High Quality Isosurface Generation from Volumetric Data and Its Application to Visualization of Medical CT data

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Abstract

We propose a method for generating an isosurface from volumetric data sampled with a face-centered cubic lattice. The display quality of the isosurface obtained by our method is greatly enhanced because it generates many good aspect ratio triangle patches. We applied the method to visualization of a colonic wall from medical data. We experimentally compared the resulting surface of our method with those of existing methods, showing the effectiveness of our method.

1. Introduction

Volumetric data is used in many disciplines such as biomedical science, computer graphics, and visualization. Computed tomography (CT) is a typical use of volumetric data. Visualization of such volumetric data is important to understand their geometrical properties. There are many ways of visualizing volumetric data. Isosurface representation is the most common one. Many methods for generating an isosurface have been reported. Most of these generate an isosurface as an approximated polyhedron composed of small triangles. The marching cubes (MC) method [1] is a well-known method often used as a visualization tool for medical CT data. The MC method tessellates the space into small cubic cells and generates triangle patches in the cells that intersect boundary surfaces. Many methods improving upon the MC method have been developed [2-4]. On the other hand, methods that deal with volumetric data sampled with other types of lattice to improve the quality of the resulting surfaces have also been reported [5-8]. The shape of each triangle patch is one of the factors that affect the quality of the surface - triangles with very acute angles lower the surface quality. Therefore the aspect ratio is often used to evaluate the isosurface quality [5,9]. Improvement in the aspect ratios enhances the display of the surface using smooth shading (such as Gouraud or Phong shading). We previously developed a method for generating an isosurface from volumetric data sampled with a face-centered cubic (FCC) lattice and demonstrated its effectiveness in terms of the number of good aspect ratio triangle patches [8].

In this paper, we propose a new method that also uses an FCC lattice. The method generates fewer triangles with poor aspect ratios and more triangles with good aspect ratios than the previous method does. We carried out preliminary experiments by using algebraically generated volumetric data and applied our method to medical CT data. These experiments compared the effectiveness of the new method with those of the previous method using an FCC lattice and the MC method.

2. Related work

The MC method [1] is used for isosurface generation from volumetric data sampled with an orthogonal cubic lattice. Each of the triangle patches is generated in a cubic cell by means of linear interpolation as shown in Fig. 1. Many modifications to this method have been developed [2-4]. On the other hand, methods not based upon the orthogonal cubic lattice have also been developed. Most of these methods deal with an FCC lattice or a body-centered cubic (BCC) lattice. To generate triangle patches, these methods use polyhedral cells of various shapes. Of the methods dealing with a BCC lattice, tetrahedral tessellation [5,6], octahedral tessellation, and hexahedral tessellation [7] have been reported.

The FCC lattice structure (Fig. 2b) is the closest packing structure in the sphere-packing problem [10]. We have already developed a method for the FCC lattice [8]. In the following sections, we call this method the previous FCC method. This method does not create false holes,

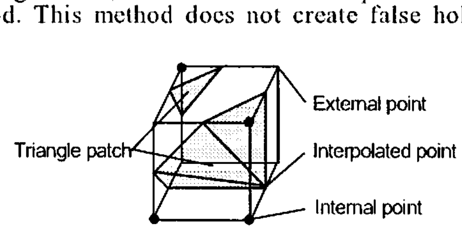

Figure 1. Triangulation in a cubic cell with the MC method

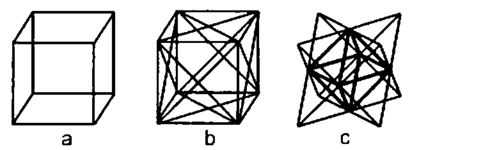

Figure 2. Face-centered cubic lattice: (a) shows an orthogonal cubic lattice, (b) shows an FCC lattice, and (c) shows an octahedral cell and eight tetrahedral cells in the FCC lattice.

