Geometric Modeling using 2D template by Freehand Drawings

Weizhong Liu†, Kunio Kondo†, Jun Mitani‡
† Department of Information and Computer Sciences, Saitama University
‡ RIKEN

ABSTRACT: We present a geometric modeling tool by freehand drawings. The idea is to use a 2D template topology library as an essential tool to reconstruct and modify the 3D shape step by step. The template topology library is called T-LIB which is consisted of 2D Edge Graphs and the corresponding algorithms to generate 3D objects. We analyze the local structure around the input strokes as a 2D Edge Graph. Once the Edge Graph can be matched to a template of T-LIB, the 3D object can be generated in basic shape reconstruction procedure, or modified in 3D shape modification procedure. After we get the polyhedral network, we use fillet operation and subdivision to get smooth shape.

KEYWORDS: CG, Sketch, Geometric Modeling, Freehand Drawing.

1. Introduction

Although it has become common to use CAD/CAM systems to increase the efficiency of the industrial design process, traditional sketch is often more efficient in the early stages of concept design. Since it is difficult to design a CAD system which can create 3D object from concept sketch directly due to the ambiguous information, recently Sketch Systems [1-9] are introduced to bridge the gap between concept design and computer-based modeling programs, combining some of the features of pencil- and-paper sketch and some of the features of CAD systems to provide a lightweight, gesture-based interface to “approximate” 3D polyhedral modeling.

Concept Sketch is a predesign process for the designer. It is used to draw the contours of the products on the paper by pencil step by step. In order to get 3D shapes, it is required to recognize these shapes from the concept sketch. Now a lot of CAD system can show the object model created by designers really, but these advanced 3D CAD systems demand precise data of the 3D object, especially in the steps of inputting data and making free-form surfaces. Designers can not feel comfortable to use these systems for realizing their idea sketches. It has become a big research area of increasing flexibility of the 3D data input techniques for CAD systems now.

This paper extends these ideas to propose an interpreter system of sketch input for designing 3D models. The essential idea of this paper is to create complex 3D object with a template topology library. The library is called T-LIB which consisting of 2D Edge Graphs and the corresponding algorithms to generate 3D objects. The input strokes are analyzed as a 2D Edge Graph. It is used both in 3D shape reconstruction and modification procedures. In 3D shape reconstruction procedure, referring to Fig. 1(a) and Fig. 1(b), we match the Edge Graph to the library and create a basic 3D object. While in modification procedure, referring to Fig. 1(c) and Fig. 1(d), the 3D object can be modified from T-LIB.

Figure 1: Modeling process. (a)Input strokes. (b) Create a basic 3D shape. (c)Input strokes again. (d)Generate a new 3D shape.

In such a simple way, a 3D object with complex topology can be analyzed and reconstructed.

〒338-8570 さいたま市桜区下大久保255 埼玉大学理工学研究科
Email: † ‡
2. Interpretation of Sketch Input

2.1 Sketch Plane

The strokes are drawn on a plane which is called Sketch Plane. It can be regarded as a plane between 3D object space and screen of user interface.

Referring to Fig. 2, there is a cube in 3D object space. The designer draws strokes on the 3D cube in order to modify it. But actually the strokes are drawn in the Sketch Plane.

The Sketch Plane is used for stroke input and modification process and Edge Graph analysis.

2.2 Edge Graph

Edge Graph is a 2D topology graph. It is calculated from the input strokes and the projected edges of 3D mesh which intersect these strokes. Here, we use a proper threshold to judge whether the strokes meet at one vertex or not.

2.2.1 Edge Graph Analysis Case 1

Referring to Fig. 3, case 1 is that no edge of 3D mesh intersects the input strokes. In this case, we will build a 2D Edge Graph directly.

2.2.2 Edge Graph Analysis Case 2

Referring to Fig. 4, case 2 is that some edges of 3D mesh intersect the strokes. In this case, we implement a process called T-EXTRACT to get the intersecting edges from 3D mesh. And then project them to Sketch Plane. From the input strokes together with the projected edges, we can build a 2D Edge Graph.

