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3D Reconstruction of Face: A Comparison of Marching Cube and Improved Marching Cube Algorithm

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***Abstract*—3D reconstruction of face is one of the advancements in physical modeling techniques which uses engineering methods in the field of medicine.The systems in development propose a software tool that will help in craniofacial surgery. The existing approaches for 3D reconstruction has different applications from real scenary to human parts of body. The analysis of the different algorithms allow developers to make vital decisions in understanding the modelling of the face. The human face has different regions including the tissue and hard bones. The paper presents a comparison of two surface rendering techniques, Marching Cube(MC) and Improved Marching Cube(IMC) algorithms, and draws conclusions for analysing the suitable approach for a specific range of application.**

***Keywords*— MC, IMC, CT, DICOM, Voxel**

I. Introduction

Surface rendering is a method to generate surfaces from a set of data points. It is a way to visualize the object by means of the image data as a set of certain basic elements, such as voxels, their faces, other polygons, line segments, and points which represents the boundary of the structure. An iso-surface is a three-dimensional surface that represents points of a constant value within a volume of space or it can be a level set of a continuous function whose domain is the 3D-space.

In medical imaging, iso-surfaces may be used to represent regions of a particular density in a three-dimensional Computed Tomography(CT) scan, allowing the visualization of internal organs, bones, or other structures. One popular method of constructing an iso-surface from a data volume like CT scan of human face is iso-surface extraction algorithms like marching cubes or marching tetrahedral.

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II. Related Works

The well-known method in iso-surface rendering is classic Marching Cubes (MC) algorithm that was first published by Lorensen and Cline in 1987[2].

A. *Marching Cube Algorithm*

The input volume data consist of samples organized into a regular 3D Cartesian grid. From such a grid, it is easy to obtain a set of cells. The cell in this case has a cube shape and consists of eight corresponding samples from two adjacent sample planes. Four samples are from the first plane and four samples are from the second plane. MC method processes sequentially all the cells that can be found in volume data. The iso-surface is specified by a threshold value.

Applying the marching cubes algorithm to reconstruct the surface, the volume data needs to be partitioned into cubes. The algorithm determines how the surface intersects the cube, then marches to the next cube. To find the surface intersection in a cube, we assign one to a cube’s vertices if their data value exceeds or equals to the value of the surface we are reconstructing, and consider them as inside vertices. Cube vertices with values below the surface receive a zero and are considered as outside vertices. Therefore a logical cube is obtained to configure the surface. Since there are eight vertices in each cube, there are only $2^8 = 256$ ways a surface can intersect the cube. Recurred to the reverse and symmetric properties of the cube, we can reduce those 256 cases to 15 patterns. Each cell face is shared by another cell. Due to such sharing, the iso-surface is continuous among adjacent cells. There are few approaches how to avoid the holes. Ambiguous cases can be detected and a special triangulation can be applied. The algorithm complexity of MC method is $O(N)$, where N is the number of all cells. The algorithm[2] provides a 3D surface reconstruction by giving physicians a 3D view of anatomy. It creates triangle models of constant density surfaces from 3D medical data. The algorithm processes the 3D medical data in scan-line order and calculates triangle vertices using linear interpolation.

B. Method Based on Modularization

A 3D surface reconstruction method of medical image based on modularization has been proposed by Bin Lee, Lian-Fang Tian, Chen Ping, Hongqiang Mo and Zong-Yuan [3] .This divides the whole process of three dimensional reconstruction into different modules and parts based on functions.

The whole process of 3D reconstruction is divided into different steps. First an appropriate segmentation method is used to given slices to get relevant information from given slices of CT images. The output of segmentation is used as the input of classical MC algorithm which will generate proper iso-surface which is required. Based on the features of the voxels, a novel voxel-tracing algorithm is developed. In normal method the whole voxels created will be searched one after the other On the other hand, the voxels that actually intersect with the iso-surface are only a small part. So in order to enhance searching efficiency, a favorable data structure is needed this will only make the process to search lesser number of voxels.

A large amount of triangle meshes will be generated using MC algorithm. So, measures should be taken to merge some triangle meshes before applying rendering to them. Here a mesh optimization method proposed is applied. Here two vertex of a triangle mesh are merged according with the two following constraints: normal constraint and space constraint. The condition for merging two vertexes is that the two above constraints are met, and then the triangle mesh is deleted.The algorithmic modularization for 3D reconstruction will improve the execution time for rendering. The voxel can be traced more faster than usual algorithm which will reduce the error surfaces and holes in the surface rendering.

C. Improved MC Algorithm

An improvement is suggested to basic iso-surface reconstruction by Jun Xiao, Miao Yu, Ningyu Jia by adding a filter module and segmentation module in 3D reconstruction algorithm. This method proposed discusses the basic principle of MC algorithm and both the advantages and disadvantages of it. The MC algorithm is improved, and a filter module, a image segmentation module and a mesh simplifying module are added. Marching cubes algorithm is a widely used surface rendering method. But MC algorithm also has its disadvantages, such as ambiguous surface and the huge quantities of the triangle patches generated. This method improves the MC algorithm by changing traversing method into multi-line traversing method to take advantage of multi-pipeline technology. And this method also resolves the ambiguity by use of asymptotic decider.

Although MC algorithm is simple in principle, and it is easy to implement, but it has following drawbacks:

1) Standard MC algorithm traverses all the voxels in a single loop way. It is dull and inefficient.

