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단면정보로부터 3차원 근사곡면의 생성
3D Surface Approximation to Serial 2D Cross Sections

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ABSTRACT

This paper describes a hybrid surface-based method for smooth 3D surface approximation to a sequence of 2D cross sections. The resulting surface is a hybrid G^1 surface represented by a mesh of triangular and rectangular Bezier patches defined on skinning, branching, or capping regions. Each skinning region is approximated with a closed B-spline surface, which is transformed into a mesh of Bezier patches. Triangular G^1 surfaces are constructed over branching and capping regions such that the transitions between each triangular surface and its neighboring skinning surfaces are G^1 continuous. Since each skinning region is represented by an approximated rectangular C^2 surface instead of an interpolated triangular G^1 surface, the proposed method can provide more smooth surfaces and realize more efficient data reduction than triangular surface-based methods.

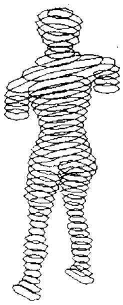
Keywords: surface reconstruction, cross-sections, branching, capping, skinning, surface fitting

1. Introduction

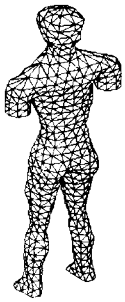
In many research and application areas such as medical science, biomedical engineering, and CAD/CAM, an object is often known by a sequence of cross sections. With improvements in data acquisition techniques such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound imaging, the cross sectional images of an object can be obtained with ease. A major concern in these areas is to reconstruct the geometric model of the object from the given cross sections.

Several surface reconstruction methods have been proposed [1-3]. However, most of them take the triangular surface-based approach where a triangular net leading to a polyhedral model is generated from the compiled contours and a triangular surface is then constructed by stitching triangular patches over the triangular net (see Figure 1). Since the triangular surface construction is based mostly on the interpolation scheme, the resulting surface model may be inefficient in both space and computational requirements when the triangular net is composed of a large number of triangles.

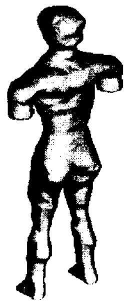
In this paper, we propose a hybrid surface-based method for smooth surface approximation to a sequence of cross sections. The resulting surface is a hybrid G^1 surface represented by a mesh of triangular and rectangular Bezier patches. It consists of skinning, branching, and capping surfaces, as shown in Figure 2.



(a) 42 cross sections



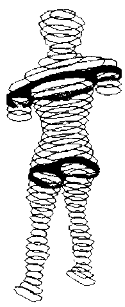
(b) a triangular net



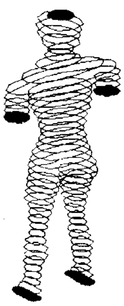
(c) a triangular surface

Figure 1. A triangular surface-based method

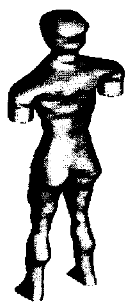
(a) skinning surfaces



(b) branching surfaces



(c) capping surfaces



(d) a hybrid surface

Figure 2. A hybrid surface

Each skinning surface is represented by a closed B-spline surface approximating to the serial contours of the skinning region. The surface is then transformed into a mesh of rectangular Bezier patches for further processing. On branching and capping regions, triangular G^1 surfaces are constructed such that the transitions between each triangular surface and its neighboring skinning surfaces are G^1 continuous. Because each skinning region is represented by an approximated rectangular C^2 surface instead of an interpolated triangular G^1 surface, the proposed method can provide more smooth surfaces and realize more efficient data reduction than triangular surface-based methods.

2. Hybrid Surface Approximation

We consider four kinds of links between contours in successive cross sections: isolation, one-to-one link, one-to-many link, and many-to-many link, as shown in Figure 3.

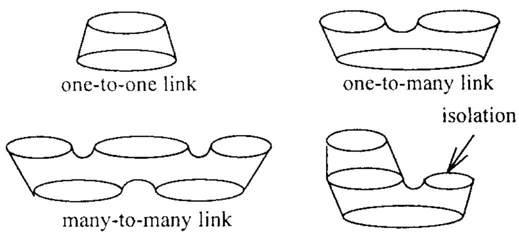


Figure 3. Four kinds of contour links

Isolation arises when a contour in a cross section has no connection with the contour(s) in the adjacent cross section. Many-to-many links, mainly coming from insufficient sampling of cross sections, are more complex than other kinds of links and may cause undesirable results. The occurrence of these links can be mostly avoided by the fine sampling of cross sections. To cope with the inevitable occurrence of them, the reconstruction method has to include an efficient algorithm which can handle complex multiple branching structures.

