Modelling the Stereo-lithography Process

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Abstract

Absorption, scattering, reflections and other physical phenomenon of light all interplay in a complex way during the stereolithography process of 3D printing. In the project, we investigate a means of modelling all these factors wholistically. We show through simulations and experiments that there is spatial linearity in the response of resins to light sources. Further experiments could be build on these initial result to make similar characterization of the curing process as a function of exposure intensity and duration.

1. Introduction

Stereolithography (SLA) was the first fully commercial rapid prototyping technology (patented in 1986) [1] and is still most widely used. The high resolution capabilities of light means SLA can handle complex design & geometrical configurations; hence, high levels of accurate design details are possible. These and a number of other advantages make the DLP SLA technology widely applicable for rapid prototyping, jewelries, industrial printing as well as medical implants which require high level of detail.

Different DLP- Stereolithography printers have diverse specifications (of slice thickness, resolution etc.) which are determined through some design considerations/limitations which is not well reported in literature. A mathematical model for the stereolithography process would define a standard for characterizing resins, 3D printing time/ performance vis-à-vis different types of resins and would also create a framework for research advancement in this area. With a standard procedure derived from the model, different resin makers can do the evaluation of the engineering parameters of their products themselves and report numbers which give the needed information for producers of 3D printer to calibrate their machines to support these various resins. This might open up the stereolithography market a little more.

2. Related Work

There are a number of physical phenomena with complex interactions in the stereolithography process; this makes accurately accounting for each of them very involved. These phenomena are either light-based (scattering, absorption, reflection, refraction etc) or material properties related. Few works have tried to analyze these characteristics.

Due to large shrinkages of acrylate resins, there is a related shape deformation in the SL process which makes characterizing curing properties challenging. [2] investigates how slice generation by computer-aided design (CAD) can be optimally planned to alleviate/control the effects of the deformation. A mask image planning method for reducing the shrinkage-related deformation was developed which generates different exposure mask patterns for each layer which are time-multiplexed i.e. each layer is cured with different decomposed exposure patterns.

This project focuses on the light-related characterization of the stereolithography process. We seek to model (predict) the shape that results when resin is exposed to a particular light configuration (intensity/duration). This would lead to a formulation of the inverse problem to determine the configuration of light needed to form the shape of a desired 3D object.

3. Method

The main idea of this project is the cone-based approximation as the point response function of the curing process of a given photo-resin. From observing that the curing process of light-sensitive resins evolve to form solid cone-shaped structure- whose size is dependent on exposure parameters, we experimentally model how the evolution of this cone size occurs.

We focused on modelling this evolution as a function of each of three variables:

- Intensity level of exposure
- Duration of exposure

- Spatial frequency of point source

Experiments were set-up to vary each of these parameters.

Measurements

For our experiments, we measured the base radius as well as height to characterize each of the solidified point responses.

The equation of a cone is given as:

$$\frac{(x-x_o)^2}{a^2} + \frac{(y-y_o)^2}{b^2} = \frac{(z-z_o)^2}{c^2}$$

We assume a regular cone i.e.: a= b = base radius, c= height of cone.

In order to make a reasonably accurate measurement, snapshots of the cured material is taken with a camera from an angle that closely captures the base and height information. Then, the snapshot is passed into an interactive MATLAB application where pixel counts between clicked points can be scaled to give the accurate measurements in metric units. Note that letters on printed text are used as reference to calculate the metric values if needed; the captured scene is made up of the 3D print placed closely beside a printed text.

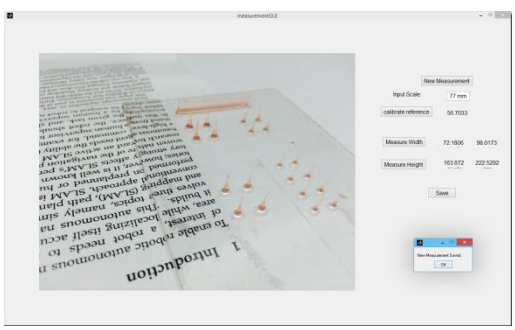

Figure 1: Measurement of cured resin. The text in the scene is used as reference for calibration.

