Research on Optimization Technology of Three Dimensional Model

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***Abstract*—Method of reconstruction and model simplification are two key optimization technologies for three dimensional model, there are several problems in these methods, such as, low time consume, bad interface and accuracy problem. Firstly, existing methods and implementation toolkits related with our research are introduced. Secondly, a modified reconstruction algorithm based on Voronoi diagram is proposed. Thirdly, a new algorithm of semi-automatic mesh simplification is presented with the aim of simplifying error correction and achieving higher efficiency. Finally, two tests are implemented to prove that our new methods can improve the efficiency of reconstruction and has a good visualization performance.**

Keywords—Three Dimensional Model; Optimization Technology; Reconstruction; Mesh simplification

I. Introduction

With the development of image processing technology and laser scanning technology, 3D reconstruction technology has become an important research content for a wide range of applications in the field of reverse engineering, pattern recognition, film and television, and obtained the rapid development. The complex model is constructed quickly and accurately through the 3D point data. The existing reconstruction algorithms are mainly divided into two main categories: volume reconstruction and surface reconstruction [1]. Volume reconstruction needs a long execution time to be processed. Surface reconstruction processing speed is relatively fast, and it is good for real-time processing. Surface reconstruction mainly includes three phases: contour line connection, contour extraction and triangulation. Contour line connection means connecting the adjacent cross section contour points. Contour extraction is a virtual cube formed by the eight neighbouring points, which represent the contour surface of a polygon. Triangulation is a construction of tetrahedral mesh. The higher the processing speed of surface reconstruction, the lower accuracy it has, because of the lack of some contour points. For this reason, we propose a 3D data reconstruction algorithm based on improving Voronoi diagram in which the 3D point data is filtered and de-noise.

The details of our research are as follows. In Section II, we introduce the critical technologies related with our research, including 3D visualization class library Visualization Toolkit (VTK), Voronoi diagram reconstruction method and semi-automated mesh simplification method. In Section III, our new method realization is presented, including realization of new construction method and Semi-automatic simplification method. There are two tests in Section IV, the first test is used to prove that our surface reconstruction method is feasible and efficient, the second test is to confirm that our method of semi-automatic mesh simplification has good interface and is accurate. In Section V, we present a conclusion about our research.

II. Critical technologies

In this section, we introduce critical technologies related with our research, including 3D visualization class library VTK, reconstruction method and semi-automated mesh simplification method.

A. 3D visualization class library VTK

In 3D visualization class library VTK, there are three key parts: Voronoi tessellation code, Vanderpool (VT) and VTK. Voronoi tessellation code defines a cellular-like structure, where each particle is associated to a region in which any point in that region is nearer to that particle than to any other particle. The parallel Voronoi tessellation code is an open source code, and it has the following characteristics: (1) parallel and optimization, has full advantage of actual multicore and distributed memory, (2) user-friendly in documentation and interface, (3) has typical I/O formats used in the field of NN-body simulations. In addition, this code also has the properties such as Voronoi densities, cell volumes, density gradients, and immediate neighbour lists. In the field of astrophysics, particularly for NN-body simulations, Voronoi tessellation code is a very useful tool to identify immediate neighbours of particles, and it is one of the best adaptive methods to recover a precise density field from a discrete distribution of points, with a clear advantage over smoothed particle hydrodynamic or other interpolation-based techniques. Its principal asset is complete independence of arbitrary smoothing functions and parameters specifying their properties.

Vanderpool (VT) in 3D visualization reproduces the anisotropies of the local particle distribution and through its adaptive and local nature proves to be optimally suited for uncovering the full structural richness in the density distribution. Other remarkable uses of VT in this field are filamentary structure identification, NN-body simulation code AREPO, halo and void identification, and nonparametric determination of halo concentrations.