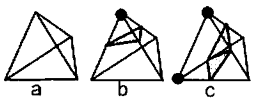

Figure 3. Triangulations in a tetrahedral cell with the previous FCC method

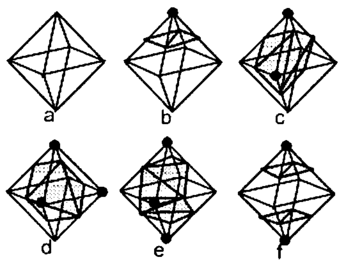

Figure 4. Triangulation in an octahedral cell with the previous FCC method

and it increases the number of good aspect ratio triangle patches [5,8]. It tessellates the space by using both a regular octahedral cell and a regular tetrahedral cell (Fig. 2c). The triangulations in these cells are achieved in the same manner as with the MC method. There are three fundamental triangulations in the tetrahedral cell (Fig. 3), and the octahedral cell has six fundamental triangulations (Fig. 4).

3. Algorithm

Our method uses the same polyhedral cells as were used in the previous FCC method (Fig. 2c). The patch generation algorithm, however, differs from the previous one. Our new method defines each vertex of a triangle as the barycenter of interpolated points on each polyhedral cell calculated with the previous FCC method (Fig. 5). This reduces the number of too-thin or too-small triangles. The pair of neighboring lattice points in which one is the internal point of the surface and the other is the external is called the boundary pair. Each boundary pair is shared among four polyhedral cells (i.e., two octahedral cells and two tetrahedral cells). The previous FCC method generates a vertex between each boundary pair. On the other hand, our method generates two triangle patches between each boundary pair. Each vertex of the triangles lies within each polyhedral cell. These triangles tend to have a good aspect ratio because of the relative position of these polyhedrons. The algorithm can be described as follows.

Step 1. If an octahedral cell has more than one boundary pair, detect the tetrahedral cells that share the boundary pair.
Step 2. For each detected tetrahedral cell and octahedral cell, temporarily calculate the interpolated points between each boundary pair by using the previous FCC method.
Step 3. A vertex in each of the cells is located at the barycenter of these temporary points as shown in Figs. 5a

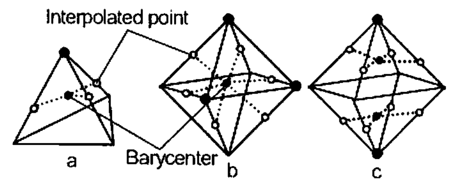

Figure 5. Definition of the vertex with our method: A vertex is defined as the barycenter of interpolated points on the polyhedral cell.

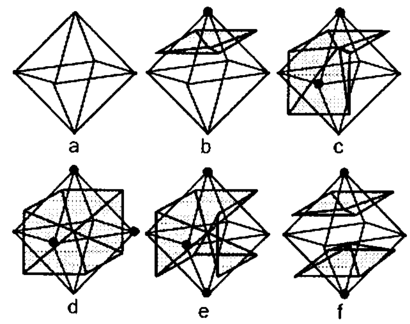

Figure 6. Triangulations around an octahedral cell with the proposed method

and b. Only in the case shown in Fig. 5c are two vertices generated inside of the octahedral cell from the two sets of the temporary points. These vertices correspond to the two separated polygons shown in Fig. 4f.
Step 4. Triangle patches are generated from these vertices so that every triangle has a vertex in the octahedral cell and two vertices in the tetrahedral cells (Fig. 6). In the case of Fig. 6f, two sets of polygons are generated.

To reduce the computational cost, our method can also use a pre-defined table containing the correspondence between the octahedral cell configurations and the ways of triangulation. There are six fundamental triangulations for the octahedral cells shown in Fig. 6. There are only three polygon shapes (i.e., tetragon, hexagon, and octagon) that have a vertex in the octahedral cell. Moreover, each polygon can be triangulated uniquely.