Hybrid surface approximation from 2D cross sections can be completed through four main phases: input compilation, region detection, skinning surface approximation, and branching (or capping) surface construction.

2.1 Input Compilation

Although there exist a variety of data acquisition devices and techniques, the cross sections obtained are mostly in the form of cross sectional images [2,3]. In the input compilation, we extract the regions of interest (or their contours) from the cross sectional images and compress each contour into a piecewise linear polygon [4]. The input data required for surface reconstruction has a hierarchical structure [3]. The vertices defining each polygonized contour are counterclockwise ordered in the cross sectional plane.

2.2 Region Detection

In the region detection, we detect skinning, branching, or capping regions. The component surfaces of a hybrid surface are defined on those regions. A skinning region denotes a surface region enclosed by a series of 2D contours, each successive pair of which forms a one-to-one link. A branching region denotes a surface region defined by either a one-to-many link or a many-to-many link. A capping region is a surface region encompassed by a contour in isolation.

Each element of the list *CAPS* is a contour in isolation. Each element of the list *OTMS* (*MTMS*) is a one-to-many (many-to-many) link. Each element of the list *SKINS* is a sequence of contours *CTLIST*. Steps for the region detection are summarized as follows:

(Step 1) Insert each contour in the lowermost and uppermost cross sections into *CAPS*.

(Step 2) For each pair of consecutive cross sections, carry out Step 3 to 5.

(Step 3) Determine contour links between two adjacent cross sections by the correspondence decision algorithm described by Park and Kim [3].

(Step 4) Insert each contour in isolation into *CAPS*. Insert each one-to-many (many-to-many) link into *OTMS* (*MTMS*).

(Step 5) For each one-to-one link $L_i = (C_{i1}, C_{i2})$, do the following steps:

- Find the skin element S_k of *SKINS* such that one of the two contours C_{i1} and C_{i2} exists in the contour list *CTLIST* of S_k.
- If L_i is not contained in any skin element, insert a new skin element *CTLIST* = $\{C_{i1}, C_{i2}\}$ into *SKINS*. Else, append the contour C_{ip} (p = 1 or 2) not contained in *CTLIST* to the appropriate position (front or back) of *CTLIST* of S_k.

2.3 Skinning Surface Approximation

In this phase, we approximate serial contours defining each skinning region to a closed B-spline surface possessing C^2 continuity. The skinning surface approximation can be completed through three main steps: contour alignment, construction of intermediate curves, and surface skinning.

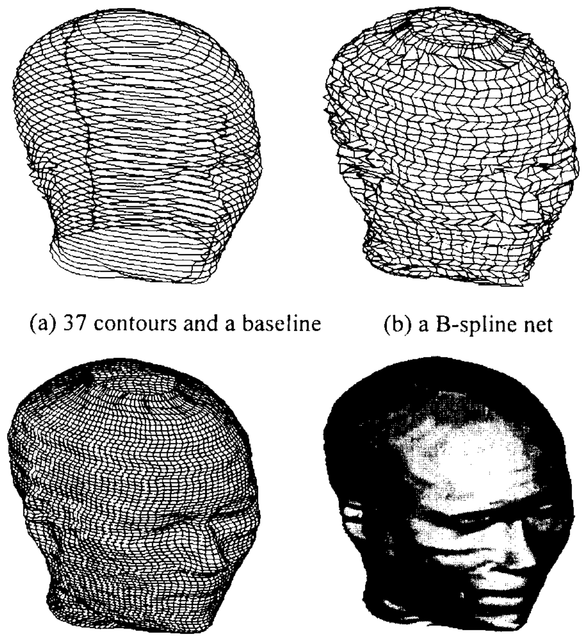
In the contour alignment, we determine a good baseline from the given contours and align them with the baseline. A baseline denotes an open polygon which traverses all the contours from the first to the last. In the construction of intermediate curves, we generate intermediate closed B-spline curves, each of which fits its contour points within an approximation accuracy. All the intermediate curves are required to be defined on a common knot vector. In order to acquire more efficient data reduction, we can generate the intermediate curves defined on the optimal common knot vector. In the surface skinning, we generate a bicubic closed B-spline surface by performing the skinning of the intermediate contour curves [6,7]. More details about the skinning surface approximation can be found in Park and Kim [7].

