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Generating subdivision surfaces from profile curves

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Abstract

The construction of freeform models has always been a challenging task. A popular approach is to edit a primitive object such that its projections conform to a set of given planar curves. This process is tedious and relies very much on the skill and experience of the designer in editing 3D shapes. This paper describes an intuitive approach for the modeling of freeform objects based on planar profile curves. A freeform surface defined by a set of orthogonal planar curves is created by blending a corresponding set of sweep surfaces. Each of the sweep surfaces is obtained by sweeping a planar curve about a computed axis. A Catmull–Clark subdivision surface interpolating a set of data points on the object surface is then constructed. Since the curve points lying on the computed axis of the sweep will become extraordinary vertices of the subdivision surface, a mesh refinement process is applied to adjust the mesh topology of the surface around the axis points. In order to maintain characteristic features of the surface defined with the planar curves, sharp features on the surface are located and are retained in the mesh refinement process. This provides an intuitive approach for constructing freeform objects with regular mesh topology using planar profile curves.

Keywords: Sketch; Sweep; Subdivision surface; Blending; Feature

1. Introduction

Although there is a large number of tools for the manipulation of curves and surfaces, techniques specifically developed for the construction of freeform objects, and especially organic shape objects, are rare. In most commercial graphics and CAD systems, a popular approach for the construction of organic freeform objects is to edit the shape of a primitive object e.g. a cube, a sphere or a cylinder so that it conforms to some projected outlines of an object. Another approach is to interpolate a freeform surface through a network of freeform curves. These freeform objects are then combined to give more complex shapes. All these rely very much on the experience and skill of the designer in manipulating curves and surfaces.

An alternative is to construct freeform objects based on planar sketches. There has been a considerable amount of research work in the construction of 3D objects from planar curves. Much work has been focused on the automatic reconstruction of a 3D model represented by a single sketch or a set of sketches describing the object [1–5]. However, most of these works concentrate on the construction of engineering components from sketches. In the construction of freeform objects from sketches, Zeleznik [6] adopted a gesture-based technique for interactively constructing 3D rectilinear models from sketches. Igarashi [7] proposed a technique for generating polygon models from sketches. In this approach, a single curve representing a view-dependent planar projection of an object is used. A polygon mesh interpolating the curve is generated. Different polygon meshes can then be merged to give more complex shaped objects. Karpenko et al. [8] adopted a similar approach for modeling freeform objects using implicit surfaces. Besides the use of sketches for the construction of 3D models, there are works on the use of sketches as a mesh editing or deformation tool [9,10]. While works on the construction of freeform models from sketches are mainly confined to the construction of mesh models, this paper focuses on the construction of freeform objects modeled with subdivision surfaces. This allows different resolutions of the constructed models to be generated for different purposes which is essential in particular for interactive applications. Based on the observation that designers usually design 3D forms using two orthogonal sketches [11], the proposed technique generates 3D objects from planar curves lying on two principle planes.

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Subdivision surfaces were introduced by Catmull–Clark [12] and Doo–Sabin [13] in the late 1970s. Other subdivision schemes [14–18] have also been introduced since the 1980s. However, subdivision surfaces were not widely adopted in CAD and computer graphics until the late 1990s when DeRose [19] successfully applied subdivision surface for character modeling and animation. Although subdivision surfaces have now become a standard surface type in popular graphics software, and are particularly suitable for modeling objects with irregular topology, the modeling of freeform objects with subdivision surfaces relies very much on the skill and experience of the user. Using subdivision surfaces, a complex freeform object is represented with a single surface. This requires careful planning of the topology of the base mesh. In general, base mesh editing tools are required to modify the topology of the mesh in the construction process. A popular approach is to construct simple primitives (e.g. box, sphere, cylinder, etc.) with subdivision surfaces. These primitives are then deformed to match a region of the final shape. The deformed primitives are then merged to obtain the final object. Throughout the process, the base mesh is considered as a polyhedral model of the final shape. The use of interpolatory subdivision schemes [15–18], or fitting a subdivision surface through a set of data points [20–23] or curves [24–27] allows surface points to be manipulated directly. However, the basic problem of selecting an appropriate set of object points or curves for the base mesh remains a critical issue.

In this paper, a subdivision surface is constructed by specifying two planar curves lying on two principle planes. These two curves are the projections or profile curves of the object on the corresponding principle planes. Sweep surfaces constructed with the profile curves are then blended to give the target shape of the object. A subdivision surface interpolating a set of data points on the object is then constructed. Fig. 1 illustrates the process in the modeling of a freeform object using the proposed algorithm. This method serves to produce the base mesh of a subdivision surface interpolating a set of profile curves. Since the object created is a standard subdivision surface, existing shape editing techniques such as freeform deformation (FFD) [28] and axial deformation [29,30] can be applied to further adjust the shape of the object.

