Structural Heatmap Creation of Resin Curing for 3D Printing Applications

EE 368 Project Proposal, Autumn 2015, Leandra Brickson

Motivation and Overview:

Excitement in 3D printing as a rapid prototyping and low scale production method has been steadily growing throughout the last decade. Among 3D printing techniques, Stereolithography (SLA) has shown to be one of the highest resolution techniques; leading to smooth, high detail structures. This process uses a projector or laser to harden thin layers of liquid photoreactive resin to build a final structure. However, the SLA process is very slow due to the layer-by-layer nature of the print. The printing speed of SLA could be dramatically increased if there was more control of the resin curing process to allow thicker layer, or single layer exposure of a 3D printed structure. In order to do this, the resin curing process must be modeled in order to predict resin response to a certain illumination pattern. This project looks at creating a growth and heatmap model of resin using experimental HDR images and IR camera images in order to accurately model and understand the resin curing process.

Background: The Resin Curing Model & Its Relation to Temperature

Fraction of resin cured is calculated from the exposure dose using the following equation:

$$Fraction\ Cured\ =\ 1 - e^{-C*E}$$

Where C is the reaction efficiency coefficient and E is the exposure dose. This fraction cured can be related to heat generation in the following way:

$$\frac{d}{dt}Fraction\ Cured\ =\ (\frac{1}{Q}) * \frac{d}{dt}Temperature$$

Where Q is the heat proportionality constant, which is related to the molar heat of the reaction. This heat is generated at the curing point and is then dissipated into the resin according to the heat equation:

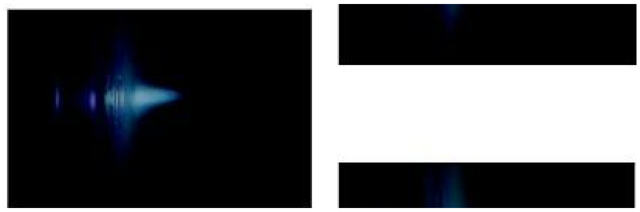
$$\frac{d}{dt}Temperature\ =\ \alpha * \triangle Temperature$$

Where $\triangle$ is the laplace operator and α is the thermal diffusivity. As the temperature of the liquid resin increases, this contributes thermal energy to the system, which in turn decreases the amount of exposure dose needed to cure. This revises the first equation to the following:

$$Fraction\ Cured\ =\ 1 - e^{-C*(E+F*T)}$$

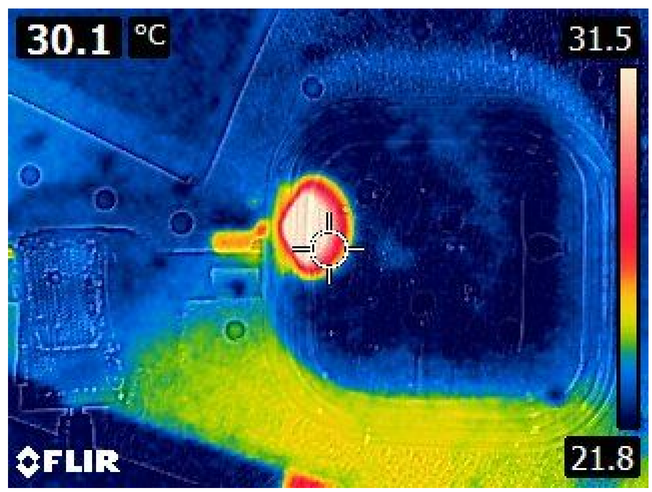
Where F is the energy conversion from temperature, which is dependent on the specific heat and other material properties of the resin. Using these equations, we can create a model for resin curing which is characterized by 4 coefficients; C, F,Q and α. Since we know the characteristics of the heat generation and transfer, we can find these coefficients by fitting to experimental data. This project will create a heatmap and structural dataset using a FLIR camera and DSLR camera images for fitting to this model. Using this, we can solve for the material parameters needed. There are two main goals for the project:

Goal 1: Structure Growth Extraction



As the resin cures, pictures are taken for characterization. These pictures are misaligned HDR images with varying light intensities and varying profiles, examples are shown in the figure on the right. The goal will be to align these sequential HDR images and then do edge detection of each picture to determine the shape of the resin as it cures. By doing this, a 2D shape of the hardened resin will be resolved from these images and the growth can be accurately visualized. Information such as structure height and width at any time will be easily determined. Alignment of these photos is non-trivial since the captured object is changing shape each time. Different edge detection methods will also be investigated for finding the outline of the structures.

Goal 2: Heatmap Creation of Resin Structures.
Along with camera images, an FLIR camera will be used to take IR images of the resin. The FLIR camera can take overlapping IR images and normal images. This can be seen in the bottom figure, which shows heat releasing as resin is exposed. However, with the on board camera, we don't have control of the images taken (exposure time, bracketing, etc). Therefore, we would like to combine these IR images with the structural information derived in goal 1. We will do this by aligning the IR images with the images from Goal 1 to create a 2D heatmap of the structure. This will show the change in temperature of the structure during exposure and a heatmap of the surrounding liquid resin as well.



With these two goals, the result should be an experimentally gathered modeling of resin shape and temperature generation/ dissipation throughout exposure. This can be fit to the known heat generation and transfer equations to solve for the material parameters C, F,Q and α to allow accurate curing prediction models.

References:

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[2] Mack, Chris, *Fundamental Principles of Optical Lithography: The Science of Microfabrication.*
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[3] Reiser, Arnost *Photoreactive Polymers : The Science and Technology of Resists*
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