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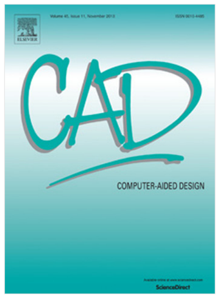

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Anti-aliasing for fused filament deposition

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Abstract

Layered manufacturing inherently suffers from staircase defects along surfaces that are gently slopped with respect to the build direction. Reducing the slice thickness improves the situation but never resolves it completely as flat layers remain a poor approximation of the true surface in these regions. In addition, reducing the slice thickness largely increases the print time.

In this work we focus on a simple yet effective technique to improve the print accuracy for layered manufacturing by filament deposition. Our method works with standard three-axis 3D filament printers (e.g. the typical, widely available 3D printers), using standard extrusion nozzles. It better reproduces the geometry of sloped surfaces *without* increasing the print time.

Our key idea is to perform a local *anti-aliasing*, working at a sub-layer accuracy to produce slightly curved deposition paths and reduce approximation errors. This is inspired by Computer Graphics anti-aliasing techniques which consider sub-pixel precision to treat aliasing effects. We show that the necessary deviation in height compared to standard slicing is bounded by half the layer thickness. Therefore, the height changes remain small and plastic deposition remains reliable. We further split and order paths to minimize defects due to the extruder nozzle shape, avoiding any change to the existing hardware. We apply and analyze our approach on 3D printed examples, showing that our technique greatly improves surface accuracy and silhouette quality while keeping the print time nearly identical.

Keywords: Fused filament fabrication, staircase, anti-aliasing, sub-layer, curved layers.

1. Introduction

Additive manufacturing (AM) technologies produce objects layer-by-layer. The final physical object is thus made of flat slabs of materials stacked on top of each others. As a consequence, only horizontal and vertical planar surfaces can be closely matched. All other regions suffer from approximation errors, which are often referred to as the *staircase effect*. This issue is illustrated in Figure 1 (b) and (c), where a wedge model is sliced into flat layers (layer thickness 0.6 mm) and 3D printed using a filament printer.

Such staircase defects lead to a deviation of the printed result from the input model, where necessary volumes in the input model may be removed in the printed result (red regions in Figure 2), while unnecessary volumes that do not exist in the input model may appear in the printed result (yellow regions in Figure 2). In addition, the final result lacks the smooth geometry of the virtual input model.

A typical approach to minimize staircase defects is to print with thinner layers, which increases the accuracy of the surface approximation. This, however, is achieved at the expense of a large increase in print time (roughly, print time doubles for each reduction of layer thickness by half). The minimal thickness is also limited by material properties – for filament printers the process becomes challenging under $50\mu m$, even though results down to tens of microns have been demonstrated by experts using precisely calibrated hardware.

Many approaches have been proposed to improve this situation, in particular by using different layer thicknesses in different parts of the model (see Section 2). However these approaches still rely on flat layers: the staircase effect is reduced but not removed, and the print time is increased.

We observe that the staircase defect bears similarity with *aliasing* in Computer Graphics, in particular when rasterizing continuous geometry on-screen produces a similar effect. In Computer Graphics, aliasing is often fought by considering information at a sub-pixel scale. We propose to follow a similar idea, and consider sub-*layer* information to produce toolpaths that are subtly