Cut-and-Paste Editing Based on Constrained B-spline Volume Fitting

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Abstract

This paper proposes an advanced cut-and-paste editing for three-dimensional models. We introduce a new parameterization technique based on constrained B-spline surface/volume fitting. Our cut-and-paste editing is performed on this parameterization. In our method, a parametric volume is generated so that its isoparametric surface fits to the base surface and the volume bounds the detail. Our volume fitting is realized by the optimization of an objective functional with a smoothness factor. We implemented and evaluated our method, and showed that our constrained fitting is effective to edit shapes that may have highly curved areas or handles.

1 Introduction

Cut-and-paste editing cuts or copies a part of the source media and pastes it to the target. It has been widely used for editing documents and images. Recently, this operation has intensively studied in three-dimensional geometric modeling. By using such a modeling operation, a user can easily cut a detail feature of a *source* model and paste it to another *target* model. In most cut-and-paste methods, the *base*s and the *detail*s are separated from the both source and target models, and the detail of the source is pasted onto the base of the target.

A lot of methods have been proposed for the cut-and-paste of three-dimensional models ([1][3][5][2]). They are convenient tools, and in many cases, allow interactive editing. However, they still have several problems, since (1) smooth parameterization is not easy, even if surface flattening techniques are applied to surfaces, (2) self-intersections may occur when surfaces are highly curved, (3) a region that is not homeomorphic to a disk cannot be pasted, and (4) parameterization cannot be controlled according to the user's intent.

Figure 1. Example of our cut-and-paste

This paper proposes an advanced cut-and-paste editing for solving these problems (see Figure 1 for an example). We introduce a new parameterization technique based on constrained B-spline surface/volume fitting. Our cut-and-paste editing is performed on this parameterization. In our method, a parametric volume is generated so that its isoparametric surface fits to the base and the volume bounds the detail. Our contributions are as follows:

- We proposed constrained B-spline volume fitting for cut-and-paste editing.
- We showed our constrained fitting is effective to edit shapes that have highly curved areas or handles.

The rest of this paper is structured as follows. In Section 2, we describe related work, and in Section 3, describe an overview of our parameterization technique and cut-and-paste editing. In Section 4, we will describe our parameterization method based on constrained B-spline fitting of surfaces and volumes, and in Section 5, cut-and-paste operations are explained. We will conclude in Section 6.

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2 Related Work

Much research has been done in cut-and-paste editing so far. The pasting technique by hierarchical splines [1][3] is well known. This technique pastes a local spline surface hierarchically on another spline surface. Recently, Biermann et al. [2] proposes interactive cut-and-paste editing of semi-regular multiresolution subdivision surfaces. This work consists of the integration of many improvements of previous methods for achieving interactive editing.

Suzuki et al. [10] explored moving existing features on a mesh. Kanai et al. [5] proposed cut-and-paste editing by mesh-based metamorphosis. Museth et al. [8] proposes cut-and-paste editing by the combination of CSG operations and smoothing based on level set.

The parameterization of surfaces is one of the essential parts of cut-and-paste editing. Many researchers have investigated the parameterization of mesh models ([4][9]). Kuriyama and Kaneko [7] propose a discrete parameterization for deforming meshes.

In addition, free-form fitting has intensively studied for reverse engineering, which generates parametric surfaces from 3D points obtained by 3D scanners. Krishnamurthy and Levoy [6] proposed resampling and fitting B-spline surface to dense polygon meshes. Weiss et al. [11] achieved automatic B-spline surface fitting by iterative surface fitting and reparameterization.

3 Overview of Cut-and-Paste Editing

This paper proposes a method of local parameterization based on constrained B-spline surface/volume fitting (LPCBF) and cut-and-paste editing of triangular meshes using LPCBF.

