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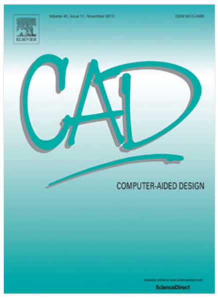

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Volumetric Covering Print-Paths for Additive Manufacturing of 3D Models

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Abstract

In additive manufacturing (AM), slicing is typically used to manufacture 3D models, one layer after another. Yet, in recent years quite a few hardware platforms were introduced toward the use of multi-axes AM with general 3D curves as print-paths. This paper presents algorithms for the generation of such general print-paths that can potentially be used to synthesize superior 3D models using AM. In slicing, a 3D model is decomposed into a series of parallel planar sections, which in turn are (usually) decomposed into a set of piecewise linear curves used as print-paths in the AM process. The methods we propose in this work ease this restriction, namely the print-paths are no longer limited to parallel planes. Like slicing, the methods we propose achieve a complete covering of a general volume with print-paths expressed as general curves. However, and unlike slicing, the created print-paths can conform better to the 3D model, its properties, and even user input. We expect that the added flexibility and freedom in the specification of AM print-paths, as opposed to limiting them to planar curves, will enable the synthesis of 3D models (using AM) with superior properties (such as mechanical strength and surface finish). As a proof of concept, we also present examples of 3D models manufactured with a low-end AM hardware and using the algorithms described in this paper.

Keywords: Additive manufacturing, 3D-printing optimization, Volumetric covering
2010 MSC: 00-01, 99-00

1. Introduction

Contemporary additive manufacturing (AM) systems largely use slicing [1]. Slicing deconstructs a three dimensional object (often specified by a polygonal mesh) to a series of two dimensional parallel (to the printing surface) planar sections. These planar sections, in turn, are decomposed into piecewise linear paths for the manufacturing process to use. In general, the slicing planes are not intrinsic to the input object. The surface finish, the strength, and possibly other properties of an object printed using some existing AM techniques, are influenced by the slicing orientation and the print-paths used to create it [2, 3]. One of the conclusions in [2] is that parts fabricated with the expected tensile loads aligned with the fibers (print-paths) would have greater effective tensile strength, and could handle greater loads. Additionally, the experiments in [4] showed that parts manufactured using curved layers that fit the part geometry (as opposed to the flat layers used in slicing) performed better under mechanical stresses. An illustration of the possible advantages of print-paths that conform to the model geometry over slicing can be seen in Figure 1. Both Figure 1 (a) and (b) show the result of printing the same model (a section from the model in Figure 2), on the same printer, using the same resolution (layer-height is 0.3mm). However, in Figure 1 (a) the model was printed using print-paths that conform to the model geometry, while in Figure 1 (b) slicing was used. Figure 1 (c) and (d) show the simulated preview of the printing result for (a) and (b) respectively. As the images show, the slicing result suffers from surface finish issues due to aliasing, the so called the staircase effect, that comes from approximating a curved shape with planar sections. In this effort, we seek to create print-paths that are more dependent on design goals, and less dependent on constraints imposed by the printing process, allowing the creation of superior printed objects in terms of surface finish, strength, etc.

There are quite a few reports on the use of multi-axis robotic hardware platforms in AM, which would allow non-planar 3D printing without using slicing [5, 6, 7, 8]. Such a hardware platform would be able to print along the main feature lines of a 3D object and gain the advantages mentioned before when compared to slicing. Yet, algorithmic support is lacking. We are aware of no algorithm that is capable of covering the volume of an arbitrary 3D object using any general user defined univariate (curve) tool paths, while also establishing a valid printing order, fully exploiting these platforms toward multi-axis AM.

Our main contributions in this paper are:

(1) Presenting an algorithm that can generate covering curves for general 3D objects represented by (possibly trimmed) trivariate volumes, that conform to the geometry of the trivariate, toward AM.

(2) Supporting the use of an additional external direction field that can be used to specify AM printing-paths for any general B-rep (boundary representation) 3D model (including polygonal meshes).

(3) Algorithms that enable the use of general (possibly user defined) 3D printing-paths, while controlling their width, resolving their accessibility, and establishing valid AM printing order and coverage.