Turning Free-form Surfaces into Manufacturable Components

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Figure 1: *To fabricate a mesh (possibly acquired by laser scanning) in a molding process, we decompose the shape into parts that largely satisfy molding constraints. The resulting constraint violation (b) can be removed by deformation (c). A reusable multi-piece mold can be produced from the final mesh by CNC milling (d) and physical copies can be produced by mold casting in different materials like resin (left) or plaster (right) (e). The buste model is provided by the AIM@SHAPE Shape Repository.*

Abstract

We consider the problem of manufacturing free-form geometry with classical fabrication techniques such as mold casting or milling. We derive a set of constraints that guarantee manufacturability. A combined deformation and segmentation algorithm yields parts that satisfy the constraints. Our main observation is that allowing some deformation significantly reduces the number of resulting parts and, thus, extends the range of shapes that can be generated in practice. Examples of actual molds and the resulting manufactured shapes for several well-known meshes demonstrate our claims.

1 Introduction

Recent developments in 3d printing have liberated digital manufacturing: today virtually arbitrary shapes can be printed and design is no longer constrained by the manufacturing process. Nonetheless, classical manufacturing techniques such as casting, stamping and 3-axis milling still have a variety of interesting and unique properties: large production volumes at low price per unit, short production times, versatility of materials and surface finishes, robust structural properties — to name a few. Unfortunately, classical manufacturing techniques are severely limited in terms of shape. E.g. only heightfields can be produced by 3-axis milling. Moreover, expert knowledge about the production technology is typically necessary throughout the design process.

Our objective is to provide a tool that helps manufacturing of arbitrary shapes using classical techniques. We observe, that a sufficient condition for manufacturability is that each part of the surface is a heightfield. To make a given free-form surface manufacturable, we decompose the surface into a small number of heightfield patches. To our knowledge, there is no system available that can execute this task automatically. However, for most shapes asking that each component satisfies the manufacturing constraints leads to a large number of components. Small intricate features can never be represented by a single heightfield and have to be divided into multiple parts. Hence, segmenting the shape is not enough and further processing is necessary to obtain an object that can be manufactured in practice.

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2 Segmentation & Deformation

We base our algorithm on the following observation: let $\mathbf{d}$ be the direction normal to the base plane of a surface. Then the surface is a heightfield if it is simply connected, has a simple boundary, and each face normal encloses an angle smaller than $\pi/2$ with $\mathbf{d}$. We sample a large set of directions $\{\mathbf{d}_i\}$ and identify face sets that can be part of a heightfield for direction $\mathbf{d}_i$. This results in a set of labels for each face, representing possible fabrication directions. The main idea of our approach is that small 'islands' violating the heightfield constraints can be fixed by small deformations or simple fill-in. This can result in a significant reduction of parts for more intricate shapes. To segment the shape into manufacturable parts, we strive for a labeling of the face set minimizing an energy. The energy models manufacturing constraints such as total number of components and the normal constraint violation, limited to small simply connected areas. An approximate minimizer of the energy is computed by a multi-label graph cut algorithm [Boykov et al. 2001]. The resulting labeling of the faces induces a segmentation (Figure 1a). The remaining error (Figure 1b) is removed by an adapted version of as-rigid-as-possible mesh deformation.

The final parts can then be fabricated by different techniques such as casting, milling or stamping. We demonstrate the production of reusable multi-piece molds by CNC milling. The molds can then be used to cast the shape using materials like plaster or resin.

3 Discussion

We introduce a method that enables free-form surfaces to be manufactured by a variety of classical fabrication techniques and demonstrate the practicability of our approach. We believe that our algorithm can be of great use for engineers and enables casual users to engage into small series production leveraging techniques like injection molding and milling.

Acknowledgments The buste model is provided by the AIM@SHAPE Shape Repository.

References

BOYKOV, Y., VEKSLER, O., AND ZABIH, R. 2001. Fast approximate energy minimization via graph cuts. *IEEE Trans. Pattern Anal. Mach. Intell. 23*, 11 (Nov.), 1222–1239.