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Visualization of Medical Images Based on Improved MC Algorithm

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***Abstract*—In order to improve the accuracy and efficiency of vascular 3D model reconstruction, an improved method is proposed to solve the ambiguity problem in the surface rendering process. Based on the researches on the expression method of surface rendering process, the causes for the ambiguity were analyzed firstly. Then an improved method for surface rendering was proposed, whose reliability was verified by experiments. Besides ensuring the effect of reconstruction, this method can improve the efficiency of the surface rendering process. With this method, the visualization of medical images was performed more efficiently. Furthermore, the more accurate subsequent 3D printing process for blood vessel is predictable.**

Keywords-Surface Rendering; Visualization of Medical Images; Surface Rendering Ambiguity; Three-dimensional Printing

I. INTRODUCTION

At present, there are two widely used technologies in the field of medical image visualization: surface rendering and volume rendering. Surface rendering is widely used in medical image visualization with relatively simple structure due to its advantages of simple algorithm, easy implementation and high efficiency [1].

Surface rendering is a three-dimensional modeling technique for fitting object surface models. Its basic principle is to extract the data of the three-dimensional data field, construct geometric elements, fit the three-dimensional model, and display the three-dimensional model on the screen according to computer graphics technologies such as lighting effects, graphic blanking and image rendering. Because surface rendering deals with the information of object edges, it is less computationally intensive and faster to generate than volume rendering, and is suitable for tissues with obvious surface features, such as human skeleton information[2]. Surface rendering algorithms can generally be divided into contour-based rendering and isosurface-based rendering. The rendering based on isosurface can be divided into Marching Cube (MC) algorithm, Dividing Cube (DC) algorithm and Matching Tetrahedral (MT) algorithm. MC algorithm is widely used among them. In reference[3], researchers from Sao Paulo University proposed an MC algorithm based on open boundary loop. In reference[4], an improved MC algorithm for 3D data is proposed.

In this paper, the MC algorithm is improved to improve the accuracy and reconstruction efficiency of the MC algorithm for the ambiguity problem in the surface rendering MC algorithm in the process of reconstructing the lesion model from intravascular ultrasound images. It provides an efficient and convenient method for the smooth generation of the model, facilitates the realization of the subsequent three-dimensional printing model entity process, and shortens the entire cycle of the model entity manufacturing process.

II. MC ALGORITHM IMPROVEMENT

A. introduction of MC algorithm

MC algorithm is a voxel-based method. Firstly, it needs to set a function value, called threshold value, then processes each voxel in the data field, compares the pixel value of each voxel vertex with the threshold value to determine the state of each vertex, judges the intersection between the voxel and the isosurface through the state of 8 vertices of each voxel, and connects all the points in the voxel that intersect with the isosurface to form the contour of the object surface.

1) voxels. The basic unit in the three-dimensional data field is voxel. People generally define voxel as follows: take the data of two adjacent layers in the data field, and take four adjacent pixel points in each layer to form a square. The cube thus formed is called voxel, and the coordinates of 8 vertices of voxel are shown in fig. 1.

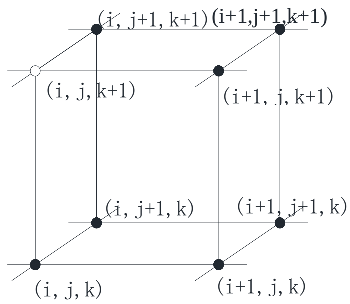


Figure 1. Voxel model

f(i, j, k) represents the coordinates of each pixel point in the three-dimensional data field, where i, j represent the position of the pixel in each layer, and k represents the number of layers. If the distances between different sampling points are Δx, Δy, Δz, x, y, z as the coordinates of the object, the conversion relation of the object coordinates is i=x/Δx, j=y/Δy, k=z/Δz. The gray value of any point P(x, y, z) in the voxel is calculated as follows:

$$f(x,y,z) = a_0 + a_1x + a_2y + a_3z + a_4xy + a_5xz + a_6yz + a_7xyz$$

Where a_i (i=0,1···,7) depends on the gray values of the eight vertices of the voxel, thus the gray values of any point in the voxel can be calculated by the formula.

2) Isosurface extraction. The isosurface extraction is generally divided into three steps:

a) judging the positional relationship between the isosurface and the voxel intersection point, and determining the subdivision mode of the isosurface in the voxel.

Let the isosurface consist of all the points of F(x, y, z)=T, T is the threshold value in MC algorithm, that is, the gray value of the image. Firstly, the states of the eight vertices and the isosurface in each voxel must be judged, and the triangular patches intersecting the isosurface on the voxel can be calculated.