4. Experimental Results

4.1. Intensity level of exposure

Liquid resin was exposed to an array of point sources of different intensities to form solidified cones. The base radius and height of each of the cones were measured and plotted as a function of the intensity level of each point source. Figure 2 show the result of these measurements.

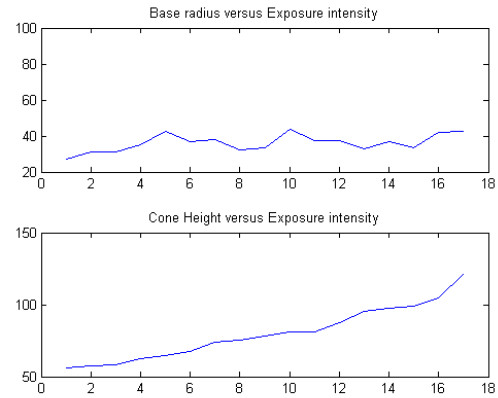

Figure 2: Size of cured cone as a function of intensity of exposure.

4.2. Duration of exposure

Figure 3 shows the response of resin to point source of varying exposure duration. This time, the size (base radius and height) of the cone is a function of the duration of exposure.

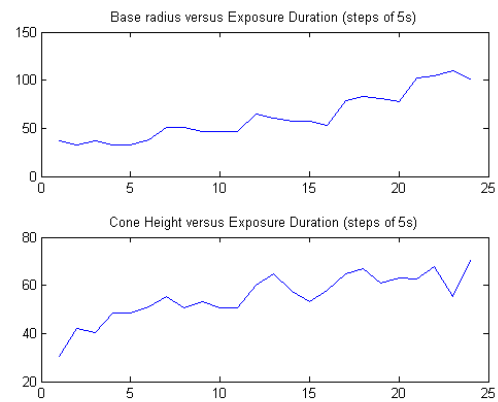

Figure 3: Size of cured cone as a function of duration of exposure.

4.3. Spatial frequency of point source

Simulations were run on MATLAB to model the linear combination of "cone-shaped point responses. The height of formation at each point is a summation of the individual contribution for each point source. Figure 4 shows the results of this simulation

Similar set-up was carried out experimentally. Resin was exposed to an array of point sources with varying inter-spacing keeping exposure time and intensity constant. The resulting formations were very comparable the simulation results. We can observe the linearity that takes place as the spacing between point sources get closer.