2) Standard MC algorithm generates a huge quantities of triangle patches, which slows the reconstruction down greatly. For example, a set of 128 × 128 × 256(8bit) skull CT data, after being processed using MC algorithm, will become more than 500,000 triangle patches.

3) Standard MC algorithm can probably generate ambiguous surface in certain situation.

This means sometimes the topological structure may be wrong. If one voxel's plane has 4 intersection points made by the arrises and the iso-surface, there will be 2 probable situation, and this can probably lead to a wrong topological structure. If the adjacent voxels which share the same plane chose different situation, there will be a hole in the topological structure.To overcome the above drawbacks of the MC algorithm, as well as to deal with the special nature of medical images, several approaches are adopted, such as adding a filter module and a image segmentation module, changing the single loop traversing method into small quantities parallel traversing method, adding a mesh simplifying module to reduce the number of iso-surface patches, and avoiding producing the wrong surface by use of the asymptote theory.

Another approach is applying Improved Marching Cube Algorithm(IMC)[14] for facial reconstruction. Based on the drawbacks of traditional MC algorithm, the following three improvements are made.

1. *Replace cube edge linear interpolation with midpoint selection.*

In the case of increasingly high-resolution of medical images, the thickness of CT slices has become increasingly small. So, taking the midpoint of the cube edge as the intersection point instead of calculating it using linear interpolation almost make no differences in reconstruction
results. At the same time, the triangular patches generated in this way could form a smoother isosurface in local area, which will benefit mesh simplifying.

2. *Index of the intersection point is used to avoid repeated calculation.*

In order to avoid the repeated calculation between the adjacent cubes, create a three-dimensional array to store the pointer which points the information of the intersection point of the cube edge and isosurface. Calculate normal of the intersection point, query the array using the coordinate of the intersection. If the current value is NULL, it indicates that the information of the intersection point has not been calculated. Repeat the calculation, and after that store the pointer of the vertex information in the array Otherwise, the information of the intersection has been calculated, and use the pointer in the array directly.

3. *Contract edge to reduce the number of triangular patches.*

Simplifying the grid method can be divided into four categories: sampling, adaptive subdivision, decimation, vertex merging. As the simplicity and robustness of vertex merging, in this paper, the edge contraction method is selected. When two vertices satisfy the following three constraint conditions, the two vertices will merge into one, and the edge consisting of the two vertices will contract into a point. If the conditions are not met, the triangle will be kept.

III. Comparison and Analysis

The visualization of such data may be done in two-dimensional manner, where each slide can be viewed separately on the screen**.** Often this will require a bit of processing, because computers typically use 8 bits per color channel to represent an image - 8 bits for red, 8 bits for green and 8 bits for blue color. If CT slice is more than 8 bits resolution, the programmer needs to scale down CT's values to make them fit into 8 bits resolution range. The Digital Imaging and Communications in Medicine(DICOM) will contain all the details of the patient taken during the CT scan. This information might be sensitive if exposed to public for medical and non medical applications. DICOM is a binary protocol and data format. DICOM has many versions of the standard, with support for 8 and 16 bit images.

Figure 1: Image viewer created to view the dataset

Perform translation on each slide. Then do a resampling operation on each slide by applying the equation

$$\frac{F(i+1, j, k+1) - F(i, j, k)}{\nabla k} \qquad (1)$$

Then calculate the normals to each slices using the equation

$$V=V_1+f(V_1)(V_1-V_2)/f(V_2)-f(V1). \qquad (2)$$

Then by determining the surface values for different tissue layers we can construct the face. The values of different layers ranges from 0-255.

A. 3D Model of a Face

3D Face is created from 415 axial slices of CT scan images of head of a patient by applying the above steps.

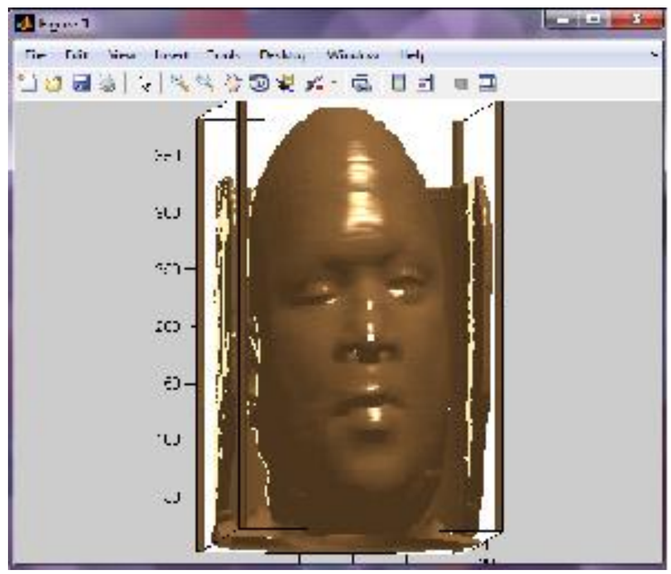

Figure 2: 3D Model of a face

B. Observations

The dataset is a series of 415 axial CT slices of size 512*512 of the head of a patient with 3mm thickness between consecutive slices. The surface rendering algorithms for 3D reconstruction, MC and IMC with transformation is compared based on time and number of vertices generated. From the result it is clear that IMC with transformation takes less time for the reconstruction process without compromising the accuracy.

TABLE I. COMPARISON OF MC AND IMC WITH TRANSFORMATION

Algorithms	Features	
	Time(Seconds)	*Vertex(number)*
MC	7.72	13148
IMC(with transformation)	3.45	5569

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