The positional relationship between the voxel vertex and the isosurface can be divided into two types: when the voxel vertex value is greater than or equal to the initially determined function value, the vertex is considered to be outside the isosurface, and the vertex is marked as "0"; On the other hand, the vertex is considered to be on the isosurface, and the vertex is recorded as "1". There are two points on the edge of voxel, and there are two cases in total: if the two vertices on one edge are in different states, then the edge is considered to intersect with the isosurface, and the edge needs to be marked; If the states of the two vertices on the edge are the same, it means that the edge is on the same side of the isosurface, does not intersect with the model surface, and is not recorded. Each vertex has two positional relationships, and each voxel has eight vertices. It can be calculated that the intersection of voxels and the model surface can be divided into 256 types, of which half of the cases are complementary and symmetrical, i.e. the topological structure of voxels themselves is unchanged, so it can be simplified to 128 types; The remaining 128 kinds can be further simplified through rotational symmetry and other changes, and finally the voxels can be divided into 15 kinds of situations.

The number of voxel vertices is $V_0,V_1,V_2,V_3,V_4,V_5,V_6,V_7$ in turn. By recording the state of each vertex in voxels, a binary index table is created to represent the state of voxels in 256. Each voxel state can record the edge where the isosurface and voxel intersect.

b) Determine the coordinates of the intersection point between the edge and the isosurface. Since the three-dimensional data field is assumed to be continuous, the coordinates of the intersection point between the edge and the isoplanar can be obtained by linear interpolation between two points.

c) Calculate the normal vector of isosurface. The gradient value of each vertex on the voxel can be obtained by the gray difference method, and the normal direction of the intersection point can be obtained by linear interpolation of the gradient between the two vertices, i.e. the normal vector of the isosurface.

B. *Ambiguity*

MC algorithm has one disadvantage: because there are different connection modes in the same voxel, the spatial position of the generated isosurface is uncertain, which is called connection ambiguity problem. The following ambiguity problem refers to: when the intersection point between the surface and voxel is determined, it needs to be connected into a triangular patch to fit the surface. If all four edges of the previous surface on voxel have intersection points with the isosurface, the connection mode between the intersection points cannot be determined.

Due to the ambiguity of the connection, different connection methods will form different triangular patches. When the surface is to be synthesized, there may be holes in the model, which will affect the final result. There are two methods commonly used to solve the ambiguity of connection: one is the moving tetrahedron method, and the other is the progressive line method.

The idea of moving tetrahedron method is to divide the cube into a plurality of small tetrahedrons, and then calculate the intersection of each tetrahedron and the curved surface. Because each face of the plurality of tetrahedrons divided by the cube is a triangular patch, there is only one connection mode, so the problem of connection ambiguity is well avoided. It is common to divide each voxel into five tetrahedrons. Although the precision of the model generated by moving tetrahedron method is higher, after voxel is divided into five tetrahedrons, more vertex states need to be judged, and the vertex coordinates of each tetrahedron and the normal direction of patches need to be calculated. Therefore, the calculation amount increases, the memory occupied increases, and higher requirements are put forward on the performance of the computer.

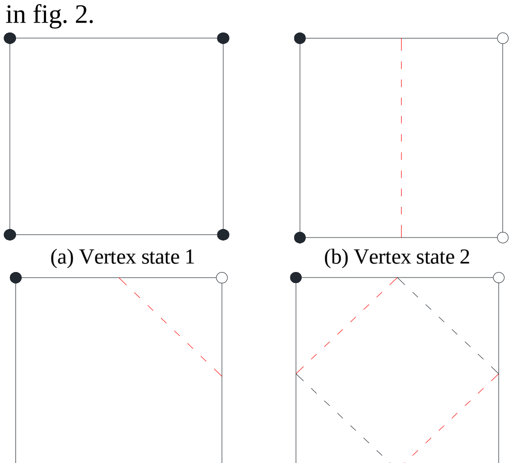
It is generally believed that the intersection line between the isosurface and any one plane of voxel is hyperbola, and there are many cases where hyperbola intersects voxel. When both asymptotes of hyperbola intersect voxel plane, ambiguity problem will occur [5].

When ambiguity occurs, it is necessary to compare the size between the pixels at the intersection of asymptotes and the isosurface: if the isosurface is smaller than the pixel value of the intersection of asymptotes, the intersection and the vertices larger than the isosurface are divided into the same area, and the coordinates of the intersection are positive, which is called the positive ambiguous surface. By the same token, when the pixel with an isoplane larger than the asymptote intersection point is obtained, the point and the vertex smaller than the isoplane are divided into the same area, and the intersection point is marked as negative, which is called negative ambiguous surface.

