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Reduction of post-processing for stereolithography systems by fabrication-direction optimization

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Abstract

The surface of stereolithography parts become rough due to the stair-stepping effect and burrs from the support structure. Therefore, most parts need some finishing work for further applications. Because post-processing operations are performed by skilled workers and require additional time and cost, the reduction of post-processing time and cost is a high priority. Basic approaches to minimizing post-processing are investigated. Surface roughness is analyzed through theoretical models and experiments developing an interpolation method to predict the behavior of the roughness under various equipment conditions and fabrication styles are conducted. Part orientation is optimized by a post-processing objective function. To accelerate the optimization, a model mapping method is developed and verified. An expert system is implemented by the suggested algorithms and examined by several models in real a workshop.

Keywords: Stereolithography; Rapid prototyping; Post-processing; Part orientation; Build direction; Genetic algorithm

1. Introduction

The needs for Rapid Product Development (RPD) are growing, given the rapid change of products in the market. Rapid prototyping, one of the major techniques in RPD, is used to verify three-dimensional CAD models, evaluate their functionality, and manufacture tools for test and production. Rapid prototyping systems are based on layered manufacturing technology. This technology fabricates three-dimensional parts by stacking two-dimensional layered features.

The Stereolithography Apparatus (SLA), one of the most popular prototyping machines, fabricates parts out of photopolymeric resin directly from a CAD model without intermediate tooling by stacking layers in the opposite direction to gravity. It requires support structures to hold cured resign and stacked layers during the fabrication process. The stair-stepping effect occurs when fabricates an inclined surface by stacking several layers. And, the removal of support structures results in attachment burrs. The stair-stepping effect and attachment burrs are the two largest factors that worsen surface quality in rapid prototyping systems such as SLA. Because of their poor surface quality, most parts fabricated from rapid prototyping systems are not suitable for direct use in functionality testing and tool making. These parts require post-processing to improve surface roughness, and the finishing process needs skilled workers and takes a relatively long time [1]. Thus there is strong need to develop an algorithm which reduces the post-processing and fabrication times and costs.

In most cases, the fabrication direction, the layer stacking direction or the so-called part orientation, is selected according to the machine operator's experience and discretion. Research on fabrication-direction optimization is mainly concerned with fabrication itself. But the direction also impacts on post-processing. Therefore, an automated optimization system that considers building and post-processing simultaneously is desirable.

This study intend to find appropriate objective functions to optimize and develop an expert system which can determine the optimal fabrication direction and reduce

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post-processing. A roughness prediction method devised with the interpolation of experimental data is introduced for the accurate prediction of surface roughness. A genetic algorithm is implemented for the optimization. And a model mapping method is developed and evaluated in order to accelerate the computation.

2. Related research

The stair-stepping effect is one of the major factors related to surface roughness and has been investigated by many researcher in order to improve the surface quality of stereolithography parts. Burrs from support attachments are not so frequently considered in surface quality issues but the structure is considered in determining laser scanning time or resin consuming cost.

The simplest idea for reducing surface roughness is to reduce the layer thickness of a slice. This reducing produces better finished parts but increases the build time and requires new material or a new recoating mechanism [2]. Several methods are being developed to improve the fabrication process such as meniscus smoothing, diagonal irradiation, and the adaptive layer thickness system. Meniscus smoothing utilizes the natural capillary attraction of a liquid polymer for cured versions of itself [3]. After a layer is completed, the part is raised above the liquid level, allowing a meniscus to form. Then, appropriate laser exposure of the residual meniscus cures the resin, thereby greatly reducing stair-stepping errors. The diagonal irradiation method improves surface roughness by means of stacking diagonal shapes solidified by diagonal laser irradiation [4]. Adaptive slicing methods assign a smaller thickness layers where the slope is flatter and a larger thickness layer where the slope is steeper [5]. They produce results that are more accurate if the numbers of layers used on a model are the same for both methods. Sloped cutting of EPS foam produces a good roughness surface but there are still many problems resulting from the weakness of this material [6]. Though these process improvements or thinner layer thickness systems increase part accuracy or finish, they usually require additional fabrication time and specially designed hardware.

In the stereolithography process, the fabrication direction of a part affects many factors such as fabrication time, fabrication cost, the support structure, and the trapped volume. Therefore, the optimization of the fabrication direction requires a trade-off among the factors. For optimization, Pham et al. [7] developed an expert system that selects the fabrication direction among CAD modeling data rather then analyzing an STL model. Cheng et al. [8] suggested a multi-objective optimization method for optimizing fabrication time and part accuracy simultaneously in SLA by assigning weights to various surface types affecting part accuracy. Lan et al. [9] determined the fabrication direction for the SLA process by establishing decision criteria and algorithms considering the surface quality, fabrication time and the complexity of the support structure. For variable layer thicknesses systems, Hur and Lee [10] developed an algorithm to calculate the stair-stepping area and quantify the process errors represented by volume that should be removed or added to the part, and suggested an optimum layer thickness. For generic part orientation, Masood and Rattanawong [11] developed a system that slices the part with horizontal planes and computes the volumetric error at different orientations by rotation about user-specified axes. This system proposes the best orientation for the least volumetric error in the part. Majha et al. [12] studied geometric optimization to obtain minimal stair-stepping, support structures and contact area.

Without post-processing, it is impossible to produce satisfactory prototypes in most rapid prototyping systems. And for the most labor-intensive work, polishing or finishing, are addressed for each material used in a different rapid prototyping system. Grinding methods such as barrel tumbling and vibration finishing were applied to rapid prototyping parts by Cobb et al. [13]. Williams and Melton [14] applied abrasive flow machining to stereolithography parts. Statistical analyses are used to determine the effects of media grit size, media pressure, build style, build orientation and resin type on flatness, the material removal rate and surface roughness.

There are many studies on the fabrication time and cost of parts that underwent rapid prototyping before the post-processing operation [15]. But it is difficult to find an example that focuses on post-processing. The rapid prototyping machine builds prototypes automatically without an operator, yet it often requires labor the intensive post-processing operation that should be considered in the process planning stage. Therefore, in this study, a method is developed for the estimation of post-processing time and cost that is required for improving surface quality to the designed level. And an algorithm for fabrication-direction optimization was developed to minimize both burrs from support attachments and the rough surface from stair-stepping. This study also suggests a simplification method for the fast optimization of developed algorithms.

3. Surface roughness of a part

The SLA stacks layers in the vertical direction like other layered manufacturing technologies. Fig. 1 explains how the SLA makes the staircase. To form a layer the SLA solidifies liquid photopolymeric resin from the resin surface to the depth of the layer thickness. The solidification is accomplished by laser scanning along the sliced contours and filling hatches. The stair-stepping effect occurs when the layers of an inclined facet or a curved surface are stacked. The surface roughness of stereolithography parts is mainly caused by the stair-stepping effect and is affected by various properties such as layer thickness, print through effects,