In 3D visualization class library, VTK is a set of 3D graphics, image processing and visualization tools which is integrated with the C++ library developed by the United States Kitware company. It is a source development, visualization technology and image processing software system; it can be used in C++, TCL/TK, Java and Python language environments [2]. It combines computer graphics, image processing and visualization technology, and it has an absolute advantage in the field of visualization and image processing. It has become often used in the research of image visualization system. VTK system mainly has two kinds: the graphic model object and visualization object model. The main function of graphical model is representing the scene which is formed from geometry by graph. VTK has 3D interactive components where users can choose the functions of parallel processing, running algorithm and visualization process. Visualization process includes functions of read data, filtering, mapping and rendering.

B. The method of Voronoi diagram reconstruction

The accuracy and efficiency are two key factors of 3D surface reconstruction by data. The accuracy is required to maintain the topology and shape. The efficiency is required to reduce the reconstruction time in the premise of maintaining the original topology under. Distance algorithm deals with noisy scattered data and it also reconstructs the surface of triangular mesh concerning for sample density and surface details based on a greedy filter.

The original Voronoi diagram [3] has a great effect on the distance between the point and other geometric objects. Assuming that in a given plane or space, there are n scattered points, point set $P = \{p_1, p_2, \ldots\ldots, p_n\}$, defined as:

$$V(p_i) = \bigcap_{j \neq i} H_i(p_i, p_j) \tag{1}$$

$$H(p_i, p_j) = \{d(p, p_i) < d(p, p_j), i \neq j, p_i, p_j \in P\} \tag{2}$$

Among them, $H(p_i, p_j)$ indicated the trajectory formed from the points. The distance between them and p_i is closer than the distance between them and p_j and the trajectory is either 1.5 or 1.5 spaces. $d(p, p_i)$ is Euclidean distance between p and p_i. $V(p_i)$ is sum of trajectories from p_j to p_i. There is a Voronoi polygon corresponding to each point in the point set P, the sum of all the polygons called the Voronoi diagram of point set P.

Delaunay triangulation is dual related to Voronoi diagram, which has the characteristics of the maximum of the minimum angle, the cavity and the local reconnection [4]. Power map is an extension of Voronoi; its generating element can be regarded as the Voronoi figure of the Power circle, and the distance is not Euclidean distance but Power distance:

The known D dimensional point set S, the weight of $p \in S$ is $w_p(-\infty < w_p < +\infty)$ and there is:

$$\pi_p(x) = \|x - p\|^2 - w_p \tag{3}$$

$\pi_p(x)$ is Power distance of x to p. Power graph and its dual regular triangulation are corresponding to weighted points of Voronoi graph and Delaunay triangulation.

If we hope to obtain better approximation of the surface vector of sampling point, we need to improve the surface reconstruction algorithm. The details of our improved method are described in Section III A.

C. Semi-automated mesh simplification method

For regular models, such as airplane, tank, etc., model conforms to a certain rule, automatic error correction can be easily achieved by feature preserving simplification [5]. However, for the cows, dinosaurs and other irregular model, or users who have special expectations to simplify models, we need select error correction mode and the expected characteristics of the region are preserved.

The basic error measure is quadric error metrics, which focuses on the feature of size in shape variable before and after the simplification. In many cases, the curvature of the model is more important than the feature ones. For surfaces that are in the same plane, only a few polygons can be expressed, however highly curved surfaces require more polygons to represent [6]. For this reason, we study the curvature error and the two-error weight as the result of automatic error correction, and do research on the triangle optimization factor to the quality of triangle.

The three vertices of the triangle V3, V2 and V1 are used to calculate the product of vectors, which are the normal vectors of triangle:

$$normal = \begin{bmatrix} v_{x1} - v_{x2} \\ v_{y1} - v_{y2} \\ v_{z1} - v_{z2} \end{bmatrix} \times \begin{bmatrix} v_{x2} - v_{x3} \\ v_{y2} - v_{y3} \\ v_{z2} - v_{z3} \end{bmatrix} \quad (4)$$

The curvature error metric of the edge (u,v) after the folding is

$$F(u,v) = Len(u,v) \times Cur(uv) \quad (5)$$

$Len(u,v)$ represents the length of the edge (u,v), $Cur(uv)$ represents the curvature of the edge (u, v). In order to find the longest distant u adjacent to the triangle from the other triangle, we compare the value of the curvature from the collapsed edge (u, v) of the two surface normal point product.