C. *Optimization of Ambiguity*

From the above, it can be seen that MC algorithm has defects, which will affect the surface contour of the model. Currently, the most commonly used methods to solve connectivity ambiguity are asymptote method and moving tetrahedron method. However, both methods need to be solved through a large amount of calculation, especially moving tetrahedron method, which decomposes a voxel into five or more tetrahedrons, thus the calculation amount is multiplied, which is undesirable. Therefore, a new solution is proposed for connectivity ambiguity.

First of all, it is necessary to know how the ambiguity of connection is generated. It is known that judging whether a voxel intersects with an isosurface depends on the positional relationship between 8 vertex pixels in a voxel and the isosurface. The positional state of 4 vertices in a voxel is shown in fig. 2.



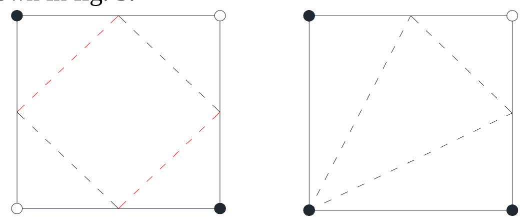
(a) Vertex state 1 (b) Vertex state 2

(c) Vertex state 3 (d) Vertex state 4

Figure 2. Vertex state

When the complementary condition is removed, the vertex condition can be divided into four types. The four points in fig. 2(a) have the same state, so there is no intersection point with the isosurface. Figs. 2(b) and 2(c) have only a single connection mode, and the ambiguity of connection appears in fig. 2(d). Red dashed lines and black lines both represent a connection mode, resulting in the ambiguity of connection.

Because in MC algorithm, it is assumed that the data in the three-dimensional data field is continuous and the data in the data field is dense, when the linear interpolation method is adopted, the coordinates of the intersection point are always between the vertices with different states. If a limit condition is considered, it is assumed that the intersection point is infinitely close to the vertex, and its coordinates are basically the same as the vertices. Thus, the simplified result is shown in fig. 3.



(a) Before optimization (b) after optimization

Figure 3. Ambiguity Optimization Diagram

Fig. 3(a) shows that there is connectivity ambiguity, and fig. 3(b) is the result of optimization. It can be seen that when two intersection points are infinitely close to the vertex, they can be approximated as new points coincident with the vertex, thus generating a new triangular patch on the voxel surface to solve the connectivity ambiguity problem. The specific idea is: if one face of voxel has connectivity ambiguity problem, judge the absolute value of the threshold difference between two vertices with the same diagonal state and the isosurface, and select the vertex with small absolute value as the intersection coordinate; For vertices with large absolute value difference, the coordinates of the two intersection points are calculated according to the original method. Using vertex values instead of interpolation points can not only solve the ambiguity problem of connection, but also use vertex values instead of intersection points, which can reduce the amount of computer operation and improve the efficiency of system operation.

The root cause of ambiguity of connection in MC algorithm lies in the uncertainty of topological structure. In this paper, the topological structure is determined and ambiguity of connection is eliminated by making intersection point approach voxel vertex.

III. APPLICATION EXAMPLES

In this paper, the segmented intravascular ultrasound image is used as the original data set, and the original MC algorithm and the optimized MC algorithm are tested in different data sets. Record the operation time of each algorithm, and record the number of vertices and triangular patches of the model, as shown in Table 1.

TABLE I. COMPARISON BETWEEN ORIGINAL MC ALGORITHM AND OPTIMIZED MC ALGORITHM

algorithm	*Data set*	*Number of triangular patches*	*Number of vertices*	*run time /s*
original MC algorithm	100 layers	333567	162547	29.456
optimized MC algorithm	100 layers	314635	158024	19.699
original MC algorithm	200 layers	795621	384697	74.739
optimized MC algorithm	200 layers	752684	377083	49.537
original MC algorithm	300 layers	1398167	674591	104.739
optimized MC algorithm	300 layers	1298504	650018	81.609
original MC algorithm	400 layers	1946119	924563	137.652
optimized MC algorithm	400 layers	1753170	877286	107.345

Through comparison, it can be found that the number of vertices and patches in the mesh model are reduced, but this part does not affect the display of the model. The results of the two algorithms are basically the same. However, in terms of reconstruction efficiency, the improved algorithm improves the efficiency by about 20%.

IV. CONCLUSION

In this paper, the principle, advantages and disadvantages of MC algorithm are introduced, and improvements are made to solve the problem of connection ambiguity. From the experimental results, it can be seen that the improved algorithm has improved the computational efficiency.

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