Figure 2 shows a sequence of cut-and-paste editing by LPCBF. Figure 2 (a) shows a selected region as the source, (b) shows the fitted B-spline surface and volume that includes the selected region and (c) shows the base surface of the source after cutting operation. Figure 2 (d) shows the target region to which the detail is pasted. Figure 2 (e) shows a lattice of control points of the fitted volume, by which the detail of the source is pasted to the target, and (f) shows the result after pasting operation.

We develop a new pasting method based on volume fitting approach as shown in Figure 3. Again, a user selects a source region for extracting the detail feature. The selected region can include highly curved areas or handles. Then, the user selects vertices near the boundary of the source region, and fits a B-spline surface using only selected vertices as shown in the left of Figure 3. Then, the original mesh region is subdivided into the base surface and the detail feature. In B-spline surface fitting, a user can easily add constraints such as fixed points and vectors. Such constrained surface fitting methods have been intensively studied in the

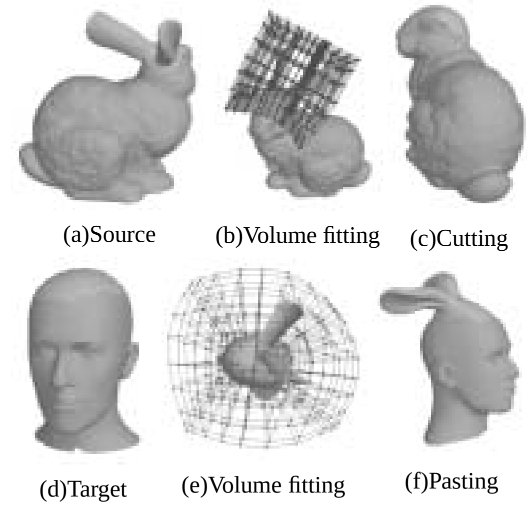


Figure 2. Sequence of cut-and-paste editing

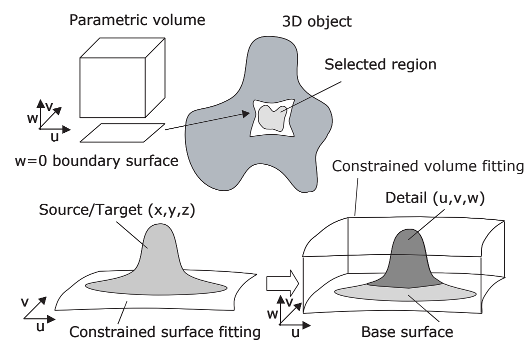


Figure 3. Parameterization based on parametric volume fitting

community of computer aided geometric design (e.g., in [11]). Next, the system generates a bounding B-spline volume that includes all vertices in the region as shown in the right of Figure 3. Control points of the B-spline volume can be determined by constrained B-spline volume fitting, which is an extension of the constrained B-spline surface fitting. Control points are obtained by minimizing the objective functional that include a smoothness factor and constraints given by the user.

4 Local Parameterization Based on Constrained B-spline Fitting (LPCBF)

Figure 4 shows a process of parameterization using B-spline fitting. The input data is points in regions selected by a user, and the output is the parameterization of each point. In this process, the B-spline fitting and the re-parameterization are iteratively performed. This framework is similar to Weiss's surface fitting [11], but we extend the

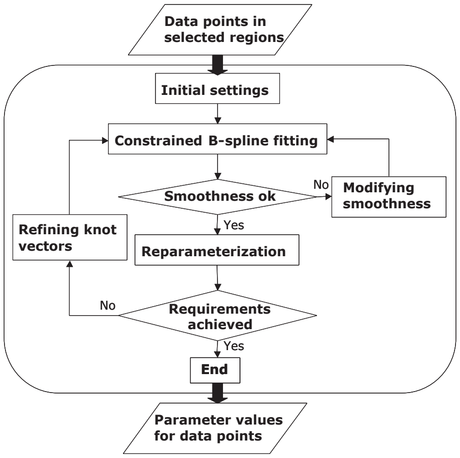


Figure 4. Flow of parameterization based on constrained B-spline fitting

method to volume fitting.