2.2.3 About Noise

The noise is caused from the illegal stroke input and illegal extracted edges of 3D mesh in section 2.2.2. So in the Edge Graph analysis process, we should implement a process to remove the noise strokes and noise edges of 3D mesh.

2.3 T-LIB

T-LIB is a template topology library. It is consisted of 2D Edge Graphs and the corresponding algorithms to create and modify 3D objects. Now in our system, we only consider the following simple templates: cube, triangular prism and triangular pyramid.

Of course, the templates are not limited to only these three ones. Based on the requirements of the designer, new template definition is feasible.

2.3.1 T-LIB 1: Convex Templates

Here, we use the term "convex" which means the 3D object of Edge Graph is either a part of 3D shape or outside of 3D shape. Referring to Fig. 4, the extracted Edge Graph (in Fig. 4(b)) is a cube Edge Graph. The 3D object of Fig. 4(b) is a 3D cube in T-LIB 1. We say that Fig. 4(b) is a convex template.

The convex templates are illustrated in Fig. 5. They are used both in 3D shape reconstruction and modification process.
2.3.2 T-LIB 2: Concave Templates

Here, we use the term "concave" which means the 3D object of Edge Graph is inside of the 3D object. Referring to Fig. 7, the extracted Edge Graph (in Fig. 7(a)) is a concave cube Edge Graph. Fig. 7(b) is the modified 3D shape by T-LIB2.

![Figure 7: Concave Edge Graph.](image)

The concave templates are illustrated in Fig. 6. They are used only in modification process.

<table>
<thead>
<tr>
<th>T-LIB</th>
<th>2D Edge Graph</th>
<th>3D Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triangular Prism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triangular Pyramid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6: T-LIB2 (Concave templates).

3. Application System

3.1 System Procedure

The system procedure is shown as the following Fig. 8. It consists of 5 parts: (1) Edge Graph analysis. (2) T-LIB and new template definition. (3) 3D shape reconstruction. (4) 3D shape modification. (5) Fillet operation, subdivision and etc. (1) and (2) has been discussed in section 2. For part (5), the related research works can be referred. So we emphasize on discussing (3) and (4).

![Figure 8: Application interface system](image)

3.2 3D Shape Reconstruction

The algorithm of cube shape reconstruction is discussed in this section. The input strokes are shown in Fig. 9(a), the extracted 2D Edge Graph is shown in Fig. 9(b). The 3D cube is calculated by evaluating a camera normal and using parallel projection.

![Figure 9: 3D cube shape reconstruction.](image)

Let vector \( n = \{ n_x, n_y, n_z \} \) be the camera normal, \( V = \{ v_x, v_y, v_z \} \) be the vertex of the 3D cube, while \( P = \{ p_x, p_y, p_z \} \) be the vertex of cube Edge Graph.

Let \( v_0 = (0,0,0) \), \( a = n_y/n_z \), \( b = n_x/n_z \), with the principle of parallel projection, we get the following equations:

\[
\frac{v^* - p^*}{n_x} = \frac{v^* - p^*_y}{n_y} = \frac{v^*_z}{n_z} \tag{1}
\]
From (1-3), we can get the following equations:

\[
\begin{align*}
\frac{v_x^2 - p_x^2}{n_x} &= \frac{v_y^2 - p_y^2}{n_y} - \frac{v_z^2}{n_z} \\
\frac{v_x^2 - p_x^2}{n_x} &= \frac{v_y^2 - p_y^2}{n_y} - \frac{v_z^2}{n_z} \\
v_1^z v_2^y + v_2^z v_1^y + v_1^z v_2^y &= 0 \\
v_2^z v_3^y + v_3^z v_2^y + v_2^z v_3^y &= 0 \\
v_3^z v_4^y + v_4^z v_3^y + v_3^z v_4^y &= 0
\end{align*}
\]

From (1-3), we can get the following equations:

\[
\begin{align*}
v_i^z &= av_i^z + p_i^z, \quad v_i^y = bv_i^z + p_i^y \\
v_i^z &= av_i^z + p_i^z, \quad v_i^y = bv_i^z + p_i^y \\
v_i^z &= av_i^z + p_i^z, \quad v_i^y = bv_i^z + p_i^y
\end{align*}
\]