1.1. Generating surface from projections on the principle planes

Given the projections of a closed surface $\mathbf{s}$, which are represented as smooth curves $\mathbf{c}_1, \mathbf{c}_2, \mathbf{c}_3, \mathbf{c}_4$ lying on the principle planes as shown in Fig. 2, $\mathbf{s}$ is constructed such that the axis of $\mathbf{s}$ is defined by these curves and is expressed as

$$\mathbf{a}(t) = \{a_x(t), a_y(t), a_z(t)\} \tag{1}$$

where

$$a_x(t) = \frac{c_{1,x}(t) + c_{3,x}(t)}{2}, \quad \text{and} \quad 0 \leqslant t \leqslant 1 \tag{1.1}$$

$$a_y(t) = \frac{c_{2,y}(t) + c_{4,y}(t)}{2} \tag{1.2}$$

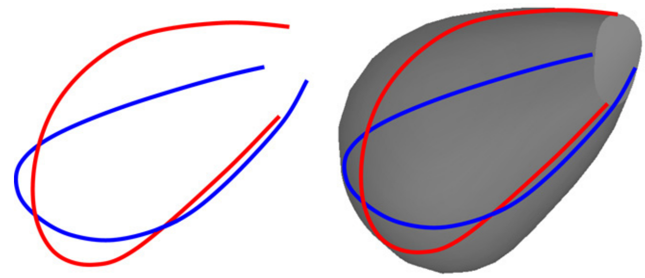

Fig. 1. Constructing a freeform object from profile curves.

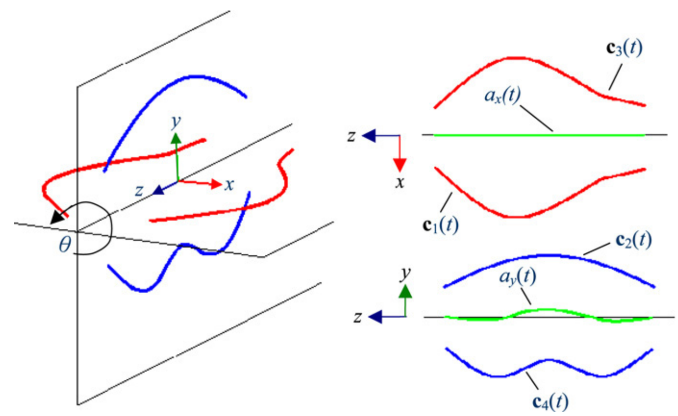

Fig. 2. Projection curves and the corresponding center lines.

$$a_z(t) = \frac{c_{1,z}(t) + c_{2,z}(t) + c_{3,z}(t) + c_{4,z}(t)}{4}. \tag{1.3}$$

Assume that the projection of $\mathbf{s}$ onto the x–z plane is determined by $\mathbf{c}_1$ and $\mathbf{c}_3$, and the projection of $\mathbf{s}$ onto the y–z plane is determined by $\mathbf{c}_2$ and $\mathbf{c}_4$. The surface $\mathbf{s}$ can be considered as a combination of four individual sweep surfaces. Each of these sweep surfaces is specified in a quadrant defined by the principle planes. Let $\mathbf{s}_i$ be the surface generated by $\mathbf{c}_i$ and $\mathbf{c}_j$, where $j = i + 1$ for $i < 4$, and $j = 1$ for $i = 4$, then

$$\mathbf{s}_i(\theta, t) = \{s_{i,x}(\theta, t) s_{i,y}(\theta, t) s_{i,z}(\theta, t)\}. \tag{2}$$

For $i = 1$, and $0 \leqslant \theta < \frac{\pi}{2}$

$$s_{1,x}(\theta, t) = (c_{1,x}(t) - a_x(t)) \cos\theta + a_x(t), \tag{3.1}$$

$$s_{1,y}(\theta, t) = (c_{2,y}(t) - a_y(t)) \sin\theta + a_y(t), \tag{3.2}$$

$$s_{1,z}(\theta, t) = c_{1,z}(t) + \frac{\theta}{\pi/2}(c_{2,z}(t) - c_{1,z}(t)). \tag{3.3}$$

For $i = 2$, and $\frac{\pi}{2} \leqslant \theta < \pi$

$$s_{2,x}(\theta, t) = -(c_{3,x}(t) - a_x(t)) \cos\theta + a_x(t), \tag{4.1}$$

$$s_{2,y}(\theta, t) = (c_{2,y}(t) - a_y(t)) \sin\theta + a_y(t), \tag{4.2}$$

$$s_{2,z}(\theta, t) = c_{2,z}(t) + \left(\frac{\theta}{\pi/2} - 1\right)(c_{3,z}(t) - c_{2,z}(t)). \tag{4.3}$$

Similar expressions can be obtained for $i = 3, \pi \leqslant \theta < \frac{3\pi}{2}$, and $i = 4, \frac{3\pi}{2} \leqslant \theta < 2\pi$.