4. Results and discussion

4.1. Comparison conditions

First, we performed preliminary experiments using volumetric data sets algebraically generated by meatballs. In the experiments, we confirmed that the improved aspect ratio of each triangle patch enhances the quality of the resulting surface using smooth shading. The resulting surfaces of our method, the previous FCC method, and the MC method were constructed under the condition of almost the same number of patches.

Second, we experimentally constructed isosurfaces from three-dimensional high-resolution medical data (1.32 mm x 1.32 mm x 2.5 mm) sampled by a CT scan with an

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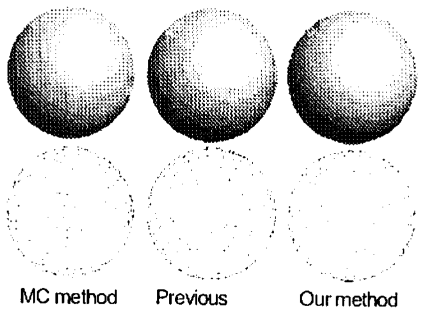

Figure 7. Resulting surfaces for a spherical surface

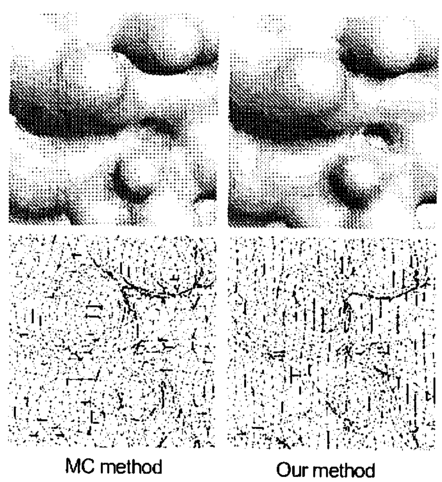

Figure 8. Resulting surfaces for a complicated surface

orthogonal cubic lattice. To apply our method and the previous FCC method to the CT data, we defined volumetric data with an FCC lattice as a subset of the original data by rotating and stretching the lattice so that each lattice point is on a sampled point of the original data. Thus, the number of sampling points decreased to 1/4. The resulting surface of our method was compared with the resulting surfaces of the MC method and the previous FCC method in terms of the aspect ratio of each triangle patch.

The aspect ratio is one of the criteria used to evaluate the shape of a triangle. A triangle that is similar to a regular triangle has a good aspect ratio close to 1, while a thin triangle has a poor aspect ratio close to 0. We defined the aspect ratio A as $A=2r/R$, where r and R represent the radius of the inscribed circle and of the circumscribed circle, respectively.

4.2. Resulting surfaces

Figures 7 and 8 show the experimental results using algebraically generated volumetric data. Some jags can be seen in the surface obtained through the MC method and the previous FCC method; these were due to the existence

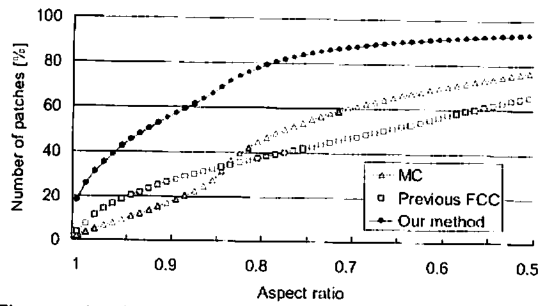

Figure 9. Cumulative histogram of the aspect ratio for the surface shown in Fig. 8

of very thin triangle patches. In contrast, few jags appeared in the resulting surface of our new method. Figure 9 shows cumulative histograms of the aspect ratio of triangle patches of the surfaces shown in Fig. 8. This demonstrates that the resulting surface of our method had many good aspect ratio triangle patches. Our method's percentage of patch numbers with a good aspect ratio (i.e., > 0.9) was the highest among the three methods, and its percentage of patch numbers with a poor aspect ratio (i.e., < 0.7) was the lowest. Thus, the appearance of the surface resulting from our method when smooth shading was used was good. This histogram feature could be seen in all experiments in this paper.

