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A process planning method for improving build performance in stereolithography

A.P. West, S.P. Sambu, D.W. Rosen*

The George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0405, USA

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Abstract

A process planning method is presented to aid stereolithography users in selecting appropriate values of process variables in order to achieve characteristics desired in a part to be fabricated. To accomplish this, the method achieves a balance of objectives specified by geometric tolerances, surface finishes, and part build time, where the balance is specified through preferences on the objectives. Given these objectives and preferences, values are chosen for six process variables to best achieve the balance of objectives. The process variables include part orientation, layer thicknesses, and four recoat variables (Z-level wait time, sweep period, hatch overcure, and fill overcure). The process planning method is adapted from multiobjective optimization and utilizes empirical data, analytical models, and heuristics to quantitatively relate process variables to the objectives. Of particular importance, a new adaptive slicing algorithm has been developed. The process planning method is demonstrated on a part with non-trivial geometric features. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Stereolithography; Process planning; Adaptive slicing

1. Introduction

The stereolithography (SLA) technology is inherently a very flexible process, one that admits over 20 process variables. This flexibility allows parts and features on those parts to be built very accurately and efficiently. However, the SLA technology is complex enough that even experienced operators may not be able to select appropriate variable values to achieve desired build objectives. It is with this in mind that we are conducting research in process planning for SLA. Through the use of empirical data, analytical models, and heuristics, methods of process planning may be developed that enable even novice users of SLA to achieve efficient and high quality builds. We believe that the methods, if not the specific data, are applicable to other layer-based manufacturing processes.

The purpose of this paper is to present a new method of process planning for SLA that seeks to balance the sometimes conflicting requirements on accuracy, surface finishes, and build times. The method is based on a multiobjective optimization problem formulation, called the compromise Decision Support Problem (cDSP), where geometric tolerances, surface roughnesses, and build times are the multiple objectives. The optimization method seeks to minimize an aggregate measure of deviation from accuracy, finish, and build time targets. The variables to be found during optimization include part orientation, layer thicknesses, and SLA process variables (scan and recoat variables). Although a specific set of variable values may enable one goal to be met, they may have unwanted effects on the other two goals. Users can specify preferences for these goals to best match their prototyping needs. For example, sometimes speed is the overriding objective, in which case, build time will be weighted more heavily than accuracy or surface finish. In contrast, for those cases where functional prototypes are desired, accuracy may be the most important consideration and will be weighted more heavily. It is the ability to perform trade-off analyses among these build goals that is the primary contribution of this process planning method.

To support the method, a formulation of the process planning problem is presented that is based on a series of three cDSP's for selecting part orientations, slicing schemes, and SLA parameter values. Mathematical models of constraints and goals are presented for each cDSP. Goals can be thought of as soft constraints, whose target values are not always achieved. For this work, goals include accuracy, surface finish, and build time. Empirical models are presented for each goal as a function of SLA process variables.

* Corresponding author. Fax: +1-404-894-9668.
E-mail address: david.rosen@me.gatech.edu (D.W. Rosen).

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Constraints include the effects of support structures and large horizontal planes.

In most approaches to rapid prototyping process planning, a single objective is sought, either to minimize build time or to minimize surface roughness. In our approach, we recognize that multiple objectives may be important to a prototype and that different prototypes will require different importance levels of those objectives. As in most process planning approaches, we utilize an adaptive slicing capability; ours is an extension of methods from the literature that works particularly well with our process planning method. We also utilize empirical models of geometric tolerance capability, surface roughness, and build time as functions of SLA process variables.

Stereolithography creates solid objects using a layer-based manufacturing approach [1]. The physical prototypes are manufactured by fabricating cross-sectional contours or slices one on top of another. These slices are created by tracing with a laser two-dimensional (2D) contours of a CAD model in a vat of photopolymer resin. The prototype to be built rests on a platform that is dipped into the vat of resin. After each slice is created, the platform is lowered and the laser starts to trace the next slice of the CAD model. Thus the prototype is built from the bottom up. The creation of the physical prototype requires a number of key steps: input data, part preparation, layer preparation, and finally laser scanning of the 2D cross-sectional slices. The input data consist of a CAD model, a precise mathematical description of the shape of an object. Part preparation is the phase at which operator controlled parameters and machine parameters are entered. These parameters control how the prototype is fabricated in the SLA machine. Layer preparation is the phase in which the CAD model is divided into a series of slices, as defined by the part preparation phase, and translated by software algorithms into a machine language. This information is then used to drive the SLA machine and fabricate the prototype. The laser scanning of the part is the phase that actually solidifies each slice of the CAD model in the SLA machine.

After reviewing relevant literature in Section 2, we present our SLA process planning problem formulation in Section 3. In Section 4, we present our overall solution procedure and specific algorithms for each major module. Two examples are used to illustrate the usage of our method and demonstrate its advantages and limitations in Section 5. Conclusions and recommendations for future serve as the paper's closure.

2. Background

2.1. Process planning literature

Currently there is a great deal of literature available for process planning of layer-based manufacturing technologies such as SLA. This literature spans from topics such as build process optimization [2], to inaccuracy prediction and correction [3], and support structure generation [4]. The work presented in this paper relates to the process planning issues that arise when building prototypes in SLA.

Many researchers have investigated adaptive slicing of parts for layer-based fabrication. The objective of adaptive slicing is to develop a slicing scheme, or method of slicing the CAD model, that meets a user-defined tolerance. This tolerance, commonly referred to as a cusp, serves as an indication of the allowable deviation between the true CAD model surface and the physical surface of the prototype. The error associated with this deviation is present in all layer-based manufacturing technologies to one degree or another and is referred to as the stairstep effect. Separately, Dolenc and Mäkelä [5] and Tata [6] were some of the first researchers. They adaptively sliced parts that were represented using STL files. Other researchers, including Sabourin et al. [7], Kulkarni and Dutta [8], and Xu et al. [9] have presented adaptive slicing methods that slice CAD part models represented by analytical surfaces. All approaches attempt to improve the geometric accuracy of the physical prototype by calculating the appropriate layer thickness based on the local geometry of the CAD model, which will minimize the error associated with the stairstep effect to an acceptable level as defined by the cusp. The effect of the adaptive slicing method is to reduce the layer thickness in areas of high vertical curvature. Generally, this work seeks to meet cusp specifications, while minimizing the time to build the prototype.

Marsan et al. [10] take a broad view of the overall process planning activity and break process planning into four steps. The first step involves entering design data into a Solid Builder, used to generate a B-rep solid model. The next step is orienting the solid model in the Orientation Module, based on one of the following criteria: minimum build height, minimum support contact area, maximum area of base, minimum volume of supports, or minimum average surface roughness. The supporting structure is then automatically generated. Next the oriented solid model is passed on to an Adaptive Slicing Module, where it is adaptively sliced to minimize the error associated with the stairstep effect. The final module is Path Planning which is currently undertaken using commercial software. The process planning system outlined supports a variety of layer-based manufacturing technologies.

Research at Georgia Tech has focused on developing methods to facilitate trade-offs among build time, accuracy, and surface finish goals. McClurkin and Rosen [11] developed a computer aided build style selection (CABSS) tool that aids users in making trade-offs among these goals. Only three variables were considered: part orientation (three discrete choices), layer thickness, and hatch spacing. Lynn [12] extended this work by conducting a detailed study of SLA accuracy. That research presents a method where response surfaces [13] are used to quantify the achievable accuracy for a set of geometric tolerances applied to a