If a triangle is closer to the equilateral triangle, it is regular [7]. Triangle optimization is to avoid appearing long and narrow triangles in the simplified process [8]-[12]. It tries to make the generated triangle approaches in an equilateral triangle.

Set in T_i , there are three generation of triangle edges l_1 , l_2 and l_3 , when the T_i triangle is an equilateral triangle, then, $\frac{(l_1 + l_2 - l_3)}{l_2} = 1$ .If the shape of the triangle is longer, the value of $\frac{(l_1 + l_2 - l_3)}{l_2}$ is closer to 0. The value of $\frac{(l_1 + l_2 - l_3)}{2 \times l_2}$ is always in (0,1). So in this paper the definition of regular triangle P is:

$$\mathrm{Re}(P) = \frac{(l_1 + l_2 - l_3)}{l_2} \quad (6)$$

In order to improve the result of the simplification, users can mark in 3D model to refine and retain in the simplified platform directly, and simplify to achieve new simplified results. The user impact factor of the marked area is embodied in the way of weight. In our new error method, we set weight value of W both by system initialization and by calculation of each point. The initialization value of W is 1. If the user did not make any other decision, the way of automatic error correction will be followed. If the user tag, the tag area will be given a new weight, and the value of W > 1, the twice error will be modified by following formula:

$$\Delta^{'}(u,v) = w_v \Delta(u) + w_v \Delta(v) \quad (7)$$

The error is multiplied twice by a weight. To calculate the initial value of weight, we provide two methods to set the initial weights in the system; the details are presented in Section III B.

III. REALIZATION OF OUR NEW METHODS

There are two improved methods in this section; one improved method is to improve Power Crust Algorithm, other improved method is semi-automatic mesh simplification method.

A. The concrete realization of Power Crust

Power Crust algorithm has the advantages of a simple process to accurately reconstruct the results, for a large number of scattered point cloud data without a normal vector [13]-[14]. The processing speed is very fast, but the disadvantage of this method is that it is not accurate [15]. Power Crust algorithm can generate a watertight and sealed 3D mesh; in addition, it can construct the estimators from the central axis of the original surface which contains noise, sharp and unclosed points cloud data. The steps of Power Crust algorithm are:

- Calculate centre axis of the sample, find out v vertices to create graph on Voronoi triangulation ,
- Connect through triangulation points of the original point cloud into triangular mesh model,
- Delete the grid which does not comply with requirements.
- Construction of the grid mesh

The advantage of Power Crust algorithm is that it can construct the region with dense points. Its disadvantage is that the output of discrete surface has sparse points. We modify Power Crust algorithm based on Voronoi diagram:

1) Set Delaunay triangulation by sampling point S; and find the Voronoi vertex which the boundary box of vertex is considered to be the sampling point in Power diagram.

2) Determine which Voronoi vertices are poles.

3) The generation of the pole penalty set Bp, calculated the Power chart.

4) Mark each pole inside or outside.

5) Set the triangle as the output, and return the results.

We would prove that our modified algorithm has better result by experiments in Section IV.

B. Modified Semi- automatic mesh simplification method

There are two methods to set weight value in mesh simplification method; in the first method, users input a weight value, the second method consists on setting an initial weight value by the system, because it may be difficult for some users and cases to actually set suitable weights. For different grid model, weights will have great differences.

The two methods of set weight value are: 1) User input weight value to system. This method can meet user different requirements. The weight values include maximum and minimum values. 2) Initial label the mean value of the error in the actual simplification process for different mesh models. If the pre-set weight range is large, it is likely that role to the quadric error led to final folding.

We modify semi-automatic mesh simplification method by calculating the weight value two times so that the error would not make model losing retention effect. Model when it is in the medium errors are in reasonable way because that model retention effect is better than at other errors .The twice error and the weight of the transfer process are done separately. The definition of weight transfer is as follows:

1) The process of Edge collapse: Point v_1 and v_2 fold to v .The weight value of v_1 is w_1, weight value of v_2 is w_2. Weight value of v is average value of w_1 and w_2.

2) The process of Split point process: The parent node V is split into two nodes, if v weight is w, then two sub-node weights are w.