Shown in Figure 4 is an application to the MRI data of a human head consisting of 37 cross sectional images. The contour in each image has been segmented and compressed into a closed polygon. Here, the approximation accuracy is 0.75 % of the contour range which denotes the longer one between x and y axial ranges, where the x (y) axial range is defined by the difference from the maximum x (y) to the minimum x (y) of the given contour points.

2.4 Branching and Capping Surface Construction

In this phase, we construct triangular G^1 surfaces over branching and capping regions such that the transitions between each triangular surface and its neighboring skinning surfaces are G^1 continuous. Before going into the construction of branching and capping surfaces, the following steps must be processed:

- Transform each skinning surface from B-spline to Bezier form in order to obtain a mesh of bicubic Bezier patches [5];
- Subdivide the boundary Bezier curve segments with large chord lengths and the rectangular Bezier patches adjacent to those segments [5];
- Replace the contours of branching or capping regions adjacent to each skinning region by the corresponding boundary curves of the skinning surface.



(a) 37 contours and a baseline (b) a B-spline net

(c) the wireframe of a surface (d) a skinning surface

Figure 4. An application to the MRI data

Next, we construct triangular nets defined over branching and capping regions. A triangular net is defined by a network of triangular facets. To a contour in each capping region, apply the contour closing algorithm described by Park and Kim [3]. To a multiple (one-to-many or many-to-many) link in each branching region, apply the multiple branching algorithm described by Park and Kim [3].

Then, we construct branching and capping surfaces, each of which is represented by a piecewise triangular Bezier G^1 surface defined over the corresponding triangular net. Based on the Clough-Tocher scheme [3,9], three quartic triangular Bezier patches are defined over each triangular facet of the triangular net, as shown in Figure 5.

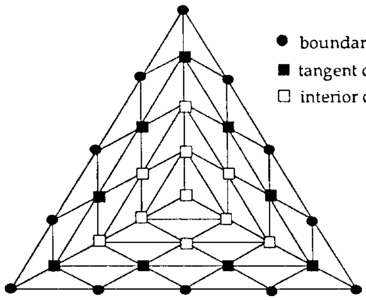


Figure 5. Control points over a triangular facet

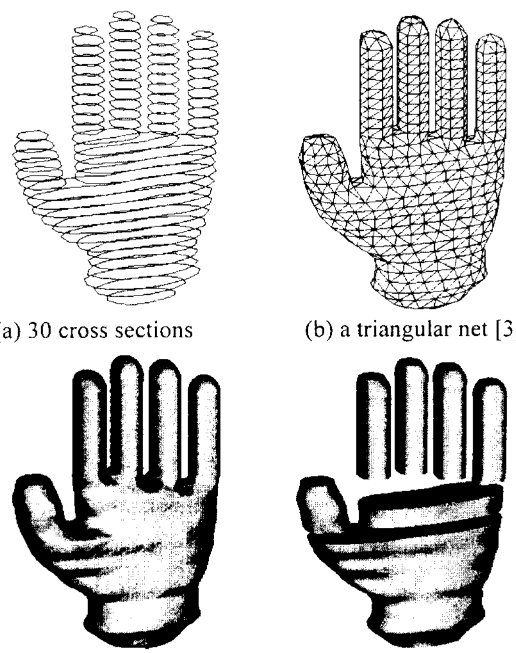
Steps for construction of a triangular G^1 surface on each branching or capping region are summarized as follows:

(Step1) Determine the unit surface normal vector at each vertex on the triangular net [3].
(Step2) Determine the boundary control points in each triangular facet to define three boundary curves over the triangular facet [3,9].
(Step3) Determine the tangent control points in each triangular facet to guarantee the G^1 continuity between two adjacent (triangular or rectangular) Bezier patches with their common boundary curve [3,8,9].
(Step4) Determine the interior control points in each triangular facet in order to guarantee the G^1 continuity between three triangular Bezier subpatches [3,9].