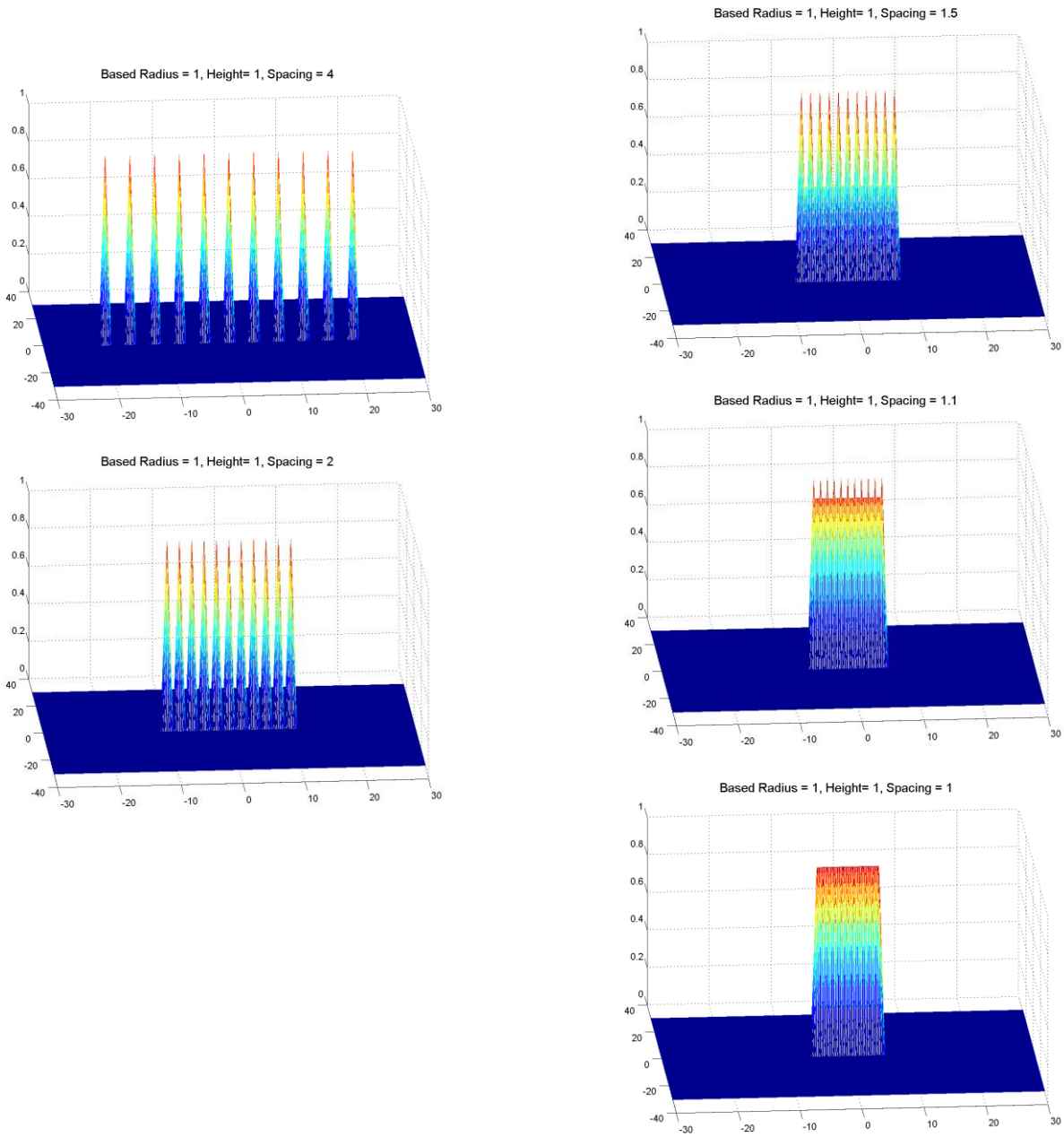

Figure 4: Simulation results using MATLAB to add-up "cone-shaped" impulse response

Figure 4: Experimental results “cone-shaped” impulse response to varied spacing of point source

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5. Conclusion and Future work

The MATLAB simulations and experimental results agree on the spatial linearity of response to point light sources.

More experimental data might be needed to further assess the validity of the models. In addition, since the cone-based model is approximation uses the basic formulation of defining a cone by its base radius and height (with a straight slanting edge), it would interesting to check the performance of modelling the edge of the cone with a quadratic edge.

The model parameters derived in this work was a function of each of the parameters (intensity level, duration and spacing). Experimentally validating how the response varies with changes in a combination of parameters would be an ideal next step.

References

[1] LeGault, M.R. “The rise of rapid manufacturing” (2009) High-Performance Composites, 17 (4),

[2] Pan, Y., Zhou, C., Chen, Y., Partanen, J. “Multitool and multi-axis computer numerically controlled accumulation for fabricating conformal features on curved surfaces” (2014) Journal of Manufacturing Science and Engineering, Transactions of the ASME, 136 (3), art. no. 031007,

6. Clarification of Workdone for this Class Project

This class project was a continuation of previous research work in Fall-2014 which focused on understanding and formulating the problem. Literature was checked for related works and the experimental approach was chosen over theoretical analysis because of the complexities in accounting for the various light phenomena. The B9Creator DLP printer was set-up to perform some experiments towards gaining initial insights into the curing process for stereolithography.

This winter, we leveraged on the previous insights to formulate a quasi-linear model of combining the “cone-like” point response of resins to a line point source. A MATLAB application was designed to interactively make measurements of cured resins by selecting distances to measure. The measurements were used to fit a function for the base radius and height of cured cone as a function of each of exposure time, exposure intensity and spatial resolution of an array of point sources. MATLAB was used to simulate and visualize the influence of these variables on the shape of the formed object, assuming the “cone-based” assumption is valid.