The semi-automatic mesh simplification code is described as follows:

1) E(u,v):=v.quadric/v.opt+F(u,v);
2) W(u,v):=(u.weight+v.weight)/2;
3) Cost(u,v):=W(u)*E(u)+W(v)*E(v);
4) Mesh.list.sort(mesh.v,cost(u,v));
5) Mesh.list.popfront();
6) Mesh.update();
7) If is Ok (mesh) then
8) return mesh;
9) else goto step5;
10) end if

The algorithm needs to deal with a large amount of data, so the definition of a suitable data structure ensures simplification and the capability of handling large data models quickly. The modified semi-automatic mesh simplification is as follows:

1) Set sequence of vertices, which record each vertex and adjacency edge, adjacent triangles, error values and weights.

2) Record vertex triangle index sequence.

3) Identify the sequence of vertices and triangles sequence model data structure.

4) Store the folded edge in the record list.

The modified algorithm will be tested and analysed by experiments in section IV.

IV. EXPERIMENT AND ANALYSIS

There are two tests in this section; one test is a reconstruction test aiming at proving our improved algorithm of reconstruction described in section III A; the second test is to verify our improved algorithm of semi-automatic mesh simplification method being described in section III B. The data used in experiment came from the 3D scanned images stored in the Txt text [16] in the form of 3D coordinates.

A. Reconstruction test and analysis

The program of surface reconstruction and visualization in 3D point cloud are designed based on Visual C++ Microsoft platform. We choose two sets of three dimensional point cloud data, such as data of whale and ocean to do the tests. They are shown in Figure 1 and Figure 2.

Figure 1. The reconstruction of whale

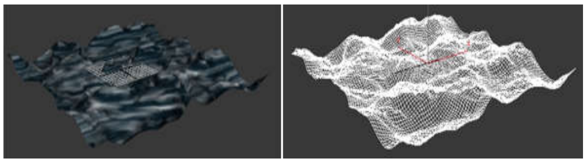

Figure 2. The reconstruction of ocean

We achieve two reconstruction effects both by using Crust Power algorithm through the 3D point cloud data and by using our algorithm through the 3D point cloud data to carry out a comparative analysis. Table 1 summarizes the results of the reconstruction of the two algorithms.

TABLE I. TWO METHODS OF SURFACE RECONSTRUCTION OF DIFFERENT POINT CLOUD MODEL

Point cloud data	Number of point	Power Crust Time/s	Our method time/s
Whale	5000	6.03	3.52
Ocean	20000	15.36	10.27

Through the above tests, we can find that the time efficiency of power crust algorithm is lower than our method. Our reconstruction method based on Voronoi diagram can achieve the stereo effect of 3D point cloud well and can retain some details of the original object. Therefore, our reconstruction method based on Voronoi diagram is an effective method in surface reconstruction.

B. Experiment and analysis of semi-automatic mesh simplification method

Our semi-automatic mesh simplification method was implemented by the standard C++ language. There are several parts in this program, such as error correction, edit mode, different simplified models and default settings.

User error correction for weight allows the users to do marking operation. In edit mode, the user can alter attention region (the region should be distinguished by different colors) which facilitate the user operation through CTRL + mouse to select smear colour; SHIFT + mouse to delete the selected colour. For different simplified models, the range

 ISBN: 978-1-61208-520-3

of calculation errors and the ranking results are different. The weight of the error is proposed to properly affect the calculation of the results of the calculation error, and therefore, the appropriate value of the initial weight is the key influence on error calculation. According to the different weights of the experimental model, the optimal setting is to obtain the minimum and maximum error, and then take the average value between the two values as the initial value for the corresponding model. The default settings for the user's marking area are the initial value and the value of the tag. Specific weights are set shown in Table II.

TABLE II. THE INITIAL WEIGHTS OF THE TWO MODELS.

model	Minimum error	Maximum error	Initial weight	Mark weight
whale	0.0	0.38589	0.194735	0.287543
Ocean	0.0	0.78723	0.287543	0.589832

The results of our method to achieve the 3D model of simplification are shown in Figure 3, Figure 4 and Figure 5. According to the initial weight of the set rules, the weights are the average between the initial weight and the maximum error.