3. Experimental Results

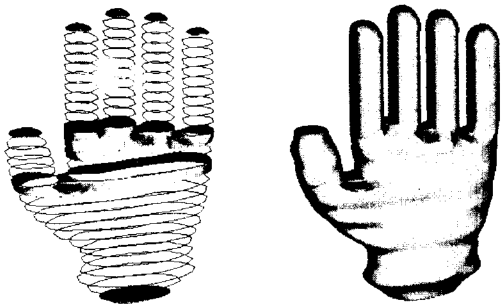
The hybrid surface-based method, implemented in C on a SUN 4/65 workstation, has been applied to the representation of complex shaped objects. The approximation accuracy is 0.5 % of the contour range. First, we used a human body-shaped object known by 42 parallel cross sections in Figure 1(a). Shown in Figure 1(b)-(c) is the application of the triangular surface-based method described by Park and Kim [3]. Skinning surfaces constructed over the skinning regions are shown in Figure 2(a). Triangular surfaces constructed over the branching and capping regions are shown in Figure 2(b)-(c). The resulting hybrid surface is shown in Figure 2(d).

Second, we used a hand-shaped object known by 30 parallel cross sections shown in Figure 6(a). The application of the triangular surface-based method [3] is shown in Figure 6(b)-(c). Skinning, branching, and capping surfaces are shown in Figure 6(d)-(e). The resulting hybrid surface is shown in Figure 6(f). Note that, in the skinning regions, the hybrid surfaces are more fair or smooth than the triangular surfaces generated by the triangular surface-based method.



(a) 30 cross sections　　(b) a triangular net [3]

(c) a triangular surface [3]　　(d) skinning surfaces



(e) triangular surfaces (f) a hybrid surface

Figure 6. An application to a hand-shaped object

Table 1 sums up the experimental results. Note that the number of (triangular and rectangular) Bezier patches of each hybrid surface is smaller than that of the corresponding triangular surface generated by the triangular surface-based method.

Table 1. Experimental results

	Human body-shaped object	Hand-shaped object
No. of cross sections	42	30
No. of points	722	797
Triangular surface-based method		
No. of triangular facets	1440	1590
No. of triangular patches	4320	4770
Hybrid surface-based method		
No. of triangular facets	143	251
No. of triangular patches	429	753
No. of rectangular patches	651	597

4. Conclusion

The reconstruction of the surface model of an object from 2D cross sections plays an important role in many applications. In this paper, we have described a hybrid surface-based method for 3D surface approximation to a sequence of cross sections. The resulting surface is a hybrid G^1 surface represented by a mesh of triangular and rectangular Bezier patches. Since each skinning region is represented by an approximated rectangular C^2 surface instead of an interpolated triangular G^1 surface, the proposed method can provide more smooth surfaces and realize more efficient data reduction than triangular surface-based methods.

References

[1] Ekoule, A. B., Peyrin, F. C., and Odet, C. L., "A triangulation algorithm from arbitrary shaped multiple planar contours," *ACM Trans. on Graphics*, Vol. 10, No. 2, 1991, pp. 182-199.

[2] Meyers, D., Skinner, S., and Sloan, K., "Surfaces from contours," *ACM Trans. on Graphics*, Vol. 11, No. 3, 1992, pp. 228-258.

[3] Park, H. and Kim, K., "3D shape reconstruction from 2D cross sections," *to appear in Journal of Design and Manufacturing*, 1995.

[4] Ballard, D. H. and Brown, C. M., *Computer Vision*, Prentice Hall, 1982.

[5] Farin, G., *Curves and Surfaces for Computer Aided Geometric Design: A Practical Guide*, Academic Press, 1988.

[6] Woodward, C. D., "Skinning techniques for interactive B-spline surface interpolation," *Comput.-Aided Des.*, Vol. 20, No. 8, 1988, pp. 441-451.

[7] Park, H. and Kim, K., "Smooth surface approximation to serial cross sections," *submitted to Comput.-Aided Des.*, 1995.

[8] Liu, D. and Hoschek, J., "GC^1 continuity conditions between adjacent rectangular and triangular Bezier surface patches," *Comput.-Aided Des.*, Vol. 21, No. 4, 1989, pp. 194-200.

[9] Piper, B., "Visually smooth interpolation with triangular Bezier patches," in Farin, G. (Ed.) *Geometric Modeling: Algorithms and New Trends*, SIAM, 1987, pp. 221-234.