Figure 10 shows isosurfaces of the colonic wall generated by the MC method and our method from CT data. Our method generated a smoother surface than that of the MC method even when the surface was viewed at close range, despite that the number of sampling points was fewer than that of the original data. It is important for visualization of medical data to provide a fine appearance over a considerable region in order to reveal phenomena such as morphological changes caused by disease.

5. Conclusion

For visualization of medical data, it is important to provide high-quality appearances. In this paper, we have described a new method for generating high-quality isosurfaces from volumetric data sampled with an FCC lattice, and have demonstrated the effectiveness of this method in experiments using medical CT data by comparing the resulting surfaces with those from existing methods in terms of the display quality. Our method provides the following benefits that are also applicable to other medical applications such as model deformation, measurements, and feature analysis.

- The quality of the resulting surface is greatly improved through the use of many good aspect ratio triangle patches, which tend to be uniform in size.
- The method is suitable for extracting isosurfaces with smooth curves such as those of bowels, bone, and muscle from medical data.
- The method provides fine appearances over considerable regions, which can reveal small morphological changes caused by a disease.
- The resulting surface does not have the topological holes affecting MC.

- The computational cost for isosurface generation is comparable to that of existing methods by using a pre-defined table for the triangulation.

Acknowledgements

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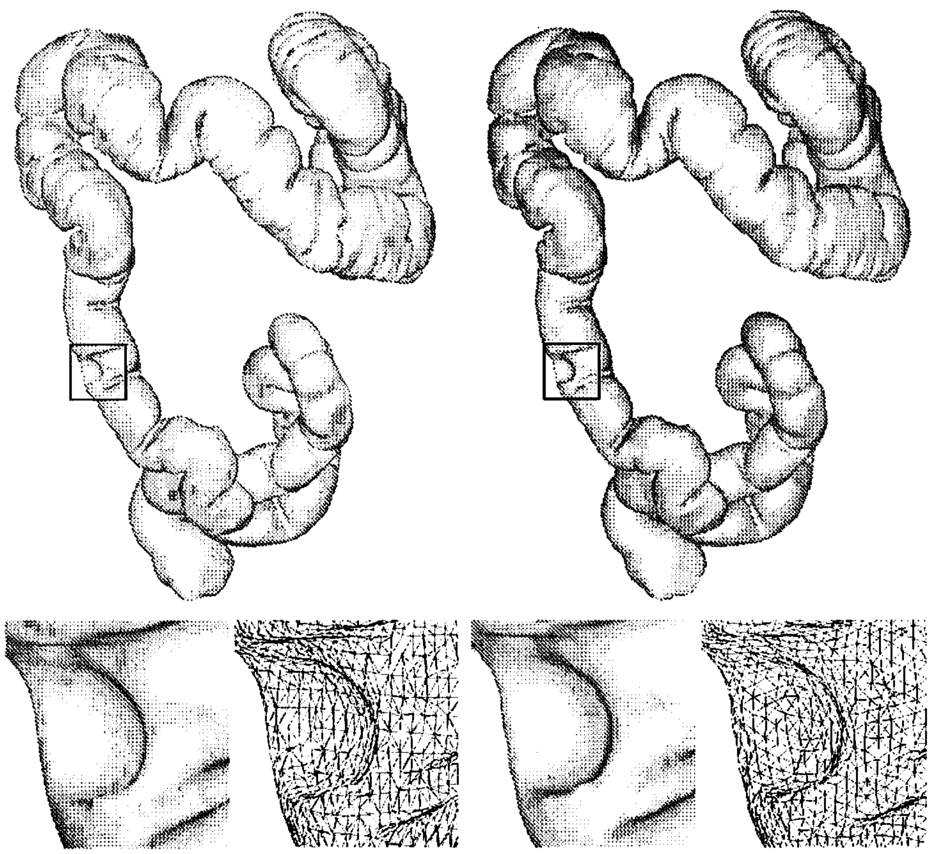

Figure 10. Resulting surfaces for a colonic wall that has a collapse caused by a disease