In this process, first, the initial settings are determined. In this step, parameters of input points, degrees and knot vectors of a B-spline surface are determined as the initial settings. Since they are optimized in the iterative process, they can be determined automatically. In addition to these settings, a user can add user-defined constraints such as fixed points and vectors. The user controls the parameterization of regions by such constraints if necessary. Then, constrained B-spline fitting is applied to the input points. If the fitted B-spline surface has reversed faces or self-intersections, or is not smooth enough to be the base surface, B-spline fitting is applied again after the number of control points in the initial settings is increased or the smoothness factor of fitting are modified. If the B-spline surface is sufficient, the input points are projected onto the B-spline surface and they are reparameterized using (u, v) values at the projected points. Then, the objective functional is evaluated if it satisfies the given tolerance. If the condition is satisfied, the process terminates; otherwise, B-spline fitting is re-calculated under the new parameterization of points.

In the rest of this section, we describe constrained B-spline fitting and reparameterization in more detail.

4.1 Surface Fitting

Surface fitting is an optimization problem as follows:

$$F_e^S(\mathbf{P}) \to \min \text{ subject to } \mathbf{C}^S(\mathbf{P}) = 0, \tag{1}$$

where $\mathbf{P}$ is a set of control points of B-spline surface and $\mathbf{C}^S$ is a set of constraint equations that include fixed points and tangent vectors. We define the objective functional F_e^S using the squared sum of differences F_p^S between the B-spline surface $\mathbf{S}$ and input data $\mathbf{Q} = \{\mathbf{Q}_t | t = 0, \cdots, n-1\}$ whose parameters are (u_t, v_t), a non-negative weight β^S and the smoothness factor F_s^S as follows:

$$\begin{aligned} F_e^S &= F_p^S + \beta^S F_s^S, \\ F_s^S &= \iint \left(|\mathbf{S}_{uu}|^2 + 2\,|\mathbf{S}_{uv}|^2 + |\mathbf{S}_{vv}|^2 \right) dudv. \end{aligned} \tag{2}$$

This factor is useful not only for smooth parameterization but for the stable optimization especially when the number of unconstrained inputs is small.

Once we obtain control points that minimize the objective functional, we re-calculate parameters of points. New parameter values $(\bar{u}_t, \bar{v}_t)$ of $\mathbf{Q}_t$ in the surface $\mathbf{S}$ satisfy

$$\mathbf{J}(\bar{u}_t, \bar{v}_t)\left(\mathbf{Q}_t - \mathbf{S}(\bar{u}_t, \bar{v}_t)\right) = \mathbf{0}, \tag{3}$$

where $\mathbf{J}$ denotes the Jacobian of the surface. This equation means that the difference of $\mathbf{Q}_t$ and $\mathbf{S}(\bar{u}_t, \bar{v}_t)$ has to be orthogonal to the tangent plane of the surface. This equation can be numerically solved by the Newton method in a few iterations.

4.2 Volume Fitting

Volume fitting is an optimization problem as follows:

$$F_e^V(\mathbf{P}) \to \min \text{ subject to } \mathbf{C}^V(\mathbf{P}) = 0, \tag{4}$$

where $\mathbf{C}^V$ is a set of constraint equations that include fixed points, tangent vectors and isoparametric surfaces. We define the objective functional F_e^V using the squared sum of differences F_p^V between the B-spline volume $\mathbf{V}$ and data $\mathbf{Q}$, a non-negative weight β^V and the smoothness factor F_s^V:

$$\begin{aligned} F_e^V &= F_p^V + \beta^V F_s^V, \\ F_s^V &= \iiint \left(|\mathbf{V}_{uu}|^2 + |\mathbf{V}_{vv}|^2 + |\mathbf{V}_{ww}|^2 \right. \\ &\left. +2\,|\mathbf{V}_{uv}|^2 + 2\,|\mathbf{V}_{vw}|^2 + 2\,|\mathbf{V}_{wu}|^2 \right) dudvdw. \end{aligned} \tag{5}$$