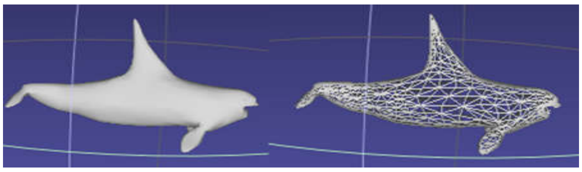

Figure 3. The initial model of whale

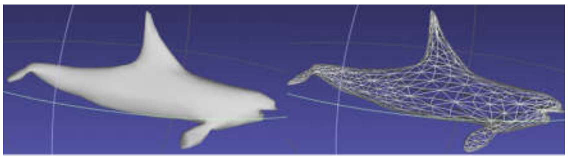

Figure 4. Reduced to 60% of whale

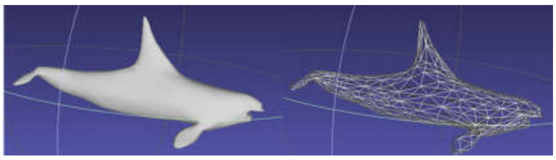

Figure 5. Reduced to 40% of whale

The result of simplification of ocean model by our method is shown in Figure 6, Figure 7 and Figure 8.

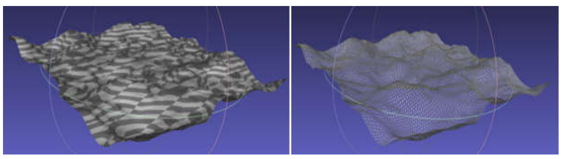

Figure 6. The initial model of ocean

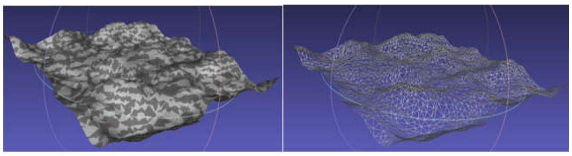

Figure 7. Reduced to 60% of ocean

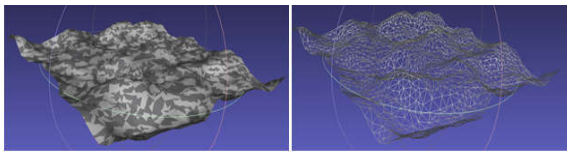

Figure 8. Reduced to 40% of ocean

We use the function of user error correction to get the best simplification result. Labelled and unlabelled mesh simplification results are shown in Table III.

TABLE III. THE NUMBER OF MESH MODEL SIMPLIFICATION RESULTS.

Simplification degree	Whole area	Marked area	Unlabeled area
Original model	2645	568	2077
60% of whale model	1587	738	849
40% of whale model	1058	539	519

From the experiment results, we conclude that our semi- automatic mesh simplification algorithm can obtain the simplified model conforms to the simplified criteria. It can also fully retain the local area which users concern about maintaining the appearance. It can be seen that our modified algorithm is important in generating a simplified model and it is consistent with user's requirements.

V. CONCLUSION

In this paper, we firstly analyse the existing surface reconstruction of Voronoi and Delaunay triangulation Power Crust algorithms and study the implementation toolkit of VTK. Secondly, we modified Power Crust algorithm based on Voronoi diagram to reconstruct the surface by using the cloud data into VTK which has a strong image processing capabilities. Our modified method can effectively improve the efficiency of reconstruction and has a good visualization performance. Thirdly, based on the two error metric algorithm, we proposed a new method of semi-automatic mesh simplification. Our algorithm provides automatic error correction and user error correction which has twice error correction functions according to different models with different types of error correction. By comparing with different models obtained by different experiments, our semi-automatic mesh simplification method has the characteristics of good retention effect and can simplify the complex structure of the model.

ACKNOWLEDGEMENT

This research is supported by (1) 2017-2020 The National Natural Science Fund (Project No.51679058). (2) 2013-2016 China Higher Specialized Research Fund (PhD supervisor category) (20132304110018).

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