(7) \quad (8) \quad (9)

Let \( c = (a p + b p)(a^2 + b^2 + 1), \) \( d = (a p + b p)(a^2 + b^2 + 1), \)
\( e = (a p + b p)(a^2 + b^2 + 1), \) \( f = (a p + b p)(a^2 + b^2 + 1), \)
\( g = (a p + b p)(a^2 + b^2 + 1), \) \( h = (a p + b p)(a^2 + b^2 + 1), \)
from equation (3-8), we get the following equations:

\[
\begin{align*}
v_i^z v_i^z + d v_i^z + c v_i^z + f &= 0 \\
v_i^z v_i^z + e v_i^z + d v_i^z + g &= 0 \\
v_i^z v_i^z + e v_i^z + c v_i^z + h &= 0
\end{align*}
\]

(10) \quad (11) \quad (12)

From equation (10-12), we can get equation (13).

\[
(g - de)(v_i^z)^2 + 2(cg - cde)v_i^z + (fh + gc^2 - cde f) = 0
\]

(13)

Then \( V_1 \) can be calculated, the vertex \( V_2, V_3 \) can be gotten from equation (4-12). Other vertices can be calculated with the parallel information. In such a way, the basic 3D shape can be generated.

For triangular prism and triangular pyramid template in T-LIB1, the algorithms of 3D shape reconstruction are also given by using the principle of parallel projection and some assumption.

### 3.3 3D Shape Modification

#### 3.3.1 Project 2D Edge Graph to 3D Object

In 3D modification process, after calculate the 2D Edge Graph in Sketch Plane, we project the 2D Edge Graph to 3D object and get a 3D Edge Graph. The hidden face can be calculated by referring to this 3D Edge Graph.

Referring to Fig. 10, we input strokes on 3D shape and build a 2D Edge Graph. Then we project the 2D Edge Graph to 3D shape and adjust the edges. The modified shape is shown in Fig. 10(d).

#### 3.3.2 Modify the 3D shape

After projected the 2D Edge Graph to 3D object, the modification procedure works as followings:

For each face of 3D object by T-LIB, if it is in a face \( f_i \) of 3D shape, we modify \( f_i \) by deleting this part from \( f_i \), while if it is not in a face \( f_i \), we create a new same face and add it to the 3D object.

Here the angle between the stroke and edge of 3D shape is used as a threshold to adjust the Edge Graph for get the parallel information.

![Figure 10: Modification process. (a)Input strokes. (b)Build 2D Edge Graph. (c)Project Edge Graph to 3D shape and adjust it, (d)Modify 3D shape.](image-url)

#### 3.3.3 About Cracking Problem

The modification process can produce a cracking problem if the hide face intersects with other face of 3D shape.

Based on the different requirements, there are two solutions of solving the cracking problem. One is automatic adjusting the parameters, the other one is calculating the intersecting lines and then modifying the intersecting faces.

### 4. Examples

Fig. 11 is an example we made by using our system for modeling a clock-like shape. The procedures are described as followings: (a)Input strokes. (b)Create basic 3D cube. (c-1)Input strokes on the 3D cube and modify it. (m,n)Implement fillet operation and subdivision. (o,p)Map strokes on the 3D objects.
Figure 11: An example for modeling a clock-like shape.

Fig. 12 is another example for modeling a mouse-like shape. (a-p) Modeling process by our sketch system. (q,r) 3D shape after fillet operation and subdivision.
4. Conclusion

We propose a geometric modeling tool by freehand drawings. The idea is to use a 2D template topology library as an essential tool to reconstruct and modify the 3D shape step by step. The template topology library is called T-LIB which is consisted of 2D Edge Graphs and the corresponding algorithms to generate 3D objects. We analyze the local structure around the input strokes as a 2D Edge Graph. Once the Edge Graph can be matched to a template of T-LIB, the 3D object can be generated in basic shape reconstruction procedure, or modified in 3D shape modification procedure. After we get the polyhedral network, we use fillet operation and subdivision to get smooth shape. Future work should be adding more templates and proposing template definition rules.

REFERENCES