Points $\mathbf{Q}_t$ in the volume $\mathbf{V}$ are reparameterized to new parameter values $(\bar{u}_t, \bar{v}_t, \bar{w}_t)$ by numerically solving

$$\mathbf{V}(\bar{u}_t, \bar{v}_t, \bar{w}_t) - \mathbf{Q}_t = \mathbf{0}. \tag{6}$$

5 Cut-and-Paste Editing by LPCBF

5.1 Base and Detail

We suppose that $\mathbf{Q}_t$ $(t = 0, \cdots, n-1)$ is parameterized by using the bounding volume $\mathbf{V}$ as $\mathbf{Q}_t = \mathbf{V}(u_t, v_t, w_t)$. Then, the base surface $\mathbf{Q}_t^b$ and the detail feature $\mathbf{Q}_t^d$ can be described as follows:

$$\mathbf{Q}_t^b = \begin{cases} \mathbf{V}(u_t, v_t, w_t) & \text{if} \quad t \in B \\ \mathbf{V}(\bar{u}_t, \bar{v}_t, 0) & \text{else} \end{cases}, \tag{7}$$

$$\mathbf{Q}_t^d = \begin{cases} \mathbf{V}(u_t, v_t, 0) & \text{if} \quad t \in B \\ \mathbf{V}(u_t, v_t, w_t) & \text{else} \end{cases}, \tag{8}$$

where B is a set of point indices on the boundaries of the selected region, and $(\bar{u}_t, \bar{v}_t, 0)$ are parameter values on the isoparametric surface of the volume after resampling.

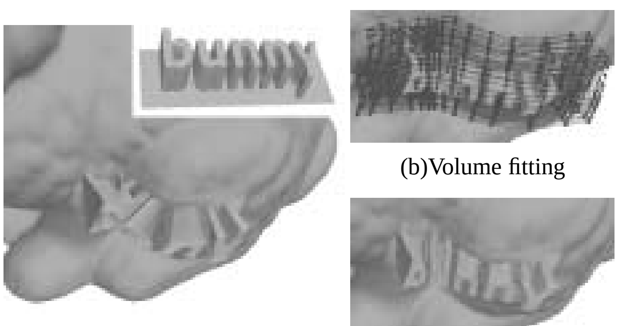
After the location of pasting is specified and the target region is remeshed again, the detail feature is pasted by using volume fitting. A volume is initially defined as a bounding B-spline volume that has the initial parameter settings, and then, its control points are determined by minimizing the objective functional.

5.2 Experimental Results

We implemented cut-and-paste editing by LPCBF and evaluated using several examples. Figure 2 shows one of the examples.

Figure 5 shows an example of editing that pastes extruded features on a highly curved surface. Figure 5 (a) shows the detail to be pasted and possible self-intersections by pasting the detail on a highly curved region. Figure 5 (b) shows a lattice of control points of a fitted volume to prevent such self-intersections and (c) is the result of pasting.

Figure 6 shows an example to edit a shape that is not homeomorphic to a disk. In Figure 6 , a handle extracted from a cup is pasted to a target by volume fitting.



(a)Self-intersections (b)Volume fitting (c)Result

Figure 5. Preventing self-intersections

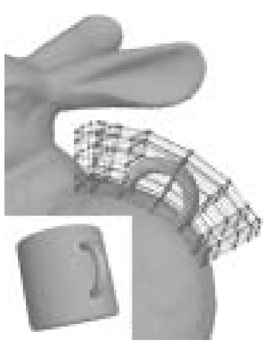


Figure 6. Pasting a handle

6 Conclusions

In this paper, we proposed a constrained B-spline fitting approach for cut-and-paste editing, and realized flexible cut-and-paste editing. Our method can be applied to shapes that have highly curved areas or handles.

Our method has the following limitations that should be solved in future work; (1) If we need precise fitting, which requires a large amount of control points of B-spline, interactive editing may be difficult; (2) It is difficult to drag the detail over the target region, although it is very useful.

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