container and the projection platform is again inside the container against the sidewall. The platform is then moved horizontally as the layers are cured.

The resins used in these tests were Photopolymer PIC 100, and PIC 100 with added EC 500 by EnvisionTEC. The PIC 100 reacts best with wavelengths close to the ultraviolet spectrum and added EC 500 makes it more sensitive to ambient light. Tests were carried out with two different types of projectors, Digital Light Processing (DLP) – projector and laser projector, using a diffusing-wave spectrometer. The results can be seen in Figure 3. As can be seen, the DLP-projectors (line) light spectrum goes much closer to the ultraviolet area (below 400 nm) than the laser projector (cut-line). This was further confirmed with a curing test in which the laser projector was not able to cure the resin at all.

First method that was tested was the top-down-orientation (Fig. 2.a). In this orientation the projector was placed under a clear plastic container and the projection platform was placed inside against the bottom of the container, only leaving one layer thickness gap in between the two. When a layer was cured the platform was raised to detach the cured layer from the bottom and to let new resin flow in between the already cured layer and the bottom of the container. After this the platform was lowered back leaving one layer thickness gap between the bottom and the lastly cured layer.

During the testing progress it was noticed that the surface tension of the resin leads to a problem that the surface isn’t completely flat. This leads to serious deformations, for example air bubbles inside the object. This problem could be solved with a sweeper that flattens the surface just before curing \[^9\], but with the size limitations that was not possible to carry out.
3. RESULTS
The Z-axis resolution was tested with previously mentioned test rig. Resin was placed on a see-through platform as light was projected on the resin from beneath. In the first test, the used resin was the PIC100 with a projection distance of 19 mm.

Figure 4 show that the layer thickness is approximately linear function of curing time. The PIC 100 with added EC 500 was tested in a similar way as the PIC100, with only difference being the distance of the projector and the projected surface (120 mm). The resin was cured onto the up and down moving platform. The first five layers were cured as a whole square using a curing time of 180 s. Secondly eight “chess board” layers were cured using a 60 s curing time. For each layer the platform was moved 125 µm. This adds up to a total of 1625 µm printed, which can be seen from Figure 5.

The main limitation of the resolution in the X-Y-plane is the resolution of the projector. The theoretical resolution can be calculated from the resolution of the projector and the size of the projected picture. The X-axis length of the projected picture in the test was 39 mm and the X-axis resolution for the projector is 854 pixels. With these numbers a resolution of 21.9 pixels/mm can be calculated.

In the projected checkerboard pattern, the width of one white square was 86 pixels. This would result in squares with a width of 3.9 mm. The squares printed were measured to be 4.3 mm wide by average. Figure 5 shows some geometric errors as well: the sharp corners were rounded during the curing process and some other deformations are noticeable in the second and third square of the top row. These geometrical anomalies could be solved by focusing the picture better and using more transparent glass to project through.

4. DISCUSSION
4.1 Device orientation
The major benefit of top-down method was the minimal amount of resin needed. There only needs to be minimum of one layer thickness of resin on the bottom of the container, but of course it has to be taken care of that the resin covers the whole region of the projection platform. Another benefit is that the height of the object isn’t restricted by any physical dimension of the components. The only problem with this setup was that sometimes the layer would stick to the bottom of the container instead of detaching. After coating the container
with non-sticking silicone elastomer this was no longer a problem. For tall and thin objects there might be a need for some reinforcement structures to keep the part in one piece during the building process.

In the second method, the bottom-up – orientation (Fig. 2.b), the projection happens straight on to the surface of the resin and the platform is then moved downwards after the layer cures. With this method the sticking is no problem and container wouldn’t need the silicone coating. First downside comparing to the first method is that this method needs a full container of resin to work. Also the height of the container physically restricts the size of the object that can be manufactured.

Horizontal orientation was tested last. The major difference compared to the top-down –orientation is that this method needs the full container of resin to work. Otherwise the benefits and downfalls are similar; the surface of the containers sidewall provides a flat area to project layers on but it still needs to be coated with the silicone elastomer. Because the density of the cured material and the resin is the same there is no need for any additional reinforcement structures for the part.

The greatest benefit that the horizontal gives is the stability of the setup. The top-down and bottom-up orientations have their centre of mass relatively high with a small area to stand on, making them unstable. The horizontal setup gives larger area to stand on with a lot lower centre of mass.

4.2 Accuracy
The z-axis resolution of the device is restricted theoretically only by the incremental movement of the platform. In this study, the lead screw was operated manually by turning the screw ⅛ revolutions at a time which corresponded to an approximate of 125 µm translation of the platform. Difference and variation in layer thicknesses this way were inevitable. To increase the resolution z-axis, a stepper motor will be used in the final assembly. With a stepper motor, a resolution of 10 µm for layer thicknesses on translation side is well achievable. However, the linear translation of a single step is not absolute. The accuracy and same time the resolution of the z-axis can be enhanced with the use of reduction gear [5].

The z-axis accuracy is also affected by the curing depth and depth focus. Curing depth is the maximum curing depth of a single layer a source of light can cure with single type of resin. Depth focus is the depth in where the projected picture is in focus. These properties can be enhanced with optics. These properties usually do not radically restrict the resolution, but sets the maximum layer thickness producible with constant accuracy. These were not in the scope of this research and a single layer thickness of 125 µm was used which was found to establish sufficient results through trial and error.

The resolution of both X and Y-axis was found to be near 0.4 mm. Theoretically it is restricted by the projector output resolution as well as the projected picture size on the inner wall of the container. X and Y-resolution seemed to mainly suffer from the blurriness and roundness of projected sharp edges. This may be due cross-talk effect, where polymers near the light might also get cured [6]. Also, the variation of light intensity in different parts of the picture is believed to derive from projector properties. This feature can later on be corrected for example by using intensity corrected background image.

There are many possibilities that can be achieved with a MiniPµSLA system. A MiniPµSLA system can easily be transported and used anywhere. The user will have the possibility to build accurate and robust parts.
5. REFERENCES


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