From Visible to Printable: Thin Surface with Implicit Interior Structures

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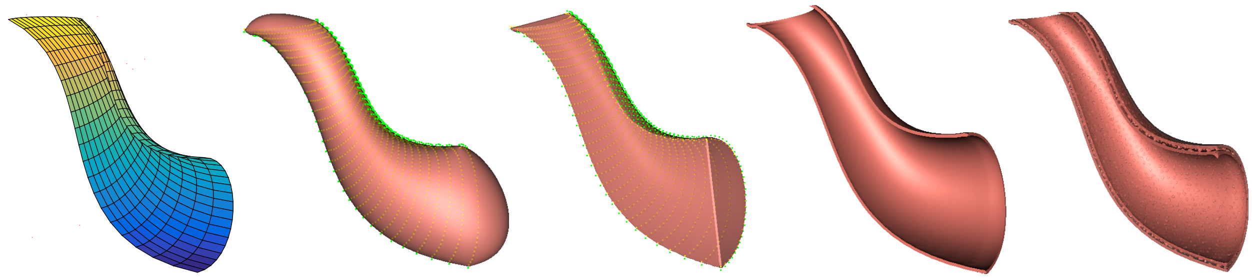

Figure 1: Construction of Thin Spout with Interior Structure

ABSTRACT

Converting a surface-based objects into a thin-surface solid representation is an essential problem for additive manufacturing. This paper proposes a simple way to thicken surfaces to thin solids based on implicit modelling technique. With the proposed technique, any surface-based object can be converted into a 3D printing friendly form that seamlessly combines both the geometric shape and its interior material structures in one single representation.

CCS CONCEPTS

• **Computing methodologies → Modeling methodologies**;

KEYWORDS

Implicit Offset Surface, Thin Implicit Surface, Implicit Interior Structures

ACM Reference format:
Quan QI and Qingde LI. 2018. From Visible to Printable: Thin Surface with Implicit Interior Structures. In *Proceedings of SIGGRAPH '18 Posters, Vancouver, BC, Canada, August 12-16, 2018,* 2 pages.
https://doi.org/10.1145/3230744.3230792

1 INTRODUCTION

Designing digitally manufacture-ready geometric objects is an essential task in the field of additive manufacturing. Geometric objects are commonly represented as surfaces due to the fact that surface-based geometric models are convenient for visualisation. However, a surface-based object is specified as an infinite thin boundary geometric shape without detailed description of its interior structures and materials. Such kind of objects are required to be converted to printable solids for additive manufacturing and interior structure reconstruction.

Parametric offset surfaces can be used on thickening surfaces. The thin solid surface thickened in this way is generally much more complex than the original surface [Maekawa 1999]. If the original surface is complex enough, it can be very difficult to get the corresponding offset surface. Although many approximation algorithms have been developed to solve this problem, it is still extremely hard to reconstruct thin solid from real-world objects with this technique and there is no effective way to embed interior structures into parametric thin solids.

In contrast, implicit modelling gives another solution on thickening surface-based objects. On the one hand, an implicit thin surface is a blending of two or more implicit objects. The thickness of the thin surface can be defined flexibly with any required accuracy. On the other hand, interior structures can be easily integrated into the implicit thin surface. These structures can be either designed with implicit represented geometric patterns or implicit object reconstructed from the interior structures of a real-world object.

2 METHODS

In the proposed method, the basic idea of converting surface-based objects to thin surface solids is based on implicit geometric reconstruction [Li et al. 2004] and implicit blending operations [Pasko et al. 1995].

In 3D space, implicit geometric reconstruction is to find an implicit surface $\mathcal{S} = Z(f)$ of a field function $f : \mathbb{R}^3 \to \mathbb{R}$, such that $f(\mathbf{P}_i) = 0$ for n distinct points $\{\mathbf{P}_i\}_{i=1}^{n}$, where $Z(f)$ is the 0 level-set of f.

Implicit blending operations are a series of set-theoretic operations acting on implicit objects with CSG techniques. Let $O_0 = \{\mathbf{X} \in \mathbb{R}^3 : f_0(\mathbf{X}) \leqslant 0\}$ and $O_1 = \{\mathbf{X} \in \mathbb{R}^3 : f_1(\mathbf{X}) \leqslant 0\}$ be two

SIGGRAPH '18 Posters, August 12-16, 2018, Vancouver, BC, Canada

ACM ISBN 978-1-4503-5817-0/18/08…$15.00
https://doi.org/10.1145/3230744.3230792

implicit objects represented by field functions $f_0 : \mathbb{R}^3 \to \mathbb{R}$ and $f_1 : \mathbb{R}^3 \to \mathbb{R}$. Then the intersection $O_0 \cap O_1$, union $O_0 \cup O_1$ and subtraction $O_0 \backslash O_1$ of O_0 and O_1 can be defined with an intersection blending operator $g : \mathbb{R}^2 \to \mathbb{R}$ in the following way:

$$\begin{cases} O_0 \cap O_1 = \{\mathbf{X} \in \mathbb{R}^3 : g(f_0(\mathbf{X}), f_1(\mathbf{X})) \leqslant 0\} \\ O_0 \cup O_1 = \{\mathbf{X} \in \mathbb{R}^3 : -g(-f_0(\mathbf{X}), -f_1(\mathbf{X})) \leqslant 0\} \\ O_0 \backslash O_1 = \{\mathbf{X} \in \mathbb{R}^3 : g(f_0(\mathbf{X}), -f_1(\mathbf{X})) \leqslant 0\} \end{cases} \quad (1)$$

2.1 Implicit Offset Surface

An implicit offset surface is an implicit surface reconstructed from a given surface representation such that the reconstructed implicit surface has a constant distance to the given surface.

An implicit offset surface $\bar{\bar{\mathcal{S}}}_d = Z(\bar{\bar{f}})$ with distance d to a surface object $\mathcal{S} = Z(f)$ can be approximately built by sampling n distinct points $\{\mathbf{P}_i\}_{i=1}^n \in \mathcal{S}$, such that $\bar{\bar{f}}(\mathbf{P}_i + d\mathbf{N}_i) = 0$, where $\mathbf{N}_i = \frac{\nabla f(\mathbf{P}_i)}{|\nabla f(\mathbf{P}_i)|}$, $i = 1, 2, \ldots, n$.

2.2 Thin Implicit Surface

A thin implicit surface can be regarded as a thin solid object blended with two offset surfaces of an implicit surface.

For constants $d_0 < d_1$, if implicit surface $\mathcal{S}$ has two offset surfaces $\bar{\bar{\mathcal{S}}}_{d_0}$ and $\bar{\bar{\mathcal{S}}}_{d_1}$, a thin implicit surface Ξ can be constructed as

$$\Xi = \bar{\bar{\mathcal{S}}}_{d_1} \backslash \bar{\bar{\mathcal{S}}}_{d_0} \quad (2)$$

and $d = d_1 - d_0$ is the thickness of the thin implicit surface.

2.3 Implicit Interior Structures

Real-world objects are of certain materials and structures. These structures are very difficult to be represented in surface-based forms. In contrast, implicitly represented structures can be easily embedded inside implicit objects thanks to the convenience in performing implicit shape blending operations.

Let $\bar{\bar{\mathcal{S}}}_{d_0}, \bar{\bar{\mathcal{S}}}_{d_1}, \bar{\bar{\mathcal{S}}}_{d_2}$ and $\bar{\bar{\mathcal{S}}}_{d_3}$ be four implicit offset surfaces of $\mathcal{S}$, where $d_0 < d_1 < d_2 < d_3$. Let O be an implicit object representing the interior structures. A thin implicit surface with interior structures can be directly constructed in the following way:

$$\begin{aligned} \Xi_o &= \bar{\bar{\mathcal{S}}}_{d_3} \backslash \bar{\bar{\mathcal{S}}}_{d_0} \\ \Xi_i &= \bar{\bar{\mathcal{S}}}_{d_2} \backslash \bar{\bar{\mathcal{S}}}_{d_1} \\ \Xi_s &= \Xi_i \backslash O \\ \Xi &= \Xi_o \backslash \Xi_s \end{aligned} \quad (3)$$

3 EXPERIMENTS

The thin surface with implicit interior structures proposed in this paper can be applied to both shape design and real-world geometric objects reconstruction. Figure 2 presents several examples. Translucent rendering is used for better observation of the interior structures.

The object in 2(a) is designed from a blending of two implicit ellipsoids. Objects in 2(b) and 2(d) are reconstructed from point sets extracted from real-world objects. Objects in 2(b) is a thin surface of a human face point set. Interior structures can be observed. Figure 2(c) gives the printed result. The object in 2(d) is a tibia with porous structures through its thin surface. It has been printed out as an object shown in 2(e). The object in 2(f) is converted from Utah teapot. Bézier surfaces are thickened to be thin implicit surfaces with the proposed method and interior structures are embedded. Figure 1 shows the surface thickening process of its spout.

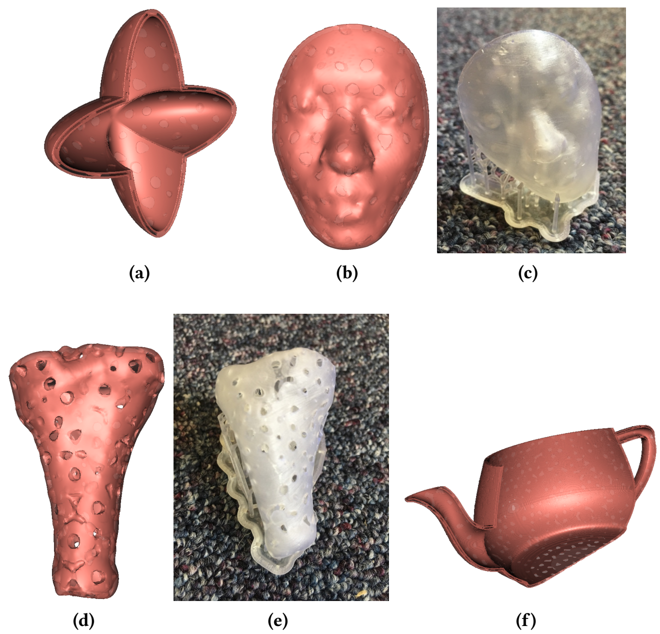

Figure 2: Thin Surfaces with Interior Structures

4 CONCLUSION

This paper gives a simple and effective method to convert surface-based objects to printable thin surfaces. Implicit offset surface is firstly used to construct thin surface with a certain thickness, and then interior structures are embedded inside the thin surface with implicit blending operations. A prominent character of this method is interior structures can be easily embedded inside thin surfaces, such that solid modelling and additive manufacturing of multi-materials and complex structures is much easier than traditional ways.

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